16 EDITION IEE WIRING REGULATIONS

EXPLAINED & ILLUSTRATED

Covers BS 7671 2001

IEE Wiring Regulations

Explained and Illustrated

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PREFACE

As a result of many years developing and teaching courses devoted to compliance with the IEE Wiring Regulations, it has become apparent to me that many operatives and personnel in the electrical contracting industry have forgotten the basic principles and concepts upon which electric power supply and its use are based. As a result of this, misconceived ideas and much confusion have arisen over the interpretation of the Regulations.

It is the intention of this book to dispel such misconceptions and to educate and where necessary refresh the memory of the reader. In this respect, emphasis has been placed on those areas where most confusion arises, namely earthing and bonding, protection, and circuit design. Much of Part 5 of the Regulations is not mentioned, since it deals with selection of accessories etc. which needs little or no explanation. The same applies to some sections of Part 6 which deals with special installations or locations.

The current sixteenth edition of the IEE Wiring Regulations, also known as BS 7671, to which this book conforms, was published in June 2001. The philosophy and concepts that this book seeks to explain remain unchanged, regardless of the edition. It is *not* a guide to the Regulations or a replacement for them; nor does it seek to interpret them Regulation by Regulation. It should, in fact, be read in conjunction with them; to help the reader, each chapter cites the relevant Regulation numbers for cross-reference.

It is hoped that the book will be found particularly useful by college students, electricians and technicians, and also by managers of smaller electrical contracting firms that do no normally employ engineers or designers. It should also be a useful addition to the library of those studying for the C & G 2381 qualification.

INTRODUCTION

It was once said, by whom I have no idea, that 'rules and regulations are for the guidance of wise men and the blind obedience of fools.' This is certainly true in the case of the IEE Wiring (BS7671) Regulations. They are not statutory rules, but recommendations for the safe selection and erection of wiring installations. Earlier editions were treated as an 'electrician's Bible': the Regulations now take the form primarily of a design document.

The IEE Wiring Regulations are divided into seven parts. These follow a logical pattern from the basic requirements to the final testing and inspection of an installation:

Part 1 indicates the range and type of installations covered by the Regulations, what they are intended for, and the basic requirements for safety.

Part 2 is devoted to the definitions of the terms used throughout the Regulations.

Part 3 details the general information needed before any design work can usefully proceed.

Part 4 informs the designer of the different methods available for protection against electric shock, overcurrent etc., and how to apply those methods.

Part 5 enables the correct type of equipment, cable, accessory etc. to be selected in accordance with the requirements of Parts 1 to 4.

Part 6 deals with particular requirements for special installations such as bathrooms, swimming pools, construction sites etc.

Part 7 provides details of the relevant tests to be performed on a completed installation before it is energized.

Appendices 1–6 provide tabulated and other background information required by the designer.

It must be remembered that the Regulations are not a collection of unrelated statements each to be interpreted in isolation; there are many cross-references throughout which may render such an interpretation valueless.

In using the Regulations I have found the index an invaluable starting place when seeking information. However, one may have to try different combinations of wording in order to locate a particular item. For example, determining how often an RCD should be tested via its test button could prove difficult since no reference is made under 'Residual current devices' or 'Testing'; however, 'Periodic testing' leads to Regulation 514–12, and the information in question is found in 514–12–02. In the index, this Regulation is referred to under 'Notices'.

1
FUNDAMENTAL REQUIREMENTS FOR SAFETY

(IEE Regs Part 1 and Chapter 13)

It does not require a degree in electrical engineering to realize that electricity at *low* voltage can, if uncontrolled, present a serious threat of injury to persons or livestock, or damage to property by fire.

Clearly the type and arrangement of the equipment used, together with the quality of workmanship provided, will go a long way to minimizing danger. The following is a list of basic requirements:

1 Use good workmanship.
2 Use approved materials and equipment.
3 Ensure that the correct type, size and current-carrying capacity of cables are chosen.
4 Ensure that equipment is suitable for the maximum power demanded of it.
5 Make sure that conductors are insulated, and sheathed or protected if necessary, or are placed in a position to prevent danger.
6 Joints and connections should be properly constructed to be mechanically and electrically sound.
7 Always provide overcurrent protection for every circuit in an installation (the protection for the whole installation is usually

provided by the supply authority), and ensure that protective devices are suitably chosen for their location and the duty they have to perform.

8 Where there is a chance of metalwork becoming live owing to a fault, it should be earthed, and the circuit concerned should be protected by an overcurrent device or a residual current device (RCD).

9 Ensure that all necessary bonding of services is carried out.

10 Do not place a fuse, a switch or a circuit breaker, unless it is a linked switch or circuit breaker, in an earthed neutral conductor. The linked type must be arranged to break all the phase conductors.

11 All single-pole switches must be wired in the phase conductor only.

12 A readily accessible and effective means of isolation must be provided, so that all voltage may be cut off from an installation or any of its circuits.

13 All motors must have a readily accessible means of disconnection.

14 Ensure that any item of equipment which may normally need operating or attending to by persons is accessible and easily operated.

15 Any equipment required to be installed in a situation exposed to weather or corrosion, or in explosive or volatile environments, should be of the correct type for such adverse conditions.

16 Before adding to or altering an installation, ensure that such work will not impair any part of the existing installation.

17 After completion of an installation or an alteration to an installation, the work must be inspected and tested to ensure, as far as reasonably practicable, that the fundamental requirements for safety have been met.

These requirements form the basis of the IEE Regulations.

It is interesting to note that, whilst the Wiring Regulations are not statutory, they may be used to claim compliance with Statutory Regulations such as the Electricity at Work Regulations, and the

Health and Safety at Work Act. In fact, the Health and Safety Executive produces guidance notes for installations in such places as schools and construction sites. The contents of these documents reinforce and extend the requirements of the IEE Regulations. Extracts from the Health and Safety at Work Act and the Electricity at Work Regulations are reproduced below.

The Health and Safety at Work Act 1974

Duties of employers

Employers must safeguard, as far as is reasonably practicable, the health, safety and welfare of all the people who work for them. This applies in particular to the provision and maintenance of safe plant and systems of work, and covers all machinery, equipment and appliances used.

Some examples of the matters which many employers need to consider are:

1 Is all plant up to the necessary standards with respect to safety and risk to health?
2 When new plant is installed, is latest good practice taken into account?
3 Are systems of work safe? Thorough checks of all operations, especially those operations carried out infrequently, will ensure that danger of injury or to health is minimized. This may require special safety systems, such as 'permits to work'.
4 Is the work environment regularly monitored to ensure that, where known toxic contaminants are present, protection conforms to current hygiene standards?
5 Is monitoring also carried out to check the adequacy of control measures?
6 Is safety equipment regularly inspected? All equipment and appliances for safety and health, such as personal protective equipment, dust and fume extraction, guards, safe access arrangement, monitoring and testing devices, need regular inspection (Section 2(1) and 2(2) of the Act).

No charge may be levied on any employee for anything done or provided to meet any specific requirement for health and safety at work (Section 9).

Risks to health from the use, storage, or transport of 'articles' and 'substances' must be minimized. The term *substance* is defined as 'any natural or artificial substance whether in solid or liquid form or in the form of gas or vapour' (Section 53(1)).

To meet these aims, all reasonably practicable precautions must be taken in the handling of any substance likely to cause a risk to health. Expert advice can be sought on the correct labelling of substances, and the suitability of containers and handling devices. All storage and transport arrangements should be kept under review.

Safety information and training

It is now the duty of employers to provide any necessary information and training in safe practices, including information on legal requirements.

Duties to others

Employers must also have regard for the health and safety of the self-employed or contractors' employees who may be working close to their own employees; and for the health and safety of the public who may be affected by their firm's activities.

Similar responsibilities apply to self-employed persons, manufacturers and suppliers.

Duties of employees

Employees have a duty under the Act to take reasonable care to avoid injury to themselves or to others by their work activities, and to cooperate with employers and others in meeting statutory requirements. The Act also requires employees not to interfere with or misuse anything provided to protect their health, safety or welfare in compliance with the Act.

The Electricity at Work Regulations 1989

Persons on whom duties are imposed by these Regulations

(1) Except where otherwise expressly provided in these Regulations, it shall be the duty of every:

(a) employer and self-employed person to comply with the provisions of these Regulations in so far as they relate to matters which are within his control; and
(b) manager of a mine or quarry (within in either case the meaning of section 180 of the Mines and Quarries Act 1954*) to ensure that all requirements or prohibitions imposed by or under these Regulations are complied with in so far as they relate to the mine or quarry or part of a quarry of which he is the manager and to matters which are within his control.

(2) It shall be the duty of every employee while at work:

(a) to cooperate with his employer so far as is necessary to enable any duty placed on that employer by the provisions of these Regulations to be complied with; and
(b) to comply with the provisions of these Regulations in so far as they relate to matters which are within his control.

Employer

(1) For the purposes of the Regulations, an employer is any person or body who (a) employs one or more individuals under a contract of employment or apprenticeship; or (b) provides training under the schemes to which the HSW Act applies through the Health and Safety (Training for Employment) Regulations 1988 (Statutory Instrument No 1988/1222).

* 1954 C.70; section 180 was amended by SI 1974/2013.

Self-employed

(2) A self-employed person is an individual who works for gain or reward otherwise than under a contract of employment whether or not he employs others.

Employee

(3) Regulation 3(2)(a) reiterates the duty placed on employees by section 7(b) of the HSW Act.

(4) Regulation 3(2)(b) places duties on employees equivalent to those placed on employers and self-employed persons where these are matters within their control. This will include those trainees who will be considered as employees under the Regulations described in paragraph 1.

(5) This arrangement recognizes the level of responsibility which many employees in the electrical trades and professions are expected to take on as part of their job. The 'control' which they exercise over the electrical safety in any particular circumstances will determine to what extent they hold responsibilities under the Regulations to ensure that the Regulations are complied with.

(6) A person may find himself responsible for causing danger to arise elsewhere in an electrical system, at a point beyond his own installation. This situation may arise, for example, due to unauthorized or unscheduled back feeding from his installation onto the system, or to raising the fault power level on the system above rated and agreed maximum levels due to connecting extra generation capacity etc. Because such circumstances are 'within his control', the effect of Regulation 3 is to bring responsibilities for compliance with the rest of the regulations to that person, thus making him a duty holder.

Absolute/reasonably practicable

(7) Duties in some of the Regulations are subject to the qualifying term 'reasonably practicable'. Where qualifying terms are absent the requirement in the Regulation is said to be absolute. The

meaning of reasonably practicable has been well established in law. The interpretations below are given only as a guide to duty holders.

Absolute

(8) If the requirement in a Regulation is 'absolute', for example, if the requirement is not qualified by the words 'so far as is reasonably practicable', the requirement must be met regardless of cost or any other consideration. Certain of the regulations making such absolute requirements are subject to the Defence provision of Regulation 29.

Reasonably practicable

(9) Someone who is required to do something 'so far as is reasonably practicable' must assess, on the one hand, the magnitude of the risks of a particular work activity or environment and, on the other hand, the costs in terms of the physical difficulty, time, trouble and expense which would be involved in taking steps to eliminate or minimize those risks. If, for example, the risks to health and safety of a particular work process are very low, and the cost or technical difficulties of taking certain steps to prevent those risks are very high, it might not be reasonably practicable to take those steps. The greater the degree of risk, the less weight that can be given to the cost of measures needed to prevent that risk.

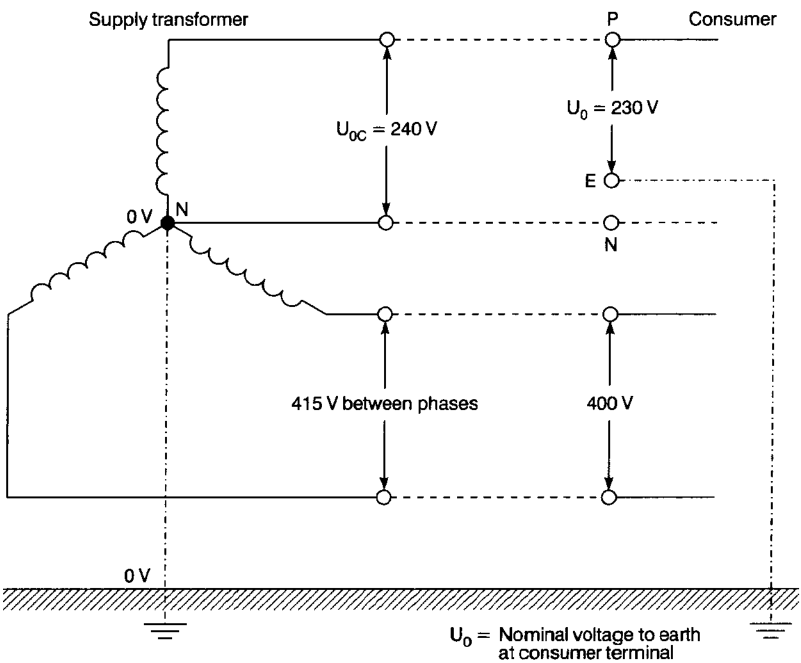
(10) In the context of the Regulations, where the risk is very often that of death, for example, from electrocution, and where the nature of the precautions which can be taken are so often very simple and cheap, e.g. insulation, the level of duty to prevent that danger approaches that of an absolute duty.

(11) The comparison does not include the financial standing of the duty holder. Furthermore, where someone is prosecuted for failing to comply with a duty 'so far as is reasonably practicable', it would be for the accused to show the court that it was not reasonably practicable for him to do more than he had in fact done to comply with the duty (section 40 of the HSW Act).

Appendix 2 of the IEE Regulations lists all of the other Statutory Regulations and Memoranda with which electrical installations must comply.

It is interesting to note that if an installation fails to comply with Chapter 13 of the Regulations, the Supply Authority has the right to refuse to give a supply or, in certain circumstances, to disconnect it.

While we are on the subject of Supply Authorities, let us look at the current declared supply voltages and tolerances. In order to align with European Harmonized Standards, our historic 415 V/240 V declared supply voltages have now become 400 V/230 V. However, this is only a paper exercise, and it is unlikely that consumers will notice any difference for many years, if at all. Let me explain, using single phase as the example.



Note: The connection of the transformer star or neutral point to earth, helps to maintain that point at or very near zero volts.

Figure 1

The supply industry declared voltage was 240 V ± 6%, giving a range between 225.6 V and 254.4 V. The new values are 230 V + 10% – 6%, giving a range between 216.2 V and 253 V. Not a lot of difference. The industry has done nothing physical to reduce voltages from 240 V to 230 V, it is just the declaration that has been altered. Hence a measurement of voltage at supply terminals will give similar readings to those we have always known. In fact the presumed open circuit voltage, U_{oc}, at the supply transformer terminals is still 240 V.

Figure 1 shows the UK supply system and associated declared voltages.

BS7671 details 2 voltage categories, Band 1 and Band 2. Band 1 is essentially Extra low voltage systems and Band 2, Low voltage systems.

ELV is less than 50 V ac between conductors or to earth. LV exceeds ELV up to 1000 V ac between conductors and 600 V between conductors and earth.

2
EARTHING

(Relevant chapters and parts
Chapters 31, 33, 41, 47, 53, 54, 55, Part 6)

Definitions used in this chapter

Bonding conductor A protective conductor providing equipotential bonding.

Circuit protective conductor A protective conductor connecting exposed conductive parts of equipment to the main earthing terminal.

Direct contact Contact of persons or livestock with live parts.

Earth The conductive mass of earth, whose electric potential at any point is conventionally taken as zero.

Earth electrode resistance The resistance of an earth electrode to earth.

Earth fault loop impedance The impedance of the phase-to-earth loop path starting and ending at the point of fault.

Earthing conductor A protective conductor connecting a main earthing terminal of an installation to an earth electrode or other means of earthing.

Equipotential bonding Electrical connection maintaining various exposed conductive parts and extraneous conductive parts at a substantially equal potential.

Exposed conductive part A conductive part of equipment which can be touched and which is not a live part but which may become live under fault conditions.

Extraneous conductive part A conductive part liable to introduce a potential, generally earth potential and not forming part of the electrical installation.

Functional earthing Connection to earth necessary for proper functioning of electrical equipment.

Indirect contact Contact of persons or livestock with exposed conductive parts made live by a fault.

Leakage current Electric current in an unwanted conductive part under normal operating conditions.

Live part A conductor or conductive part intended to be energized in normal use, including a neutral conductor but, by convention, not a PEN conductor.

PEN conductor A conductor combining the functions of both protective conductor and neutral conductor.

Phase conductor A conductor of an AC system for the transmission of electrical energy, other than a neutral conductor.

PME An earthing arrangement, found in TN–C–S systems, where an installation is earthed via the supply neutral conductor.

Protective conductor A conductor used for some measure of protection against electric shock and intended for connecting together any of the following parts:

exposed conductive parts
extraneous conductive parts
main earthing terminal
earth electrode(s)
earthed point of the source.

Residual current device An electromechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under given conditions.

Simultaneously accessible parts Conductors or conductive parts which can be touched simultaneously by a person or, where applicable, by livestock.

Earth: what it is, and why and how we connect to it (IEE Regs Section 413)

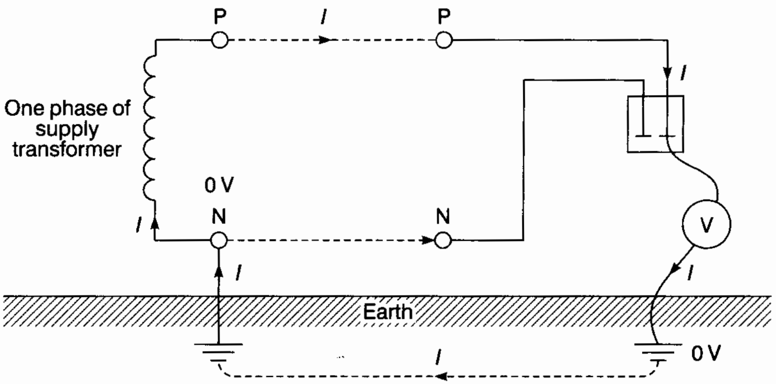
The thin layer of material which covers our planet, be it rock, clay, chalk or whatever, is what we in the world of electricity refer to as earth. So, why do we need to connect anything to it? After all, it is not as if earth is a good conductor.

Perhaps it would be wise at this stage to investigate potential difference (PD). A potential difference is exactly what it says it is: a difference in potential (volts). Hence, two conductors having PDs of, say, 20 V and 26 V have a PD between them of $26 - 20 = 6$ V. The original PDs, i.e. 20 V and 26 V, are the PDs between 20 V and 0 V and 26 V and 0 V.

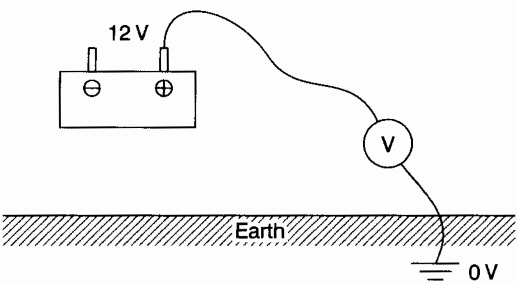
So where does this 0 V or zero potential come from? The simple answer is, in our case, the earth. The definition of earth is therefore the conductive mass of earth, whose electric potential at any point is conventionally taken as zero.

Hence, if we connect a voltmeter between a live part (e.g. the phase conductor of, say, a socket outlet) and earth, we may read 230 V; the conductor is at 230 V, the earth at zero. The earth provides a path to complete the circuit. We would measure nothing at all if we connected our voltmeter between, say, the positive 12 V terminal of a car battery and earth, as in this case the earth plays no part in any circuit. Figure 2 illustrates this difference.

Hence, a person in an installation touching a live part whilst standing on the earth would take the place of the voltmeter in Figure 2(a), and could suffer a severe electric shock. Remember that the accepted lethal level of shock current passing through a



(a)



(b)

Figure 2

person is only 50 mA or 1/20 A. The same situation would arise if the person were touching say, a faulty appliance and a gas or water pipe (Figure 3).

One method of providing some measure of protection against these effects is to join together (bond) all metallic parts and connect them to earth. This ensures that all metalwork in a healthy situation is at or near zero volts, and under fault conditions all metalwork will rise to a similar potential. So, simultaneous contact with two such metal parts would not result in a dangerous shock, as there will be no significant PD between them. This method is known as earthed equipotential bonding.

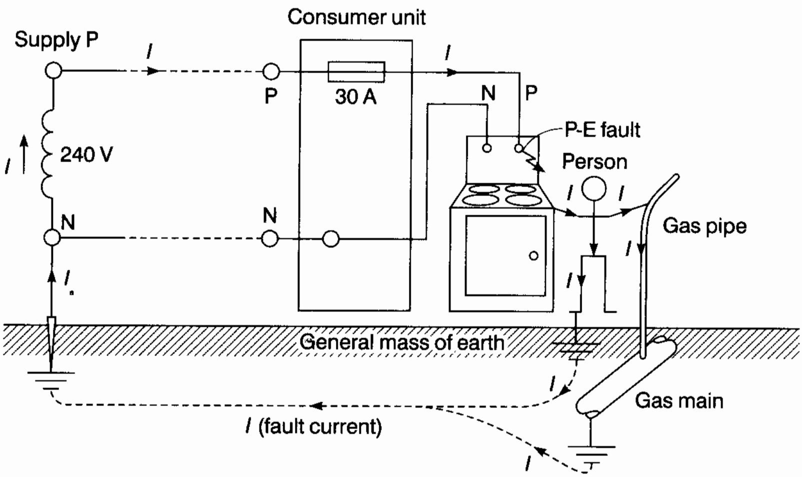


Figure 3

Unfortunately, as previously mentioned, earth itself is not a good conductor unless it is very wet, and therefore it presents a high resistance to the flow of fault current. This resistance is usually enough to restrict fault current to a level well below that of the rating of the protective device, leaving a faulty circuit uninterrupted. Clearly this is an unhealthy situation. The methods of overcoming this problem will be dealt with later.

In all but the most rural areas, consumers can connect to a metallic earth return conductor which is ultimately connected to the earthed neutral of the supply. This, of course, presents a low-resistance path for fault currents to operate the protection.

Summarizing, then, connecting metalwork to earth, places that metal at or near zero potential, and bonding between metallic parts puts such parts at a similar potential even under fault conditions.

Connecting to earth

In the light of previous comments, it is obviously necessary to have as low an earth path resistance as possible, and the point of connection to earth is one place where such resistance may be reduced. When two conducting surfaces are placed in contact with each other, there will be a resistance to the flow of current dependent on the surface areas in contact. It is clear, then, that the greater surface contact area with earth that can be achieved, the better.

There are several methods of making a connection to earth, including the use of rods, plates and tapes. By far the most popular method in everyday use is the rod earth electrode. The plate type needs to be buried at a sufficient depth to be effective and, as such plates may be 1 or 2 metres square, considerable excavation may be necessary. The tape type is predominantly used in the earthing of large electricity substations, where the tape is laid in trenches in a mesh formation over the whole site. Items of plant are then earthed to this mesh.

Rod electrodes

These are usually of solid copper or copper-clad carbon steel, the latter being used for the larger-diameter rods with extension facilities. These facilities comprise: a thread at each end of the rod to enable a coupler to be used for connection of the next rod; a steel cap to protect the thread from damage when the rod is being driven in; a steel driving tip; and a clamp for the connection of an earth tape or conductor (Figure 4).

The choice of length and diameter of such a rod will, as previously mentioned, depend on the soil conditions. For example, a long thick electrode is used for earth with little moisture retention. Generally, a 1–2 m rod, 16 mm in diameter, will give a relatively low resistance.

Earth electrode resistance

(IEE Regs Definitions)

If we were to place an electrode in the earth and then measure the resistance between the electrode and points at increasingly larger distance from it, we would notice that the resistance increased with distance until a point was reached (usually around 2.5 m) beyond which no increase in resistance was noticed (Figure 5).

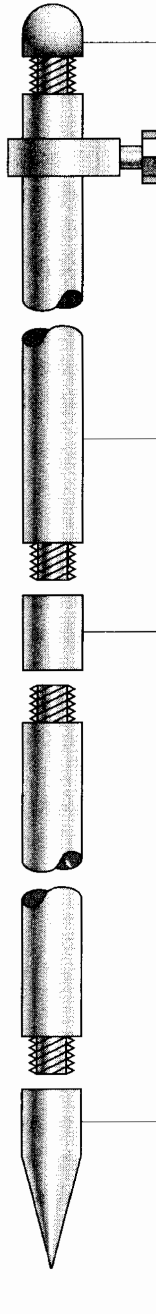

Steel driving cap
Earthing conductor clamp
Earth rod
Coupler
Steel tip

Figure 4

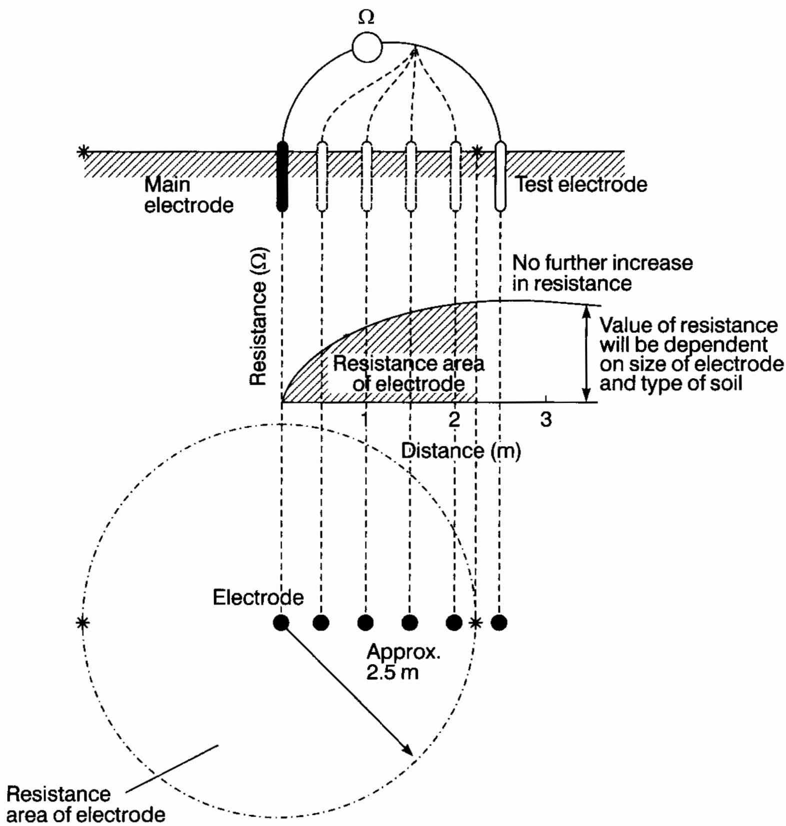


Figure 5 Resistance area of electrode

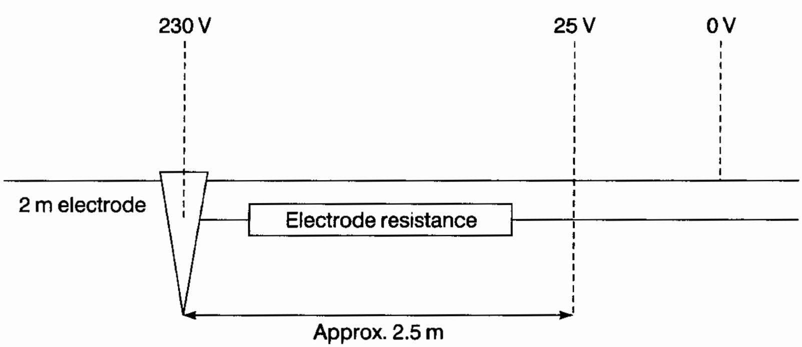


Figure 6

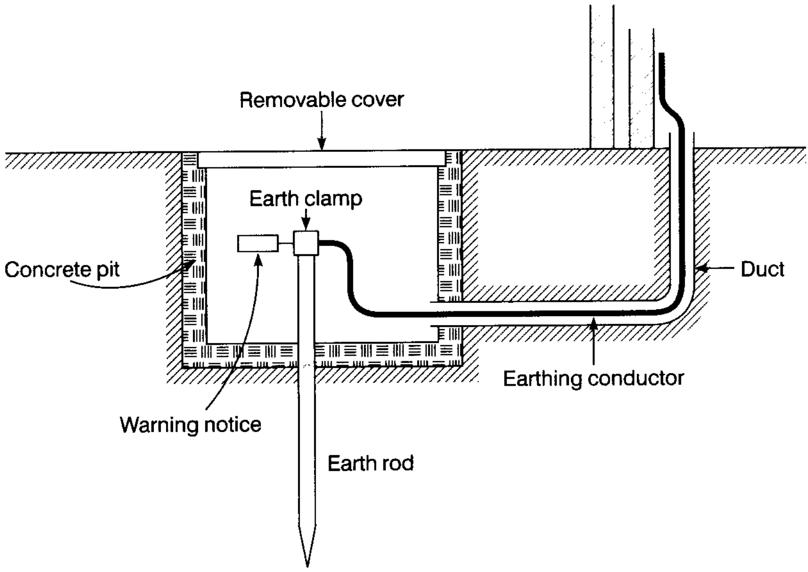


Figure 7

The resistance area around the electrode is particularly important with regard to the voltage at the surface of the ground (Figure 6). For a 2 m rod, with its top at ground level, 80–90% of the voltage appearing at the electrode under fault conditions is dropped across the earth in the first 2.5 to 3 m. This is particularly dangerous where livestock is present, as the hind and fore legs of an animal can be respectively inside and outside the resistance area: a PD of 25 V can be lethal! One method of overcoming this problem is to house the electrode in a pit below ground level (Figure 7) as this prevents voltages appearing at ground level.

Earthing in the IEE Regulations

(IEE Regs Chapter 4)
(IEE Regs 413-02-01 to 28)

In the preceding pages we have briefly discussed the reasons for, and the importance and methods of, earthing. Let us now examine the subject in relation to the IEE Regulations.

Contact with metalwork made live by a fault is called *indirect contact*. One popular method of providing some measure of protection against such contact is by earthed equipotential bonding and automatic disconnection of supply. This entails the bonding together and connection to earth of:

1 All metalwork associated with electrical apparatus and systems, termed exposed conductive parts. Examples include conduit, trunking and the metal cases of apparatus.
2 All metalwork liable to introduce a potential including earth potential, termed extraneous conductive parts. Examples are gas, oil and water pipes, structural steelwork, radiators, sinks and baths.

The conductors used in such connections are called *protective conductors*, and they can be further subdivided into:

1 Circuit protective conductors, for connecting exposed conductive parts to the main earthing terminal.
2 Main equipotential bonding conductors, for bonding together main incoming services, structural steelwork etc.
3 Other equipotential bonding conductors, for bonding together sinks, baths, taps etc.
4 Supplementary bonding conductors for bonding exposed conductive parts and extraneous conductive parts, when circuit disconnection times cannot be met, or, in special locations, such as bathrooms, swimming pools etc.

The effect of all this bonding is to create a zone in which all metalwork of different services and systems will, even under fault conditions, be at a substantially equal potential. If, added to this, there is a low-resistance earth return path, the protection should operate fast enough to prevent danger. [IEE Reg 413–02–04.]

The resistance of such an earth return path will depend upon the system (see the next section), either TT, TN–S or TN–C–S (IT systems will not be discussed here, as they are extremely rare and unlikely to be encountered by the average contractor).

Earthing systems

(IEE Regs Definitions (Systems))

These have been designated in the IEE Regulations using the letters T, N, C and S. These letters stand for:

- T terre (French for earth) and meaning a direct connection to earth
- N neutral
- C combined
- S separate

When these letters are grouped they form the classification of a type of system. The first letter in such a classification denotes how the supply source is earthed. The second denotes how the metalwork of an installation is earthed. The third and fourth indicate the functions of neutral and protective conductors. Hence:

1 A TT system has a direct connection of the supply source to earth and a direct connection of the installation metalwork to earth. An example is an overhead line supply with earth electrodes, and the mass of earth as a return path (Figure 8).
2 A TN–S system has the supply source directly connected to earth, the installation metalwork connected to the earthed

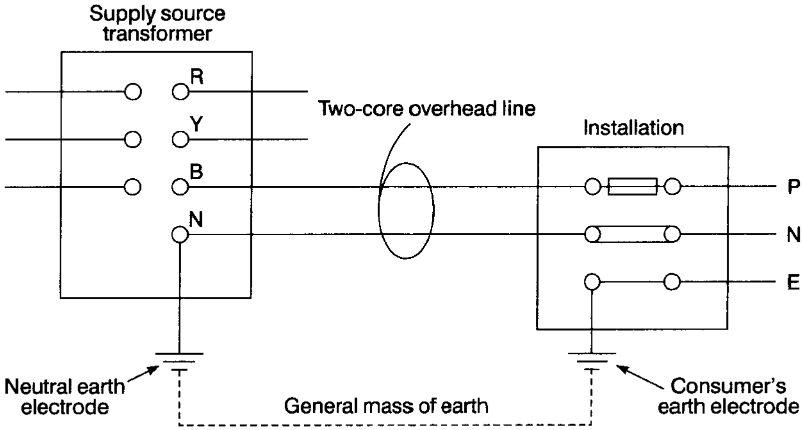


Figure 8 TT system

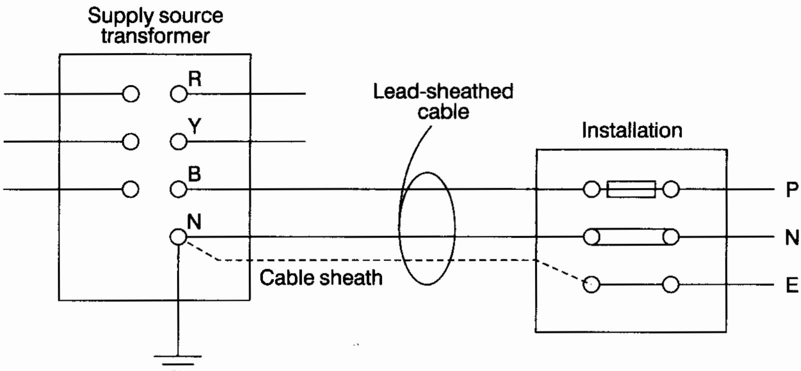


Figure 9 TN–S system

neutral of the supply source via the lead sheath of the supply cable and the neutral and protective conductors throughout the whole system performing separate functions (Figure 9).

3 A TN–C–S system is as the TN–S but the supply cable sheath is also the neutral, i.e. it forms a combined earth/neutral conductor known as a PEN (protective earthed neutral) conductor (Figure 10). The installation earth and neutral are separate conductors. This system is also known as PME (protective multiple earthing).

Note that only single-phase systems have been shown, for simplicity.

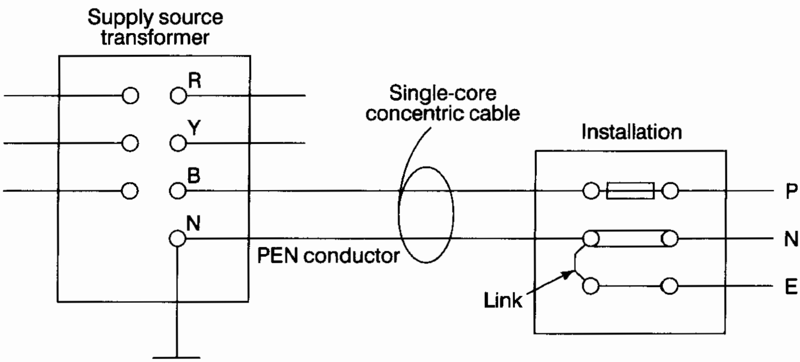


Figure 10 TN–C–S system

Summary

In order to reduce the risk of serious electric shock, it is important to provide a path for earth leakage currents to operate the circuit protection, and to endeavour to maintain all metalwork at a substantially equal potential. This is achieved by bonding together metalwork of electrical and non-electrical systems to earth. The path for leakage currents would then be via the earth itself in TT systems or by a metallic return path in TN–S or TN–C–S systems.

Earth fault loop impedance

(IEE Regs Definitions)

As we have seen, circuit protection should operate in the event of a direct fault from phase to earth. The speed of operation of the protection is of extreme importance and will depend on the magnitude of the fault current, which in turn will depend on the impedance of the earth fault loop path, Z_s.

Figure 11 shows this path. Starting at the fault, the path comprises:

1 The circuit protective conductor (CPC).
2 The consumer's earthing terminal and earth conductor.

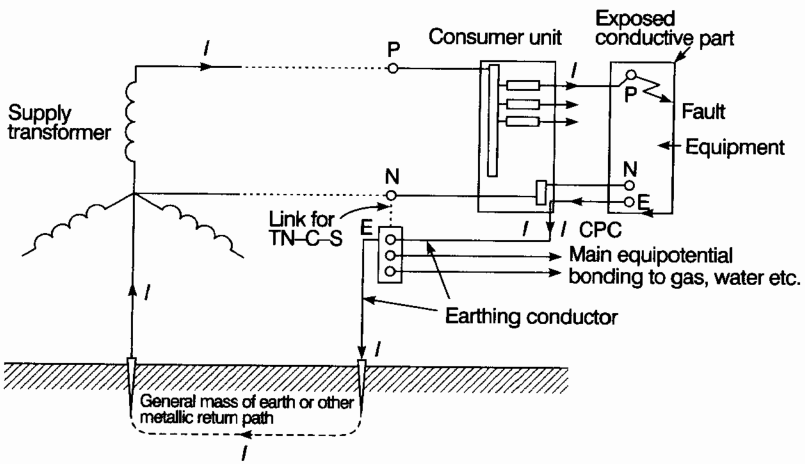


Figure 11

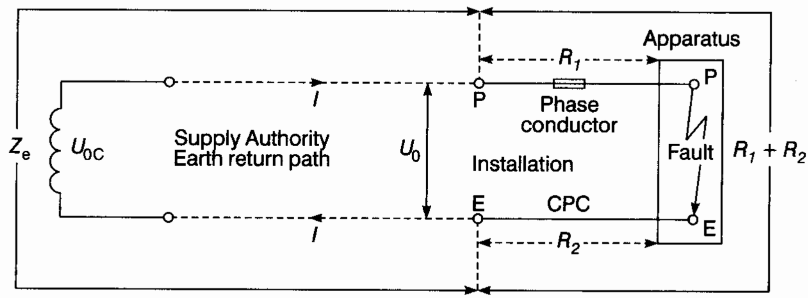


Figure 12

3 The return path, either metallic or earth.
4 The earthed neutral of the supply transformer.
5 The transformer winding.
6 The phase conductor from the transformer to the fault.

Figure 12 is a simplified version of this path. We have:

$$Z_s = Z_e + R_1 + R_2$$

where Z_s is the actual total loop impedance, Z_e is the loop impedance external to the installation, R_1 is the resistance of the phase conductor, and R_2 is the resistance of the CPC. We also have:

$$I = U_{0c}/Z_s$$

where I is the fault current and U_{0c} is the voltage at the supply transformer (assumed to be 240 V).

Determining the value of total loop impedance (IEE Regs 413-02-04)

The IEE Regulations require that when the general characteristics of an installation are assessed, the loop impedance Z_e external to the installation shall be ascertained.

This may be measured in existing installations using a phase-to-earth loop impedance tester. However, when a building is only at the drawing board stage it is clearly impossible to make such a measurement. In this case, we have three methods available to assess the value of Z_e:

1 Determine it from details (if available) of the supply transformer, the main distribution cable and the proposed service cable; or
2 Measure it from the supply intake position of an adjacent building having service cable of similar size and length to that proposed; or
3 Use maximum likely values issued by the supply authority as follows:
   TT system: 21 Ω maximum
   TN-S system: 0.80 Ω maximum
   TN-C-S system: 0.35 Ω maximum.

Method 1 will be difficult for anyone except engineers. Method 3 can, in some cases, result in pessimistically large cable sizes. Method 2, if it is possible to be used, will give a closer and more realistic estimation of Z_e. However, if in any doubt, use method 3.

Having established a value for Z_e, it is now necessary to determine the impedance of that part of the loop path internal to the installation. This is, as we have seen, the resistance of the phase conductor plus the resistance of the CPC, i.e. $R_1 + R_2$. Resistances of copper conductors may be found from manufacturers' information which gives values of resistance/metre for copper and aluminium conductors at 20°C in mΩ/m. The following table gives resistance values for copper conductors up to 35 mm^2.

A 25 mm^2 phase conductor with a 4 mm^2 CPC has $R_1 = 0.727$ and $R_2 = 4.61$, giving $R_1 + R_2 = 0.727 + 4.61 = 5.337$ mΩ/m. So, having established a value for $R_1 + R_2$, we must now multiply it by the length of the run and divide by 1000 (the values given are in mΩ/m). However, this final value is based on a temperature of 20°C, but when the conductor is fully loaded its temperature will increase. In order to determine the value of resistance at conductor operating temperature, a multiplier is used.

This multiplier, applied to the 20°C value of resistance is determined from the following formula:

$$R_t = R_{20} \{1 + \alpha_{20} (\theta^\circ - 20^\circ)\}$$

Where R_t = the resistance at conductor operating temperature
R_{20} = the resistance at 20°C
α_{20} = the 20°C temperature coefficient of copper, 0.004 Ω/Ω/°C
θ° = the conductor operating temperature.

Clearly, the multiplier is $\{1 + \alpha_{20} (\theta^\circ - 20^\circ)\}$.

So, for a 70°C, PVC insulated conductor. (Table 54C IEE Regulations), the multiplier becomes:

$$\{1 + 0.004(70^\circ - 20^\circ)\} = 1.2$$

And for a 90°C XLPE type cable it becomes:

$$\{1 + 0.004(90^\circ - 20^\circ)\} = 1.28$$

Hence, for a 20 m length of 70°C PVC insulated 16 mm^2 phase conductor with a 4 mm^2 CPC, the value of $R_1 + R_2$ would be:

$$R_1 + R_2 = (1.15 + 4.61) \times 20 \times 1.2/1000 = 0.138\ \Omega$$

We are now in a position to determine the total earth fault loop impedance Z_s from:

$$Z_s = Z_e + R_1 + R_2$$

Table 1 Resistance of copper conductors in at 20°C

Conductor CSA (mm^2)	*Resistance (m*/m)*
1.0	18.1
1.5	12.1
2.5	7.41
4.0	4.61
6.0	3.08
10.0	1.83
16.0	1.15
25.0	0.727
35.0	0.524

As previously mentioned, this value of Z_s should be as low as possible to allow enough fault current to flow to operate the protection as quickly as possible. Tables 41B1, B2 and D of the IEE Regulations give maximum values of loop impedance for different sizes and types of protection for both socket outlet circuits, and circuits feeding fixed equipment.

Provided that the actual values calculated do not exceed those tabulated, socket outlet circuits will disconnect under earth fault conditions in 0.4 s or less, and circuits feeding fixed equipment in 5 s or less. The reasoning behind these different times is based on the time that a faulty circuit can reasonably be left uninterrupted. Hence, socket outlet circuits from which hand-held appliances may be used, clearly present a greater shock risk than circuits feeding fixed equipment. BS7671 does not mention dis- connection times in bathrooms, but it would be wise to assume the lower disconnection time of 0.4 s, as bathrooms etc. are hazardous areas.

It should be noted that these times, i.e. 0.4 s and 5 s, do not indicate the duration that a person can be in contact with a fault. They are based on the probable chances of someone being in contact with exposed or extraneous conductive parts at the precise moment that a fault develops.

See also Tables 41A, 604A and 605A of the IEE Regulations.

Example 1

Let us now have a look at a typical example of, say, a shower circuit run in an 18 m length of 6.0 mm^2 (6242Y) twin cable with CPC, and protected by a 30 A BS 3036 semi-enclosed rewirable fuse. A 6.0 mm^2 twin cable has a 2.5 mm^2 CPC. We will also assume that the external loop impedance Z_e, is measured as 0.27 Ω. Will there be a shock risk if a phase-to-earth fault occurs?

The total loop impedance $Z_s = Z_e + R_1 + R_2$. We are given $Z_e = 0.27\ \Omega$. For a 6.0 mm^2 phase conductor with a 2.5 mm^2 CPC, $R_1 + R_2$ is 10.49 mΩ/m. Hence, with a multiplier of 1.2 for 70°C PVC,

$$\text{total } R_1 + R_2 = 18 \times 10.49 \times 1.2/1000 = 0.23\ \Omega$$

Therefore, $Z_s = 0.27 + 0.23 = 0.53\ \Omega$. This is less than the $1.14\ \Omega$ maximum given in Table 41B1 for a 30 A BS 3036 fuse. Hence, the protection will disconnect the circuit in less than 0.4 s. In fact it will disconnect in less than 0.1 s, the determination of this time will be dealt with in Chapter 5.

Example 2

Consider now, a more complex installation, and note how the procedure remains unchanged.

In this example, a 3-phase motor is fed using $25\,mm^2$ single PVC conductors in trunking, the CPC being $2.5\,mm^2$. The circuit is protected by BS 1361 45 A fuses in a distribution fuseboard. The distribution circuit or sub-main feeding this fuseboard comprises $70\,mm^2$ PVC singles in trunking with a $25\,mm^2$ CPC the protection being by BS 88 160 A fuses. The external loop impedance Z_e has a measured value of $0.2\ \Omega$. Will this circuit arrangement comply with the shock risk constraints?

The formula $Z_s = Z_e + R_1 + R_2$ must be extended, as the $(R_1 + R_2)$ component comprises both sub-main and motor circuit, it therefore becomes:

$$Z_s = Z_e + (R_1 + R_2)_1 + (R_1 + R_2)_2$$

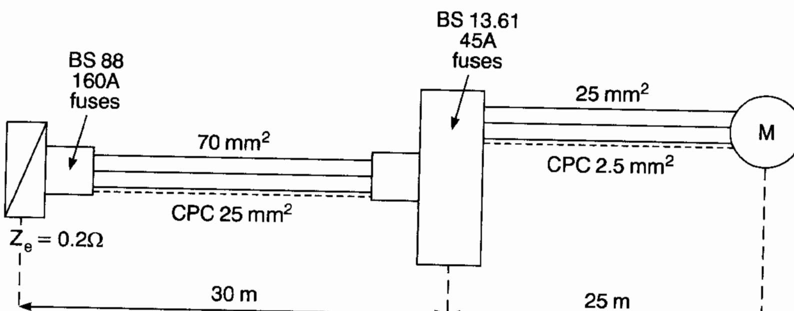


Figure 13

Distribution circuit $(R_1 + R_2)_1$

This comprises 30 m of 70 mm² single-phase conductor and 30 m of 25 mm² CPC. Typical values for conductors over 35 mm² are shown in Table 2.

As an alternative we can use our knowledge of the relationship between conductor resistance and area, e.g. a 10 mm² conductor has approximately 10 times less resistance than a 1 mm² conductor:

$$\begin{aligned} 10\,\text{mm}^2 \text{ resistance} &= 1.83\,\text{m}\Omega/\text{m} \\ 11\,\text{mm}^2 \text{ resistance} &= 18.1\,\text{m}\Omega/\text{m} \end{aligned}$$

Hence a 70 mm² conductor will have a resistance approximately half that of a 35 mm² conductor.

$$35\,\text{mm}^2 \text{ resistance} = 0.524\,\text{m}\Omega/\text{m}$$

$$\therefore \quad 70\,\text{mm}^2 \text{ resistance} = \frac{0.524}{2} = 0.262\,\text{m}\Omega/\text{m}$$

which compares well with the value given in Table 2.

$$25\,\text{mm}^2 \text{ CPC resistance} = 0.727\,\text{m}\Omega/\text{m}$$

so the distribution circuit

$$(R_1 + R_2)_1 = 30 \times (0.262 + 0.727) \times 1.2/1000 = 0.035\,\Omega$$

Table 2

Area of conductor (mm²)	*Resistance (m*/m)*	
	Copper	*Aluminium*
50	0.387	0.641
70	0.263	0.443
95	0.193	0.320
120	0.153	0.253
185	0.0991	0.164
240	0.0754	0.125
300	0.0601	0.1

Hence $Z_s = Z_e + (R_1 + R_2)_1 = 0.2 + 0.035 = 0.235\ \Omega$ which is less than the Z_s, maximum of $0.267\ \Omega$ quoted for a 160 A BS 88 fuse in Table 41D of the Regulations.

Motor circuit $(R_1 + R_2)_2$

Here we have 25 m of 25 mm^2 conductor with 25 m of 2.5 mm^2 CPC. Hence:

$$(R_1 + R_2)_2 = 25 \times (0.727 + 7.41) \times 1.2/1000$$
$$= 0.24\ \Omega$$
$$\therefore \quad \text{Total } Z_s = Z_e + (R_1 + R_2)_1 + (R_1 + R_2)_2$$
$$= 0.2 + 0.035 + 0.24$$
$$= 0.48\ \Omega$$

which is less than the Z_s maximum of $1.0\ \Omega$ quoted for a 45 A BS 1361 fuse from Table 41D of the Regulations.

Hence we have achieved compliance with the shock-risk constraints.

Residual current devices

(IEE Regs 531, 412-06, 413-02-15 and 471-16-01)

We have seen how very important is the total earth loop impedance Z_s in the reduction of shock risk. However, in TT systems where the mass of earth is part of the fault path, the maximum values of Z_s given in Tables 41 B1, B2 and D of the Regulations may be hard to satisfy. Added to this, climatic conditions will alter the resistance of the earth in such a way that Z_s may be satisfactory in wet weather but not in very dry.

The IEE Regulations recommend therefore that protection for socket outlet circuits in a TT system be achieved by a residual current device (RCD), such that the product of its residual operating current and the loop impedance will not exceed a figure of 50 V. Residual current breakers (RCBs), residual current circuit breakers (RCCBs) and RCDs are one and the same thing. RCBO's are combined circuit breakers (CB's) and RCD's in one unit.

For construction sites and agricultural environments this value is reduced to 25 V.

Principle of operation of an RCD

Figure 14 illustrates the construction of an RCD. In a healthy circuit the same current passes through the phase coil, the load, and back through the neutral coil. Hence the magnetic effects of phase and neutral currents cancel out.

In a faulty circuit, either phase to earth or neutral to earth, these currents are no longer equal. Therefore the out-of-balance current produces some residual magnetism in the core. As this magnetism is alternating, it links with the turns of the search coil, inducing an EMF in it. This EMF in turn drives a current through the trip coil, causing operation of the tripping mechanism.

It should be noted that a phase-to-neutral fault will appear as a load, and hence the RCD will not operate for this fault.

A three-phase RCD works on the same out of balance principle, in this case the currents flowing in the three phases when they are all equal, sum to zero, hence there is no resultant magnetism. Even if they are unequal, the out of balance current flows in the neutral which cancels out this out of balance current. Figure 14(b) shows the arrangement of a three-phase RCD, and Figure 14(c), how it can be connected for use on single-phase circuits.

Nuisance tripping

Certain appliances such as cookers, water heaters and freezers tend to have, by the nature of their construction and use, some leakage currents to earth. These are quite normal, but could cause the operation of an RCD protecting an entire installation. This can be overcome by using split-load consumer units, where socket outlet circuits are protected by a 30 mA RCD, leaving all other circuits controlled by a normal mains switch. Better still, especially in TT systems, is the use of a 100 mA RCD for protecting circuits other than socket outlets.

Modern developments in MCB, RCD and consumer unit design now make it easy to protect any individual circuit with a

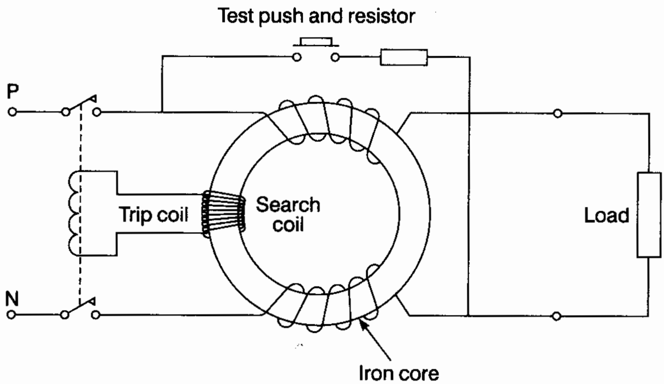


Figure 14a Residual current device

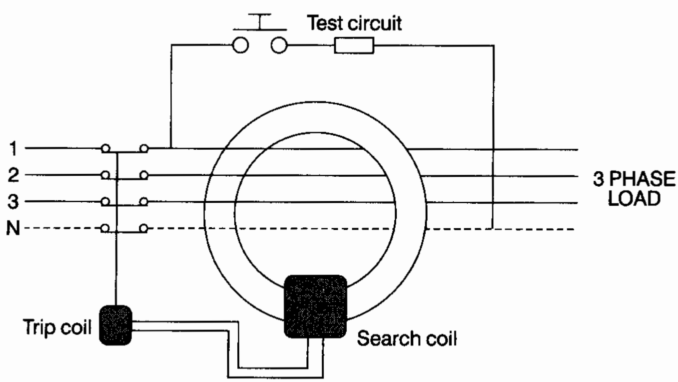


Figure 14b Three-phase RCD

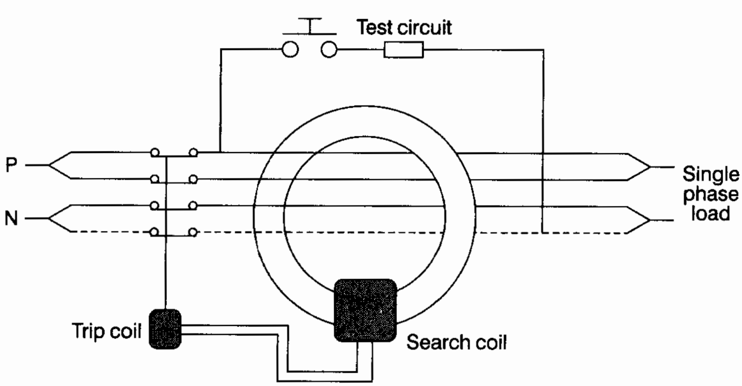


Figure 14c Connections for single phase

combined MCB/RCD (RCBO), making the use of split-load boards unnecessary.

One area where the use of 30 mA RCDs is required is in the protection of socket outlets intended for the connection of portable appliances for use outside the main equipotential zone. Hence, socket outlets in garages or even within the main premises which are likely to be used for supplying portable tools such as lawn mowers and hedge trimmers must be protected by an RCD rated at 30 mA or less. All other equipment outside the main equipotential zone should, in the event of an earth fault, disconnect in 0.4 s.

An exception to the RCD requirement is where fixed equipment is connected to the supply via a socket outlet, provided that some means of preventing the socket outlet being used for hand-held appliances is ensured.

Supplementary bonding

(IEE Regs 413-02-15(i), 413-02-27 and 28 and Section 547-03)

This is perhaps the most debated topic in the IEE Regulations. The confusion may have arisen because of a lack of understanding of earthing and bonding. Hopefully, this chapter will rectify the situation.

By now we should know why bonding is necessary; the next question, however, is to what extent bonding should be carried out. This is perhaps answered best by means of question and answer examples:

1 Q: Why do I need to bond the hot and cold taps and a metal sink together? Surely they are all joined anyway?
A: In most sinks the holes for connection of the taps are usually surrounded by a plastic insert which tends to insulate the taps from the sink. The sink is a large metallic part which could be 'earthy', the hot and cold taps are both parts of different

systems. These, therefore, could be extraneous conductive parts and may need to be bonded together, although there is no specific requirement in BS 7671 to do this.

2 Q: Do I have to bond radiators in a premises to, say, metal clad switches or socket outlets etc.?

A: Supplementary bonding is only necessary when extraneous conductive parts are simultaneously accessible with exposed conductive parts and the disconnection time for the circuit concerned cannot be achieved. In these circumstances the bonding conductor should have a resistance $R \leqslant \frac{50}{I_a}$, where I_a is the operating current of the protection.

3 Q: Do I need to bond metal window frames?

A: In general, no. Apart from the fact that most window frames will not introduce a potential from anywhere, the part of the window most likely to be touched is the opening portion, to which it would not be practicable to bond. There may be a case for the bonding of patio doors, which could be considered earthy with rain running from the lower portion to the earth. However, once again the part most likely to be touched is the sliding section, to which it is not possible to bond. In any case there would need to be another simultaneously accessible part to warrant considering any bonding.

4 Q: What about bonding in bathrooms?

A: Bathrooms are particularly hazardous areas with regard to shock risk, as body resistance is drastically reduced when wet. Hence, supplementary bonding between exposed conductive parts must be carried out in addition to their existing CPCs. Also of course, taps and metal baths need bonding together, and to other extraneous and exposed conductive parts. It may be of interest to note that in older premises a toilet basin may be connected into a cast iron collar which then tees outside into a cast iron soil pipe. This arrangement will clearly introduce earth potential into the bathroom, and hence the collar should be bonded to any simultaneously accessible conductive parts. This may require an unsightly copper earth strap.

5 Q: What size of bonding conductors should I use?
A: Main equipotential bonding conductors should be not less than half the size of the main earthing conductor, subject to a minimum of 6.0 mm^2 or, where PME (TNCS) conditions are present, 10.0 mm^2. For example, most new domestic installations now have a 16.0 mm^2 earthing conductor, so all main bonding will be in 10.0 mm^2. Supplementary bonding conductors are subject to a minimum of 2.5 mm^2 if mechanically protected or 4.0 mm^2 if not. However, if these bonding conductors are connected to exposed conductive parts, they must be the same size as the CPC connected to the exposed conductive part, once again subject to the minimum sizes mentioned. It is sometimes difficult to protect a bonding conductor mechanically throughout its length, and especially at terminations, so it is perhaps better to use 4.0 mm^2 as the minimum size.

6 Q: Do I have to bond free-standing metal cabinets, screens, workbenches etc.?
A: No. These items will not introduce a potential into the equipotential zone from outside, and cannot therefore be regarded as extraneous conductive parts.

7 Q: What are the bonding requirements for plumbing installations that incorporate plastic pipes.
A: There is an increasing amount of plastic plumbing installations being used in modern houses for both domestic hot and cold water and C.H. systems. If the pipework is plastic but terminates in copper at taps, radiators etc NO bonding is needed.

The Faraday cage

In one of his many experiments, Michael Faraday (1791–1867) placed an assistant in an open-sided cube which was then covered in a conducting material and insulated from the floor. When this cage arrangement was charged to a high voltage, the assistant found that he could move freely within it touching any of the sides, with no adverse effects. Faraday had, in fact, created an equipotential zone, and of course in a correctly bonded installation, we live and/or work in Faraday cages!

Problems

1 What is the resistance of a 10 m length of 6.0 mm^2 copper phase conductor if the associated CPC is 1.5 mm^2?
2 What is the length of a 6.0 mm^2 copper phase conductor with a 2.5 mm^2 CPC if the overall resistance is 0.189 Ω?
3 If the total loop impedance of a circuit under operating conditions is 0.96 Ω and the cable is a 20 m length of 4.0 mm^2 copper with a 1.5 mm^2 CPC, what is the external loop impedance?
4 Will there be a shock risk if a double socket outlet, fed by a 23 m length of 2.5 mm^2 copper conductor with a 1.5 mm^2 CPC, is protected by a 20 A BS 3036 rewirable fuse and the external loop impedance is measured as 0.5 Ω?
5 A cooker control unit incorporating a socket outlet is protected by a 32 A BS 88 fuse, and wired in 6.0 mm^2 copper with a 2.5 mm^2 CPC. The run is some 25 m and the external loop impedance of the TN–S system is not known. Is there a shock risk, and if so, how could it be rectified?

3
PROTECTION

(Relevant IEE parts, chapters and sections
Part 4; Chapters 41, 42, 43, 44, 45, 48; Section 471, 473, 514, 522, 543, 547)

Definitions used in this chapter

Arm's reach A zone of accessibility to touch, extending from any point on a surface where persons usually stand or move about, to the limits which a person can reach with his hand in any direction without assistance.

Barrier A part providing a defined degree of protection against contact with live parts, from any usual direction.

Class 2 equipment Equipment in which protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as supplementary insulation are provided. There is no provision for the connection of exposed metalwork of the equipment to a protective conductor, and no reliance upon precautions to be taken in the fixed wiring of the installation.

Circuit protective conductor A protective conductor connecting exposed conductive parts of equipment to the main earthing terminal.

Design current The magnitude of the current intended to be carried by a circuit in normal service.

Direct contact Contact of persons or livestock with live parts.

Enclosure A part providing an appropriate degree of protection of equipment against certain external influences and a defined degree of protection against contact with live parts from any direction.

Exposed conductive part A conductive part of equipment which can be touched and which is not a live part but which may become live under fault conditions.

External influence Any influence external to an electrical installation which affects the design and safe operation of that installation.

Extraneous conductive part A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

Fault current A current resulting from a fault.

Fixed equipment Equipment fastened to a support or otherwise secured in a specific location.

Indirect contact Contact of persons or livestock with exposed conductive parts which have become live under fault conditions.

Isolation Cutting off an electrical installation, a circuit or an item of equipment from every source of electrical energy.

Insulation Suitable non-conductive material enclosing, surrounding or supporting a conductor.

Live part A conductor or conductive part intended to be energized in normal use, including a neutral conductor but, by convention, not a PEN conductor.

Obstacle A part preventing unintentional contact with live parts but not preventing deliberate contact.

Overcurrent A current exceeding the rated value. For conductors the rated value is the current-carrying capacity.

Overload An overcurrent occurring in a circuit which is electrically sound.

Residual current device An electromechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions.

Short-circuit current An overcurrent resulting from a fault of negligible impedance between live conductors having a difference of potential under normal operating conditions.

Skilled person A person with technical knowledge or sufficient experience to enable him to avoid the dangers which electricity may create.

What is protection?

The meaning of the word 'protection', as used in the electrical industry, is no different to that in everyday use. People protect themselves against personal or financial loss by means of insurance and from injury or discomfort by the use of the correct protective clothing. They further protect their property by the installation of security measures such as locks and/or alarm systems. In the same way, electrical systems need:

1 To be protected against mechanical damage, the effects of the environment and electrical overcurrents; and
2 To be installed in such a fashion that persons and/or livestock are protected from the dangers that such an electrical installation may create.

Let us now look at these protective measures in more detail.

Protection against mechanical damage

The word 'mechanical' is somewhat misleading in that most of us associate it with machinery of some sort. In fact a serious electrical overcurrent left uninterrupted for too long can cause distortion of conductors and degradation of insulation; both of these effects are considered to be mechanical damage.

However, let us start by considering the ways of preventing mechanical damage by physical impact and the like.

Cable construction

A cable comprises one or more conductors each covered with an insulating material. This insulation provides protection from shock by direct contact and prevents the passage of leakage currents between conductors.

Clearly, insulation is very important and in itself should be protected from damage. This may be achieved by covering the insulated conductors with a protective sheathing during manufacture, or by enclosing them in conduit or trunking at the installation stage.

The type of sheathing chosen and/or the installation method will depend on the environment in which the cable is to be installed. For example, metal conduit with PVC singles or mineral-insulated (MI) cable would be used in preference to PVC sheathed cable clipped direct, in an industrial environment. Figure 15 shows the effect of physical impact on MI cable.

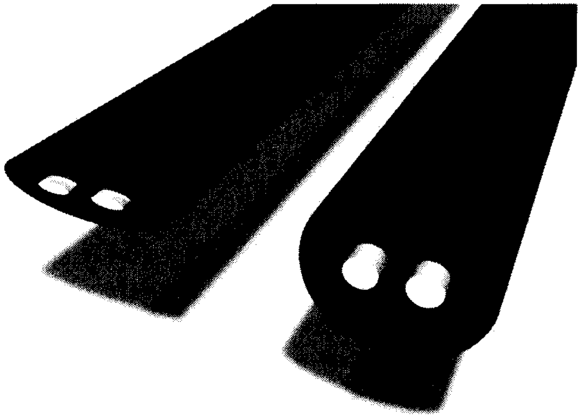


Figure 15 Mineral-insulated cable. On impact, all parts including the conductors are flattened, and a proportionate thickness of insulation remains between conductors, and conductors and sheath, without impairing the performance of the cable at normal working voltages

Protection against corrosion

Mechanical damage to cable sheaths and metalwork of wiring systems can occur through corrosion, and hence care must be taken to choose corrosion-resistant materials and to avoid contact between dissimilar metals in damp situations.

Protection against thermal effects

This is the subject of Chapter 42 of the IEE Regulations. Basically, it requires common-sense decisions regarding the placing of fixed equipment, such that surrounding materials are not at risk from damage by heat.

Added to these requirements is the need to protect persons from burns by guarding parts of equipment liable to exceed temperatures listed in Table 42A of the Regulations.

Polyvinyl chloride

Polyvinyl chloride (PVC) is a thermoplastic polymer widely used in electrical installation work for cable insulation, conduit and trunking. General-purpose PVC is manufactured to the British Standard BS 6746.

PVC in its raw state is a white powder; it is only after the addition of plasticizers and stabilizers that it acquires the form that we are familiar with.

Degradation

All PVC polymers are degraded or reduced in quality by heat and light. Special stabilizers added during manufacture help to retard this degradation at high temperatures. However, it is recommended that PVC-sheathed cables or thermoplastic fittings for luminaries (light fittings) should not be installed where the temperature is likely to rise above 60°C. Cables insulated with high-temperature PVC (up to 80°C) should be used for drops to lampholders and entries into batten-holders. PVC conduit and trunking should not be used in temperatures above 60°C.

Embrittlement and cracking

PVC exposed to low temperatures becomes brittle and will easily crack if stressed. Although both rigid and flexible, PVC used in cables and conduit can reach as low as 5°C without becoming brittle, it is recommended that general-purpose PVC insulated cables should not be installed in areas where the temperature is likely to be consistently below 0°C, and that PVC-insulated cable should not be handled unless the ambient temperature is above 0°C and unless the cable temperature has been above 0°C for at least 24 hours.

Where rigid PVC conduit is to be installed in areas where the ambient temperature is below –5°C but not lower than –25°C, type B conduit manufactured to BS 4607 should be used.

When PVC-insulated cables are installed in loft spaces insulated with polystyrene granules, contact between the two polymers can cause the plasticizer in the PVC to migrate to the granules. This causes the PVC to harden and although there is no change in the electrical properties, the insulation may crack if disturbed.

External influences

Appendix 5 of the IEE Regulations classifies external influences which may affect an installation. This classification is divided into three sections, the environment (A), how that environment is utilized (B) and construction of buildings (C). The nature of any influence within each section is also represented by a letter, and the level of influence by a number. The following gives examples of the classification:

Environment	*Utilization*	*Building*
Water	Capability	Materials
AD6 Waves	**BA3** Handicapped	**CA1** Non-combustible

With external influences included on drawings and in specifications, installations and materials used can be designed accordingly.

Protection against ingress of solid objects and liquid

In order to protect equipment from damage by foreign bodies or liquid, and also to prevent persons from coming into contact with live or moving parts, such equipment is housed inside an enclosure.

The degree of protection offered by such an enclosure is the subject of BS EN 60529, commonly known as the IP code, part of which is as shown in the accompanying table. It will be seen from this table that, for instance, an enclosure to IP56 is dustproof and waterproof.

IP codes

First numeral: mechanical protection

0 No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.

1 Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example, a hand, but not protection against deliberate access to such parts. Protection against ingress of large solid foreign bodies.

2 Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium-size solid foreign bodies.

3 Protection against contact with live or moving parts inside the enclosures by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small foreign bodies.

4 Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small solid foreign bodies.

5 Complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed.

6 Complete protection against contact with live or moving parts inside the enclosures. Protection against ingress of dust.

Second numeral: liquid protection

0 No protection.

1 Protection against drops of condensed water. Drops of condensed water falling on the enclosure shall have no harmful effect.

2 Protection against drops of liquid. Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical.

3 Protection against rain. Water falling in rain at an angle equal to or smaller than 60° with respect to the vertical shall have no harmful effect.

4 Protection against splashing. Liquid splashed from any direction shall have no harmful effect.

5 Protection against water jets. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect.

6 Protection against conditions on ships' decks (deck with watertight equipment). Water from heavy seas shall not enter the enclosures under prescribed conditions.

7 Protection against immersion in water. It must not be possible for water to enter the enclosure under stated conditions of pressure and time.

8 Protection against indefinite immersion in water under specified pressure. It must not be possible for water to enter the enclosure.

X Indicates no *specified* protection.

The most commonly quoted IP codes in the Regulations are IP2X, IP4X and IPXXB. (The X denotes that no protection is specified, *not* that no protection exists.)

Hence, IP2X means that an enclosure can withstand the ingress of medium-sized solid foreign bodies (12.5 mm diameter), and a jointed test finger, known affectionately as the British Standard finger! IPXXB denotes protection against the test finger only, and IP4X indicates protection against small foreign bodies and a 1 mm diameter test wire.

IEE Regulations 522–01 to 12 give details of the types of equipment, cables, enclosure etc. that may be selected for certain environmental conditions, e.g an enclosure housing equipment in an AD8 environment (under water) would need to be to IPX8.

Protection against electric shock

(IEE Regs Chapter 41 and Section 471)

There are two ways of receiving an electric shock: by direct contact, and by indirect contact. It is obvious that we need to provide protection against both of these conditions.

Protection against direct contact

(IEE Regs Section 412 and Regs 471–04 to 07)

Clearly, it is not satisfactory to have live parts accessible to touch by persons or livestock. The IEE Regulations recommend five ways of minimizing this danger:

1 By covering the live part or parts with insulation which can only be removed by destruction, e.g. cable insulation.
2 By placing the live part or parts behind a barrier or inside an enclosure providing protection to at least 1P2X or IPXXB. In most cases, during the life of an installation it becomes necessary to open an enclosure or remove a barrier. Under these circumstances, this action should only be possible by the use of a key or tool, e.g. by using a screwdriver to open a junction box. Alternatively, access should only be gained after the supply to the live parts has been disconnected, e.g. by isolation on the front of a control panel where the cover cannot be removed until the isolator is in the ‘off’ position. An intermediate barrier of at least IP2X or IPXXB will give protection when an enclosure is opened: a good example of this is the barrier inside distribution fuseboards, preventing accidental contact with incoming live feeds.
3 By placing obstacles to prevent unintentional approach to or contact with live parts. This method must only be used where skilled persons are working.
4 By placing out of arm’s reach: for example, the high level of the bare conductors of travelling cranes.
5 By using an RCD. Whilst not permitted as the sole means of protection, this is considered to reduce the risk associated with direct contact, provided that one of the other methods just

mentioned is applied, and that the RCD has a rated operating current of not more than 30 mA and an operating time not exceeding 40 ms at 150 mA.

Protection against indirect contact

(IEE Regs Section 413 and Regs 471–08 to 12)

The IEE Regulations suggest five ways of protecting against indirect contact. One of these, earthed equipotential bonding and automatic disconnection of supply, has already been discussed in Chapter 2. The other methods are as follows.

Use of class 2 equipment

Often referred to as double-insulated equipment, this is typical of modern appliances where there is no provision for the connection of a CPC. This does not mean that there should be no exposed conductive parts and that the casing of equipment should be of an insulating material; it simply indicates that live parts are so well insulated that faults from live to conductive parts cannot occur.

Non-conducting location

This is basically an area in which the floor, walls and ceiling are all insulated. Within such an area there must be no protective conductors, and socket outlets will have no earthing connections.

It must not be possible simultaneously to touch two exposed conductive parts, or an exposed conductive part and an extraneous conductive part. This requirement clearly prevents shock current passing through a person in the event of an earth fault, and the insulated construction prevents shock current passing to earth.

Earth-free local equipotential bonding

This is, in essence, a Faraday cage, where all metal is bonded together but *not* to earth. Obviously great care must be taken when entering such a zone in order to avoid differences in potential between inside and outside.

The areas mentioned in this and the previous method are very uncommon. Where they do exist, they should be under constant supervision to ensure that no additions or alterations can lessen the protection intended.

Electrical separation

This method relies on a supply from a safety source such as an isolating transformer to BS EN 60742 which has no earth connection on the secondary side. In the event of a circuit that is supplied from a source developing a live fault to an exposed conductive part, there would be no path for shock current to flow: see Figure 16.

Once again, great care must be taken to maintain the integrity of this type of system, as an inadvertent connection to earth, or interconnection with other circuits, would render the protection useless.

Exemptions

(IEE Regs 471–13)

As with most sets of rules and regulations, there are certain areas which are exempt from the requirements. These are listed quite clearly in IEE Regulations 471–13, and there is no point in repeating them all here. However, one example is the dispensing of the need to

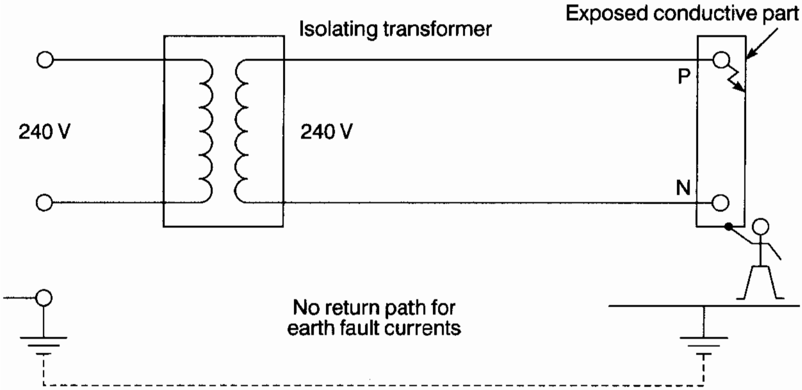


Figure 16

earth exposed conductive parts such as small fixings, screws and rivets, provided that they cannot be touched or gripped by a major part of the human body (not less than 50 mm by 50 mm), and that it is difficult to make and maintain an earth connection.

Protection against direct and indirect contact (IEE Regs Section 411)

So far we have dealt separately with direct and indirect contact. However, we can protect against both of these conditions with the following methods.

Separated extra low voltage (SELV)

This is simply extra low voltage (less than 50 V AC) derived from a safety source such as a class 2 safety isolating transformer to BS 3535; or a motor generator which has the same degree of isolation as the transformer; or a battery or diesel generator; or an electronic device such as a signal generator.

Live or exposed conductive parts of SELV circuits should not be connected to earth, or protective conductors of other circuits, and SELV circuit conductors should ideally be kept separate from those of other circuits. If this is not possible, then the SELV conductors should be insulated to the highest voltage present.

Obviously, plugs and sockets of SELV circuits should not be interchangeable with those of other circuits.

SELV circuits supplying socket outlets are mainly used for hand lamps or soldering irons, for example, in schools and colleges. Perhaps a more common example of a SELV circuit is a domestic bell installation, where the transformer is to BS EN 60742. Note that bell wire is usually only suitable for 50–60 V, which means that it should not be run together with circuit cables of higher voltages.

Reduced voltage systems (IEE Regs 471-15)

The Health and Safety Executive accepts that a voltage of 65 V to earth, three-phase, or 55 V to earth, single-phase, will give

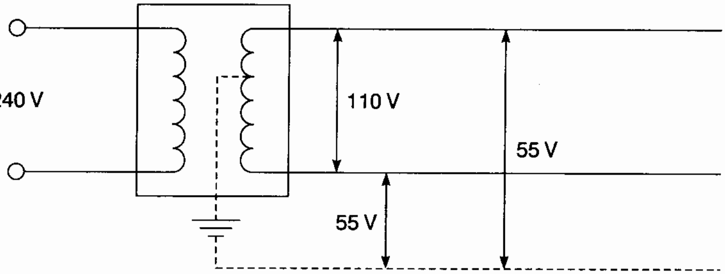


Figure 17

protection against severe electric shock. They therefore recommend that portable tools used on construction sites etc. be fed from a 110 V centre-tapped transformer to BS 4343. Figure 17 shows how 55 V is derived. Earth fault loop impedance values for these systems may be taken from Table 471A of the Regulations.

Protection against overcurrent

(IEE Regs Chapter 43 and Definitions)

An overcurrent is a current greater than the rated current of a circuit. It may occur in two ways:

1 As an overload current; or
2 As a short-circuit or fault current.

These conditions need to be protected against in order to avoid damage to circuit conductors and equipment. In practice, fuses and circuit breakers will fulfil both of these needs.

Overloads

Overloads are overcurrents occurring in healthy circuits. They may be caused, for example, by faulty appliances or by surges due to motors starting or by plugging in too many appliances in a socket outlet circuit.

Short circuits

A short-circuit current is the current that will flow when a 'dead short' occurs between live conductors (phase to neutral for single phase; phase to phase for three–phase). Prospective short-circuit current is the same, but the term is usually used to signify the value of short-circuit current at fuse or circuit breaker positions.

Prospective short-circuit current is of great importance. However, before discussing it or any other overcurrent further, it is perhaps wise to refresh our memories with regard to fuses and circuit breakers and their characteristics.

Fuses and circuit breakers

As we all know, a fuse is the weak link in a circuit which will break when too much current flows, thus protecting the circuit conductors from damage.

There are many different types and sizes of fuse, all designed to perform a certain function. The IEE Regulations refer to only four of these: BS 3036, BS 88, BS 1361 and BS 1362 fuses. It is perhaps sensible to include, at this point, circuit breakers to BS 3871, BS EN 60898.

Breaking capacity of fuses and circuit breakers (IEE Reg 432-04-01)

When a short-circuit occurs, the current may, for a fraction of a second, reach hundreds or even thousands of amperes. The protective device must be able to break, and in the case of circuit breakers, make such a current without damage to its surroundings by arcing, overheating or the scattering of hot particles.

The table on page 50 indicates the performance of circuit breakers and the more commonly used British Standard fuse links.

Although all reference to BS 3871 MCB's have been removed from BS 7671, they are still used and therefore worthy of mention.

Circuit breakers	*Breaking capacity (kA)*	
BS3871 Types 1, 2, 3 etc	1	(M1)
	1.5	(M 1.5)
	3	(M3)
	4.5	(M4.5)
	6	(M6)
	9	(M9)
BS EN 60898 Types B, C, D	Icn	Ics
	1.5	1.5
	3	3
	6	6
	10	7.5
	15	7.5
	25	10

Icn is the rated ultimate breaking capacity.
Ics is the maximum breaking capacity operation after which the breaker may still be used without loss of performance.

Fuse and circuit breaker operation

(IEE Regs 433-02 and 434-03)

Let us consider a protective device rated at, say, 10 A. This value of current can be carried indefinitely by the device, and is known as its nominal setting I_n. The value of the current which will cause operation of the device, I_2, will be larger than I_n, and will be dependent on the device's *fusing factor*. This is a figure which, when multiplied by the nominal setting I_n, will indicate the value of operating current I_2.

For fuses to BS 88 and BS 1361 and circuit breakers to BS 3871 this fusing factor is approximately 1.45; hence our 10 A device would not operate until the current reached $1.45 \times 10 = 14.5$ A. The IEE Regulations require coordination between conductors and protection when an overload occurs, such that:

1 The nominal setting of the device I_n is greater than or equal to the design current of the circuit I_b ($I_n \geqslant I_6$).

2 The nominal setting I_n is less than or equal to the lowest current-carrying capacity I_z of any of the circuit conductors ($I_n \leqslant I_z$).
3 The operating current of the device I_2 is less than or equal to $1.45I_z$ ($I_2 \leqslant 1.45I_z$).

So, for our 10 A device, if the cable is rated at 10 A then condition 2 is satisfied. Since the fusing factor is 1.45, condition 3 is also satisfied: $I_2 = I_n \times 1.45 = 10 \times 1.45$, which is also 1.45 times the 10 A cable rating.

The problem arises when a BS 3036 semi-enclosed rewirable fuse is used, as it may have a fusing factor of as much as 2. In order to comply with condition 3, I_n should be less than or equal to $0.725I_z$. This figure is derived from $1.45/2 = 0.725$. For example, if a cable is rated at 10 A, then I_n for a BS 3036 should be $0.725 \times 10 = 7.25$ A. As the fusing factor is 2, the operating current $I_2 = 2 \times 7.25 = 14.5$, which conforms with condition 3, i.e. $I_2 \leqslant 1.45 \times 120 = 14.5$.

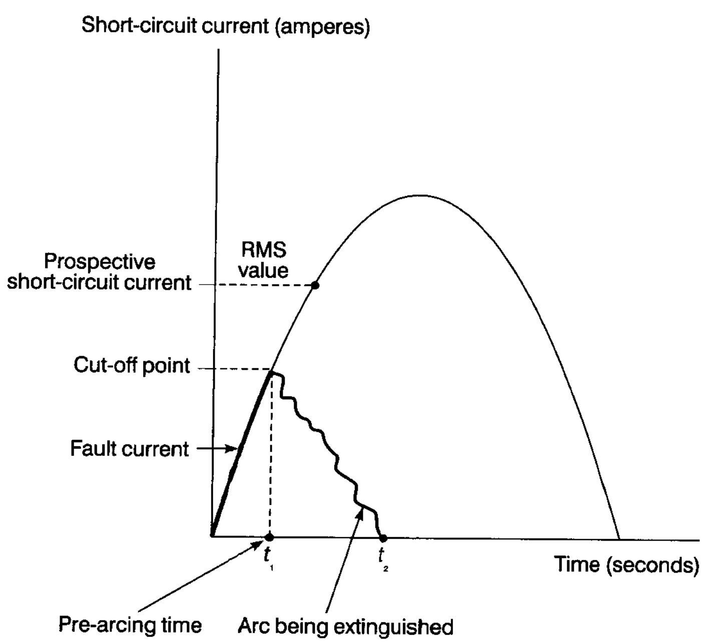


Figure 18

British Standards for fuse links

Standard	Current rating	Voltage rating
1 BS 2950	Range 0.05 to 25 A	Range 1000 V (0.05 A) to 32 V (25 A) AC and DC
2 BS 646	1, 2, 3 and 5 A	Up to 250 V AC and DC
3 BS 1362 cartridge	1, 2, 3, 5, 7, 10 and 13 A	Up to 250 V AC
4 BS 1361 HRC cut-out fuses	5, 15, 20, 30, 45 and 60 A	Up to 250 V AC
5 BS 88 motors	Four ranges, 2 to 1200 A	Up to 660 V, but normally 250 or 415 V AC and 250 or 500 V DC
6 BS 2692	Main range from 5 to 200 A; 0.5 to 3 A for voltage transformer protective fuses	Range from 2.2 to 132 kV
7 BS 3036 rewirable	5, 15, 20, 30, 45, 60, 100, 150 and 200 A	Up to 250 V to earth
8 BS 4265	500 mA to 6.3 A 32 mA to 2 A	Up to 250 V AC

British Standards for fuse links (continued)

Breaking capacity	Notes
1 Two or three times current rating	Cartridge fuse links for telecommunication and light electrical apparatus. Very low breaking capacity
2 1000 A	Cartridge fuse intended for fused plugs and adapters to BS546: ‘round-pin’ plugs
3 6000 A	Cartridge fuse primarily intended for BS1363: ‘flat pin’ plugs
4 16 500 A 33 000 A	Cartridge fuse intended for use in domestic consumer units. The dimensions prevent interchangeability of fuse links which are not of the same current rating
5 Ranges from 10 000 to 80 000 A in four AC and three DC categories	Part 1 of Standard gives performance and dimensions of cartridge fuse links, whilst Part 2 gives performance and requirements of fuse carriers and fuse bases designed to accommodate fuse links complying with Part 1
6 Ranges from 25 to 750 MVA (main range) 50 to 2500 MVA (VT fuses)	Fuses for AC power circuits above 660 V
7 Ranges from 1000 to 12000 A	Semi-enclosed fuses (the element is a replacement wire) for AC and DC circuits
8 1500 A (high breaking capacity) 35 A (low breaking capacity)	Miniature fuse links for protection of appliances of up to to 250 V (metric standard)

All of these foregoing requirements ensure that conductor insulation is undamaged when an overload occurs.

Under short-circuit conditions it is the conductor itself that is susceptible to damage and must be protected. Figure 18 shows one half-cycle of short-circuit current if there were no protection. The RMS value (0.7071 × maximum value) is called the prospective short-circuit current. The cut-off point is where the short-circuit current is interrupted and an arc is formed; the time t_1 taken to reach this point is called the pre-arcing time. After the current has been cut off, it falls to zero as the arc is being extinguished. The time t_2 is the total time taken to disconnect the fault.

During the time t_1, the protective device is allowing energy to pass through to the load side of the circuit. This energy is known as the pre-arcing let-through energy and is given by I^2t_1, where I is the short-circuit current. The total let-through energy from start to disconnection of the fault is given by I^2t_2 (see Figure 19).

For faults of up to 5 s duration, the amount of heat energy that cable can withstand is given by k^2S^2, where s is the cross-sectional area of the conductor and k is a factor dependent on the conduct or material. Hence, the let-through energy should not exceed k^2s^2, i.e. $I^2\ t = k^2s^2$. If we transpose this formula for t, we get $t = k^2s^2/I^2$, which is the maximum disconnection time in seconds.

Remember that these requirements refer to short-circuit currents only. If, in fact, the protective device has been selected to protect against overloads and has a breaking capacity not less than the

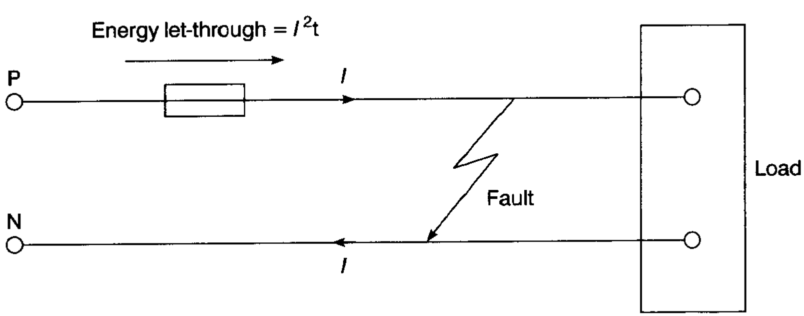


Figure 19

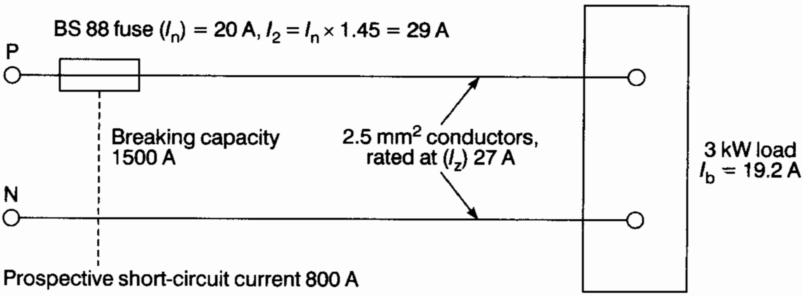


Figure 20

prospective short-circuit current (PSCC) at the point of installation, it will also protect against short-circuit currents. However, if there is any doubt the formula should be used.

For example, in Figure 20, if I_n has been selected for overload protection, the questions to be asked are as follows:

1 Is $I_n \geqslant I_b$? Yes.
2 Is $I_n \leqslant I_z$? Yes.
3 Is $I_2 \geqslant 1.45I_z$? Yes.

Then, if the device has a rated breaking capacity not less than the PSCC, it can be considered to give protection against short-circuit current also.

When an installation is being designed, the prospective short-circuit current at every relevant point must be determined, by either calculation or measurement. The value will decrease as we move farther away from the intake position (resistance increases with length). Thus, if the breaking capacity of the lowest rated fuse in the installation is greater than the prospective short-circuit at the origin of the supply, there is no need to determine the value except at the origin.

Discrimination

(IEE Reg 533–01–06)

When we discriminate, we indicate our preference over other choices: this house rather than that house, for example. With protection we have to ensure that the correct device operates when there is a fault. Hence, a 13 A BS 1362 plug fuse should operate before the main circuit fuse. Logically, protection starts at the origin of an installation with a large device and progresses down the chain with smaller and smaller sizes.

Simply because protective devices have different ratings, it cannot be assumed that discrimination is achieved. This is especially the case where a mixture of different types of device is used. However, as a general rule a 2:1 ratio with the lower-rated devices will be satisfactory. The table on page 57 shows how fuse links may be chosen to ensure discrimination.

Fuses will give discrimination if the figure in column 3 does not exceed the figure in column 2. Hence:

a 2 A fuse will discriminate with a 4 A fuse
a 4 A fuse will discriminate with a 6 A fuse
a 6 A fuse will *not* discriminate with a 10 A fuse
a 10 A fuse will discriminate with a 16 A fuse

All other fuses will *not* discriminate with the next highest fuse, and in some cases, several sizes higher are needed e.g. a 250 A fuse will only discriminate with a 400 A fuse.

Position of protective devices (IEE Regs Section 473)

When there is a reduction in the current-carrying capacity of a conductor, a protective device is required. There are, however, some exceptions to this requirement; these are listed quite clearly in Section 473 of the IEE Regulations. As an example, protection is not needed in a ceiling rose where the cable size changes from 1.0 mm^2 to, say, 0.5 mm^2 for the lampholder flex. This is permitted as it is not expected that lamps will cause overloads.

Protection against overvoltage (IEE Regs Chapter 44)

This chapter deals with the requirements of an electrical installation to withstand overvoltages caused by lightning or switching

I^2t characteristics: 2–800 A fuse links. Discrimination is achieved if the total I^2t of the minor fuse does not exceed the pre-arcing I^2t of the major fuse

Rating (A)	I^2t pre-arcing	I^2t total at 415 V
2	0.9	1.7
4	4	12
6	16	59
10	56	170
16	190	580
20	310	810
25	630	1 700
32	1 200	2 800
40	2 000	6 000
50	3 600	11 000
63	6 500	14 000
80	13 000	36 000
100	24 000	66 000
125	34 000	120 000
160	80 000	260 000
200	140 000	400 000
250	230 000	560 000
315	360 000	920 000
350	550 000	1 300 000
400	800 000	2 300 000
450	700 000	1 400 000
500	900 000	1 800 000
630	2 200 000	4 500 000
700	2 500 000	5 000 000
800	4 300 000	10 000 000

surges. It is unlikely that installations in the UK will be affected by the requirements of this section as the number of thunderstorm days per year is not likely to exceed 25.

Protection against undervoltage

(IEE Regs Chapter 45 and Section 535)

From the point of view of danger in the event of a drop or loss of voltage, the protection should prevent automatic restarting of machinery etc. In fact, such protection is an integral part of motor starters in the form of the control circuit.

Precautions where there is a particular risk of fire (IEE Regs Chapter 48)

This chapter outlines details of locations and situations where there may be a particular risk of fire. These would include locations where combustible materials are stored or could collect and where a risk of ignition exists. This section does not include locations where there is a risk of explosion.

4
CONTROL

Definitions used in this chapter

Emergency switching Rapid cutting off of electrical energy to remove any hazard to persons, livestock or property which may occur unexpectedly.

Isolation Cutting off an electrical installation, a circuit, or an item of equipment from every source of electrical energy.

Mechanical maintenance The replacement, refurbishment or cleaning of lamps and non-electrical parts of equipment, plant and machinery.

Switch A mechanical switching device capable of making, carrying and breaking current under normal circuit conditions, which may include specified overload conditions, and also of carrying, for a specified time, currents under specified abnormal conditions such as those of short circuit.

Isolation and switching

(Relevant parts, sections and chapters Chapter 46 and Sections 476 and 537)

The essential part of a motor control circuit that will ensure undervoltage protection is the 'hold-on' circuit (Figure 21).

When the start button is pushed, the coil becomes energized and its normally open (N/O) contacts close. When the start button is

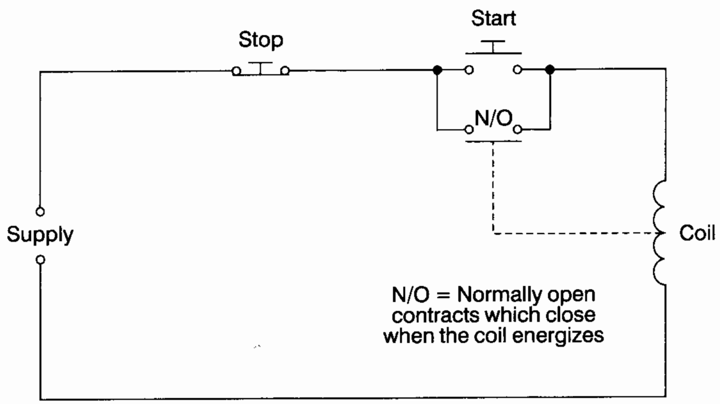


Figure 21 Hold-on circuit

released the coil remains energized via its own N/O contacts. These are known as the 'hold-on' contacts.

The coil can only be de-energized by opening the circuit by the use of the stop button or by a considerable reduction or loss of

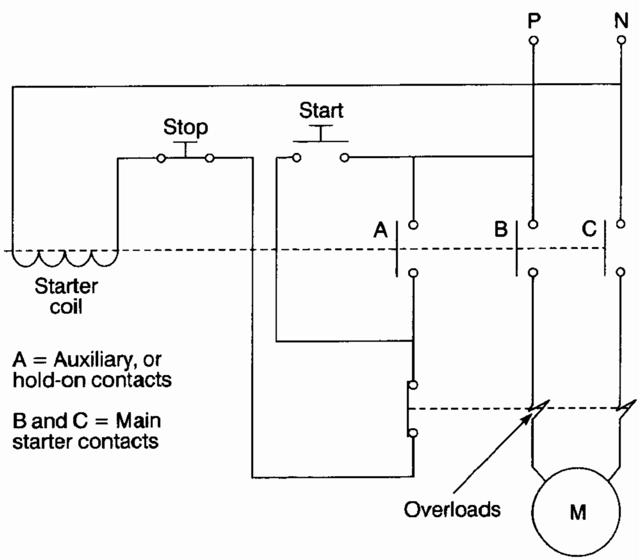


Figure 22 Single-phase motor starter

voltage. When this happens, the N/O contacts open and, even if the voltage is restored or the circuit is made complete again, the coil will remain de-energized until the start button is pushed again. Figure 22 shows how this 'hold-on' facility is built into a typical single-phase motor starter.

Having decided how we are going to earth an installation, and settled on the method of protecting persons and livestock from electric shock, and conductors and insulation from damage. We must now investigate the means of controlling the installation. In simple terms, this means the switching of the installation or any part of it 'on' or 'off'. The IEE Regulations refer to this topic as 'isolation and switching'.

By definition, isolation is the cutting off of electrical energy from every source of supply, and this function is performed by a switch, a switch fuse or a fuse switch. A switch is sometimes referred to as an isolator or a switch disconnector. A switch fuse is a switch housed in the same enclosure as the fuses. A fuse switch has the fuses as part of the switch mechanism, and is used mainly where higher load currents are anticipated.

On the grid system there is a distinct difference between an isolator and a switch. A switch, or breaker as it is known, is capable of breaking fault currents as well as normal load currents. By contrast, an isolator is installed for the purpose of isolating sections of the system for maintenance work etc. (see Figure 23). For work to be carried out on the breaker, the part of the network that the circuit supplies is fed from another source. The breaker is then operated and both isolators are opened, thus preventing supply from any source reaching the breaker.

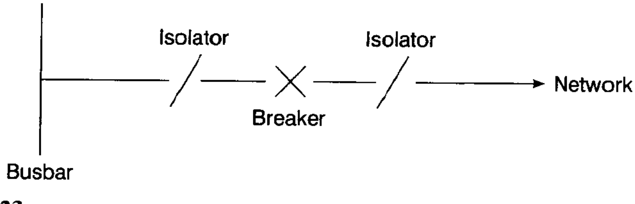


Figure 23

With a domestic installation, the main switch in a consumer unit is considered to be a means of isolation for the whole installation, and each fuse or circuit breaker to be isolators for the individual circuits. Ideally all of these devices should have some means of preventing unintentional re-energization, either by locks or interlocks. In the case of fuses and circuit breakers, these can be removed and kept in a safe place.

In many cases, isolating and locking off come under the heading of switching off for mechanical maintenance. Hence, a switch controlling a motor circuit should have, especially if it is remote from the motor, a means of locking in the 'off' position (Figure 24).

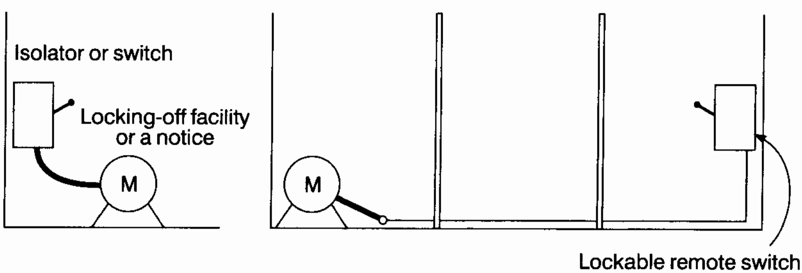


Figure 24

A one-way switch controlling a lighting point is a functional switch, but could be considered as a means of isolation, or a means of switching off for mechanical maintenance (changing a lamp). A two-way switching system, however, does not provide a means of isolation, as neither switch cuts off electrical energy from all sources of supply.

In an industrial or workshop environment it is important to have a means of cutting off the supply to the whole or parts of the installation in the event of an emergency. The most common method is the provision of stop buttons suitably located and used in conjunction with a contactor or relay (Figure 25).

Pulling a plug from a socket to remove a hazard is not permitted as a means of emergency switching. It is, however, allowed as a

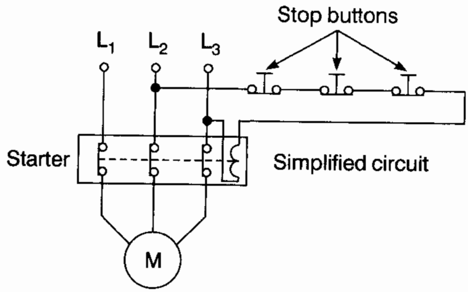


Figure 25

means of functional switching, e.g. switching off a hand lamp by unplugging.

Whilst we are on the subject of switching, it should be noted that a switch controlling discharge lighting (this includes fluorescent fittings) should, unless it is specially designed for the purpose, be capable of carrying at least twice the steady load of the circuit. The reason for this is that discharge lighting contains chokes which are inductive and cause arcing at switch contacts. The higher rating of the switch enables it to cope with arcing.

5
CIRCUIT DESIGN

Definitions used in this chapter

Ambient temperature The temperature of the air or other medium where the equipment is to be used.

Circuit protective conductor A protective conductor connecting exposed conductive parts of equipment to the main earthing terminal.

Current-carrying capacity The maximum current which can be carried by a conductor under specified conditions without its steady state temperature exceeding a specified value.

Design current The magnitude of the current intended to be carried by a circuit in normal service.

Earthing conductor A protective conductor connecting a main earthing terminal of an installation to an earth electrode or other means of earthing.

Overcurrent A current exceeding the rated value. For conductors the rated value is the current-carrying capacity.

Short-circuit current An overcurrent resulting from a fault of negligible impedance between live conductors having a difference of potential under normal operating conditions.

Design procedure

(IEE Regs 514–09 and 712–01–03 (xviii); IEE Regs Chapter 3; IEE Regs Appendix 4)

The requirements of IEE Regulations make it clear that circuits must be designed and the design data made readily available. In fact this has always been the case with previous editions of the Regulations, but it has not been so clearly indicated.

How then do we begin to design? Clearly, plunging into calculations of cable size is of little value unless the type of cable and its method of installation is known. This, in turn, will depend on the installation's environment. At the same time, we would need to know whether the supply was single- or three-phase, the type of earthing arrangements, and so on. Here then is our starting point and it is referred to in the Regulations, Chapter 3, as 'Assessment of general characteristics'.

Having ascertained all the necessary details, we can decide on an installation method, the type of cable, and how we will protect against electric shock and overcurrents. We would now be ready to begin the calculation part of the design procedure.

Basically there are eight stages in such a procedure. These are the same whatever the type of installation, be it a cooker circuit or a submain cable feeding a distribution board in a factory. Here, then, are the eight basic steps in a simplified form:

1 Determine the design current I_b.
2 Select the rating of the protection I_n.
3 Select the relevant correction factors (CFs).
4 Divide I_n by the relevant CFs to give tabulated cable current-carrying capacity I_t.
5 Choose a cable size, to suit I_t.
6 Check the voltage drop.
7 Check for shock risk constraints.
8 Check for thermal constraints.

Let us now examine each stage in detail.

Design current

In many instances the design current I_b is quoted by the manufacturer, but there are times when it has to be calculated. In that case there are two formulae involved, one for single-phase and one for three-phase:

Single-phase:

$$I_b = \frac{P\text{ (watts)}}{V}\text{ (V usually 230 V)}$$

Three phase:

$$I_b = \frac{P\text{ (watts)}}{\sqrt{3} \times V_L}\ (V_L\text{ usually 400 V})$$

Current is in amperes, and power P in watts.

If an item of equipment has a power factor (PF) and/or has moving parts, efficiency (*eff*) will have to be taken into account.

Hence:

Single-phase:

$$I_b = \frac{P\text{ (watts)} \times 100}{V \times PF \times eff}$$

Three-phase:

$$I_b = \frac{P \times 100}{\sqrt{3} \times V_L \times PF \times eff}$$

Nominal setting of protection

Having determined I_b we must now select the nominal setting of the protection such that $I_n \geqslant I_b$. This value may be taken from IEE Regulations, Tables 41B1, B2 or D or from manufacturers' charts. The choice of fuse or MCB or CB type is also important and may have to be changed if cable sizes or loop impedances are too high. These details will be discussed later.

Correction factors

When a cable carries its full load current it can become warm. This is no problem unless its temperature rises further due to other influences, in which case the insulation could be damaged by overheating. These other influences are: high ambient temperature; cables grouped together closely; uncleared overcurrents; and contact with thermal insulation.

For each of these conditions there is a correction factor (CF) which will respectively be called C_a, C_g, C_f and C_i, and which derates cable current-carrying capacity or conversely increases cable size.

Ambient temperature C_a

The cable ratings in the IEE Regulations are based on an ambient temperature of 30°C, and hence it is only above this temperature that an adverse correction is needed. Table 4C 1 of the Regulations gives factors for all types of protection other than BS 3036 semi-enclosed rewirable fuses, which are accounted for in Table 4C2.

Grouping C_g

When cables are grouped together they impart heat to each other. Therefore, the more cables there are the more heat they will generate, thus increasing the temperature of each cable. Table 4B of the Regulations gives factors for such groups of cables or circuits. It should be noted that the figures given are for cables of the same size, and hence correction may not necessarily be needed for cables grouped at the outlet of a domestic consumer unit, for example, where there is a mixture of different sizes.

A typical situation where correction factors need to be applied would be in the calculation of cable sizes for a lighting system in a large factory. Here many cables of the same size and loading may be grouped together in trunking and could be expected to be fully loaded all at the same time.

Protection by BS 3036 fuse C_f

As we have already discussed in Chapter 3, because of the high fusing factor of BS 3036 fuses, the rating of the fuse I_n, should be $\leqslant 0.725 I_z$. Hence 0.725 is the correction factor to be used when BS 3036 fuses are used.

Thermal insulation C_i

With the modern trend towards energy saving and the installation of thermal insulation, there may be a need to derate cables to account for heat retention.

The values of cable current-carrying capacity given in Appendix 4 of the IEE Regulations have been adjusted for situations when thermal insulation touches one side of a cable. However, if a cable is totally surrounded by thermal insulation for more than 0.5 m, a factor of 0.5 must be applied to the tabulated clipped direct ratings. For less than 0.5 m, derating factors (Table 52A of the Regulations) should be applied.

Application of correction factors

Some or all of the onerous conditions just outlined may affect a cable along its whole length or parts of it, but not all may affect it at the same time. So, consider the following:

1 If the cable in Figure 26 ran for the whole of its length, grouped with others of the same size in a high ambient temperature, and was totally surrounded with thermal insulation, it would seem

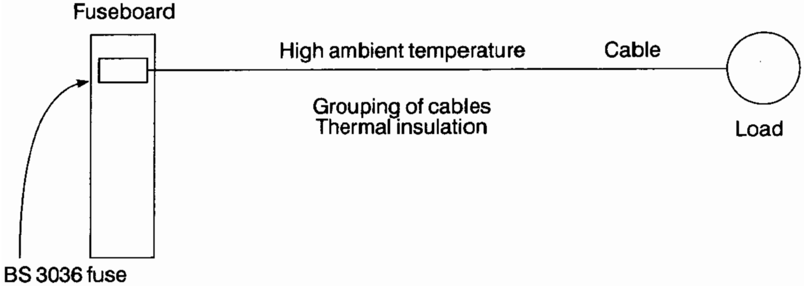


Figure 26

logical to apply all the CFs, as they all affect the whole cable run. Certainly the factors for the BS 3036 fuse, grouping and thermal insulation should be used. However, it is doubtful if the ambient temperature will have any effect on the cable, as the thermal insulation, if it is efficient, will prevent heat reaching the cable. Hence, apply C_g, C_f and C_i.

2 In Figure 27(a) the cable first runs grouped, then leaves the group and runs in high ambient temperature, and finally is enclosed in thermal insulation. We therefore have three different conditions, each affecting the cable in different areas. The BS 3036 fuse affects the whole cable run and therefore C_f must be used, but there is no need to apply all of the remaining factors as the worse one will automatically compensate for the others. The relevant factors are shown in Figure 27(b): apply only $C_f = 0.725$ and $C_i = 0.5$. If protection was *not* by BS 3036 fuse, then apply only $C_i = 0.5$.

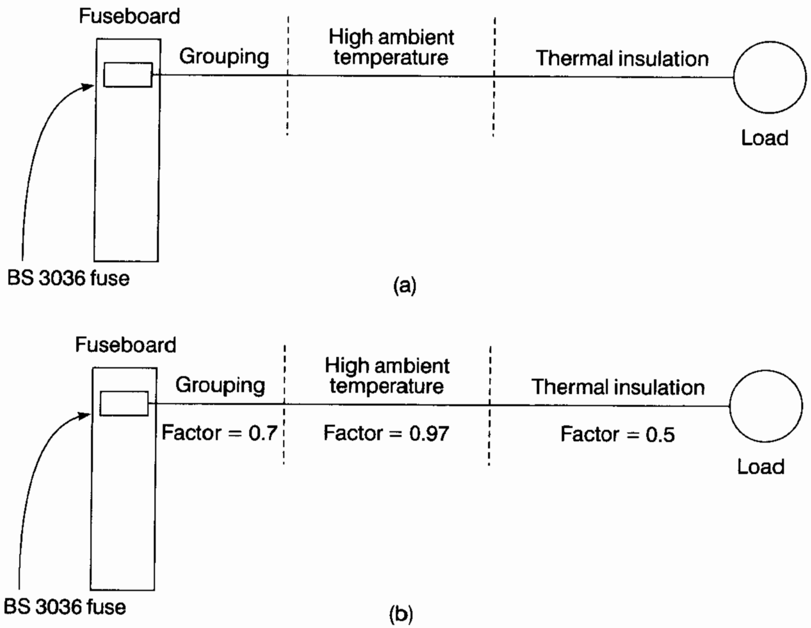


Figure 27

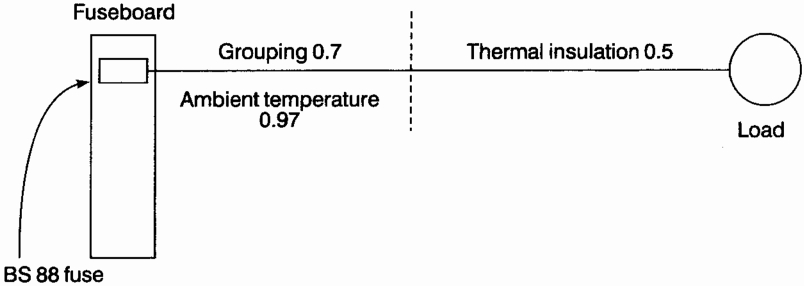


Figure 28

3 In Figure 28 a combination of cases 1 and 2 is considered. The effect of grouping and ambient temperature is $0.7 \times 0.97 = 0.69$. The factor for thermal insulation is still worse than this combination, and therefore C_i is the only one to be used.

Having chosen the *relevant* correction factors, we now apply them to the nominal rating of the protection I_n as divisors in order to calculate the current-carrying capacity I_t of the cable.

Tabulated current-carrying capacity

The required formula for current-carrying capacity I_t is:

$$I_t \geqslant \frac{I_n}{\text{relevant CFs}}$$

In Figure 29 the current-carrying capacity is given by:

$$I_t \geqslant \frac{I_n}{C_f C_i} = \frac{30}{0.725 \times 0.5} = 82.75\ \text{A}$$

or, without the BS 3036 fuse:

$$I_t \geqslant \frac{30}{0.5} = 60\ \text{A}$$

In Figure 30, $C_a\ C_g = 0.97 \times 0.5 = 0.485$, which is worse than C_i (0.5).

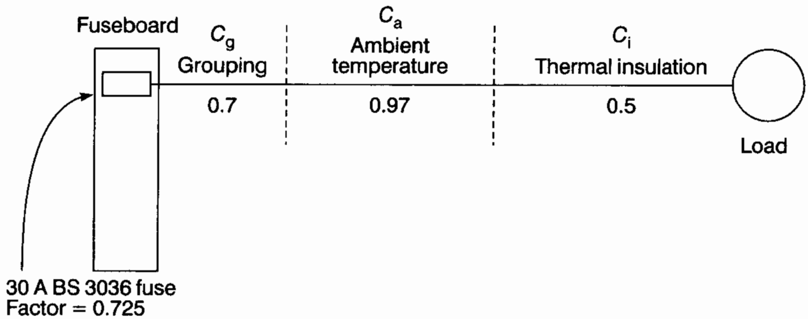


Figure 29

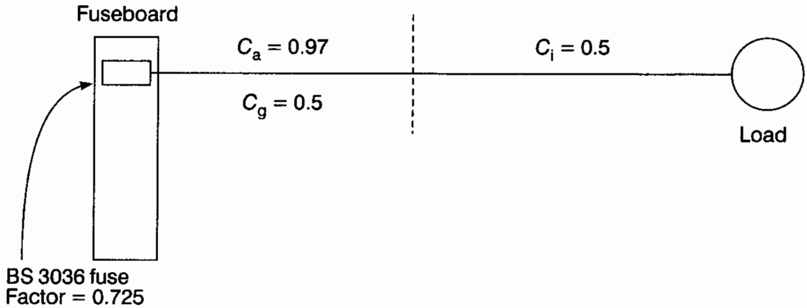


Figure 30

Hence:

$$I_t \geqslant \frac{I_n}{C_f C_a C_g} = \frac{30}{0.725 \times 0.485} = 85.3\ \text{A}$$

or, without the BS 3036 fuse:

$$I = \frac{30}{0.485} = 61.85\ \text{A}$$

Note: If the circuit is not subject to overload, I_n can be replaced by I_b so the formula becomes:

$$I_t \geqslant \frac{I_b}{\text{CFs}}$$

Choice of cable size

Having established the tabulated current-carrying capacity I_t of the cable to be used, it now remains to choose a cable to suit that value. The tables in Appendix 4 of the IEE Regulations list all the cable sizes, current-carrying capacities and voltage drops of the various types of cable. For example, for PVC-insulated singles, single-phase, in conduit, having a current-carrying capacity of 45 A, the installation is by reference method 3 (Table 4A), the cable table is 4D1A and the column is 4. Hence, the cable size is 10.0 mm^2 (column 1).

Voltage drop

(IEE Regs 525)

The resistance of a conductor increases as the length increases and/ or the cross-sectional area decreases. Associated with an increased resistance is a drop in voltage, which means that a load at the end of a long thin cable will not have the full supply voltage available (Figure 31).

The IEE Regulations require that the voltage drop V should not be so excessive that equipment does not function safely. They further indicate that a drop of no more than 4% of the nominal voltage at the *origin* of the circuit will satisfy. This means that:

1 For single-phase 230 V, the voltage drop should not exceed 4% of 230 V = 9.2 V.
2 For three-phase 400 V, the voltage drop should not exceed 4% of 400 V = 16 V.

For example, the voltage drop on a circuit supplied from a 230 V source by a 16.0 mm^2 two core copper cable 23 m long, clipped direct and carrying a design current of 33 A, will be:

$$V_c = \frac{\text{mV} \times I_b \times L}{1000} \qquad \text{(mV from Table 4D2B)}$$

$$= \frac{2.8 \times 33 \times 23}{1000} = 2.125\ \text{V}$$

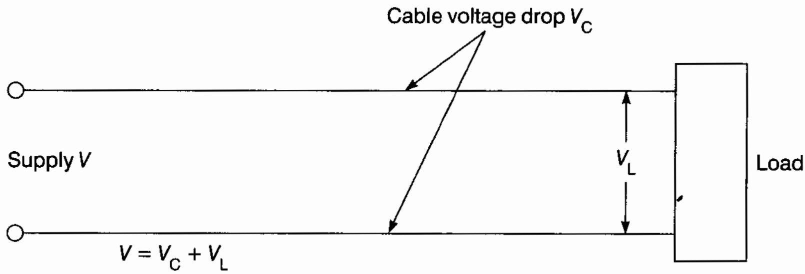


Figure 31

As we know that the maximum voltage drop in this instance (230 V) is 9.2 V, we can determine the maximum length by transposing the formula:

$$\text{maximum length} = \frac{V_c \times 1000}{\text{mV} \times I_b}$$

$$= \frac{9.2 \times 1000}{2.8 \times 23} = 142\,\text{m}$$

There are other constraints, however, which may not permit such a length.

Shock risk

(IEE Regs 413-02-04)

This topic has already been discussed in full in Chapter 2. To recap, the actual loop impedance Z_s should not exceed those values given in Tables 41B1, B2 and D of the IEE Regulations. This ensures that circuits feeding socket outlets and equipment outside the equipotential zone will be disconnected, in the event of an earth fault, in less than 0.4 s, and that fixed equipment will be disconnected in less than 5 s.

Remember: $Z_s = Z_e + R_1 + R_2$.

Thermal constraints

(IEE Regs 543)

The IEE Regulations require that we either select or check the size of a CPC against Table 54F of the Regulations, or calculate its size using an adiabatic equation.

Selection of CPC using Table 54G

Table 54G of the Regulations simply tells us that:

1 For phase conductors up to and including 16 mm^2, the CPC should be at least the same size.
2 For sizes between 16 m^2 and 35 mm^2, the CPC should be at least 16 mm^2.
3 For sizes of phase conductor over 35 mm^2, the CPC should be at least half this size.

This is all very well, but for large sizes of phase conductor the CPC is also large and hence costly to supply and install. Also, composite cables such as the typical twin with CPC 6242Y type have CPCs smaller than the phase conductor and hence do not comply with Table 54G.

Calculation of CPC using an adiabatic equation

The adiabatic equation

$$s = \sqrt{(I^2 t)}/k$$

enables us to check on a selected size of cable, or on an actual size in a multicore cable. In order to apply the equation we need first to calculate the earth fault current from:

$$I = U_{oc}/Z_s$$

where U_{oc} is the transformer open circuit voltage (usually 240 V) and Z_s is the actual earth fault loop impedance. Next we select a k factor from Tables 54B to F of the Regulations, and then determine the disconnection time t from the relevant curve.

For those unfamiliar with such curves, using them may appear a daunting task. A brief explanation may help to dispel any fears. Referring to any of the curves for fuses in Appendix 3 of the IEE Regulations, we can see that the current scale goes from 1 A to 10 000 A, and the time scale from 0.01 s to 10 000 s. One can imagine the difficulty in drawing a scale between 1 A and 10 000 A in divisions of 1 A, and so a logarithmic scale is used. This cramps the large scale into a small area. All the subdivisions between the major divisions increase in equal amounts depending on the major division boundaries; for example, all the subdivisions between 100 and 1000 are in amounts of 100 (Figure 32).

Figures 34 and 35 give the IEE Regulations time/current curves for BS 88 fuses. Referring to the appropriate curve for a 32 A fuse (Figure 34), we find that a fault current of 200 A will cause disconnection of the supply in 0.6 s.

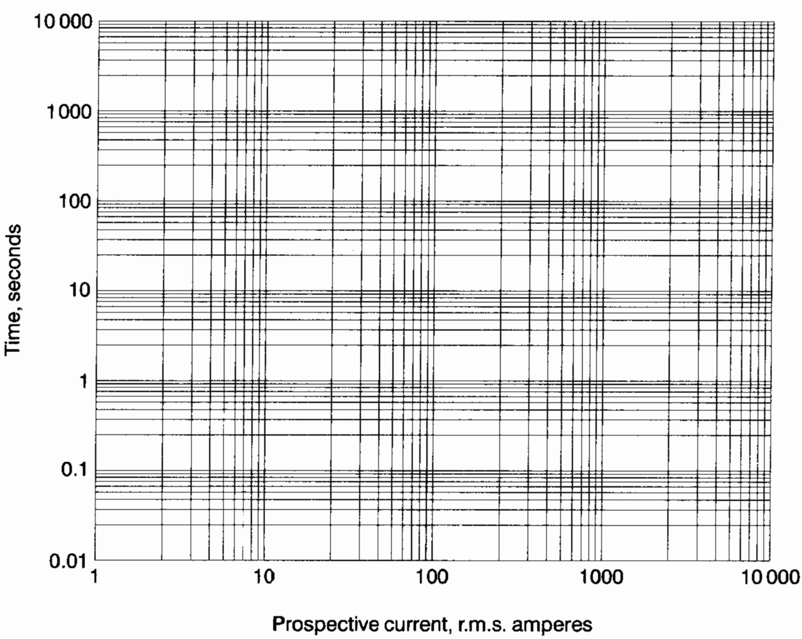


Figure 32

Where a value falls between two subdivisions, e.g. 150 A, an estimate of its position must be made. Remember that even if the scale is not visible, it would be cramped at one end; so 150 A would not fall half-way between 100 A and 200 A (Figure 33).

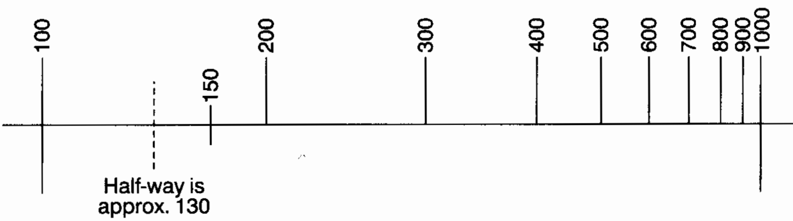


Figure 33

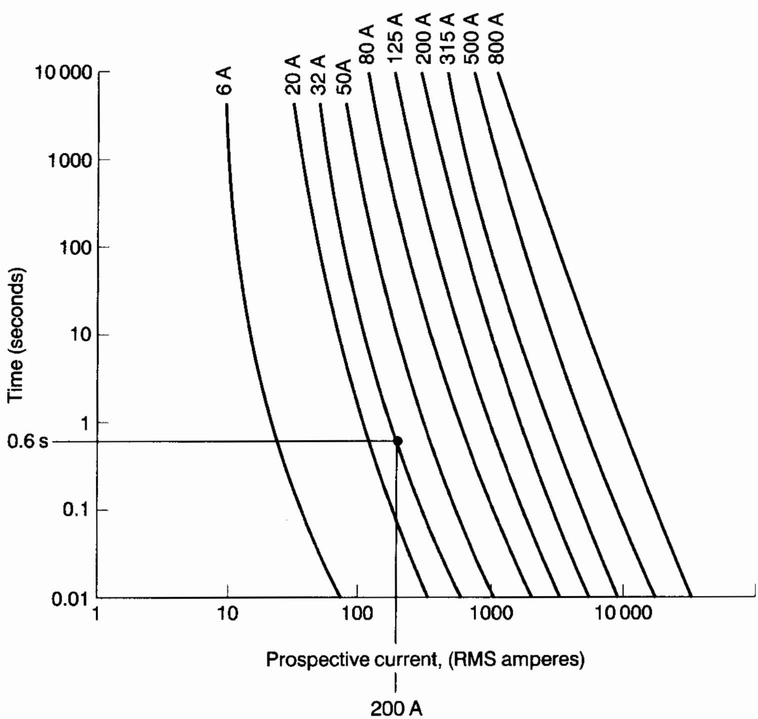


Figure 34 *Time/current characteristics for fuses to BS 88 Part 2. Example for 32 A fuse superimposed*

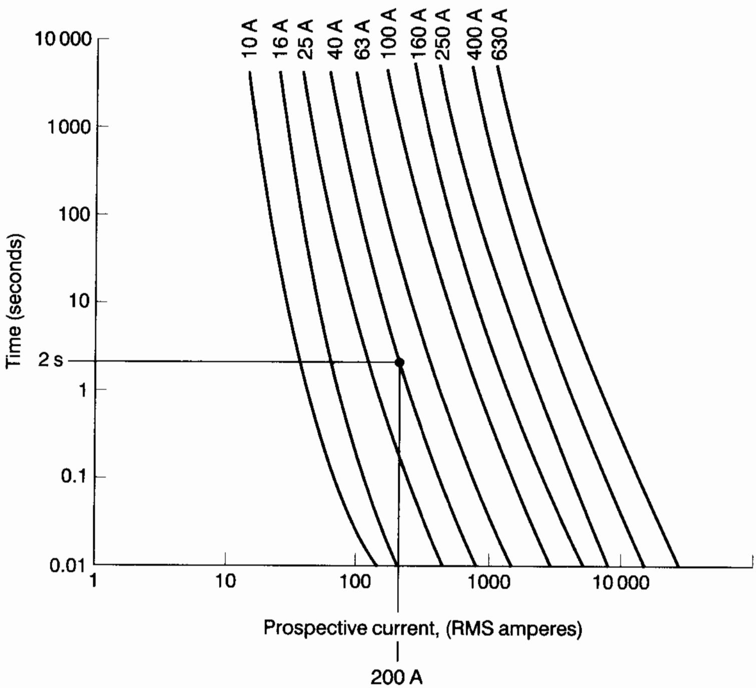


Figure 35 *Time/current characteristics for fuses to BS 88 Part 2. Example for 40 A fuse superimposed*

It will be noted in Appendix 3 of the Regulations that each set of curves is accompanied by a table which indicates the current that causes operation of the protective device for disconnection times of 0.1 s, 0.4 s and 5 s.

The IEE Regulations curves for CBs to BS EN 60898 type B and RCBO's are shown in Figure 36.

Having found a disconnection time, we can now apply the formula.

Example of use of an adiabatic equation

Suppose that in a design the protection was by 40 A BS 88 fuse; we had chosen a 4 mm^2 copper CPC running with our phase conductor; and the loop impedance Z_s was 1.2Ω. Would the chosen CPC size be

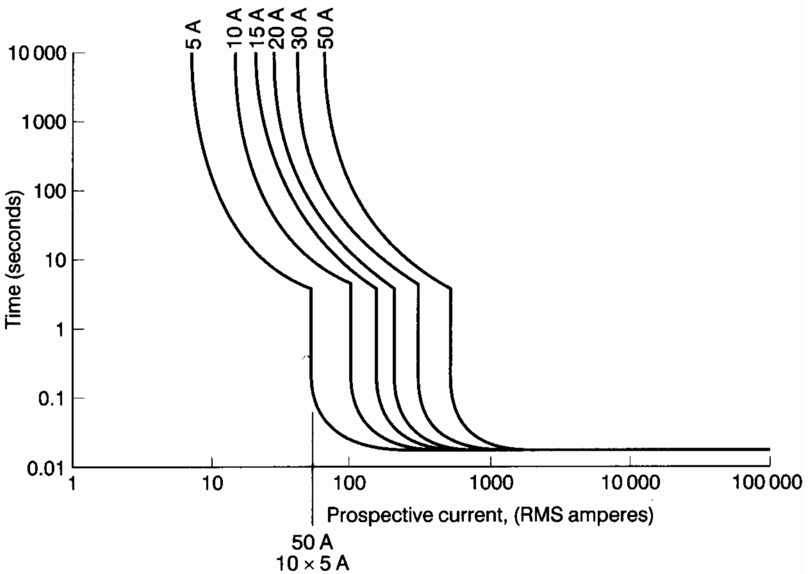


Figure 36 *Time/current characteristics for type 3 CBs to BS EN 60898 and RCBO's. Example for 50 A superimposed. For times less than 20 ms, the manufacturer should be consulted*

large enough to withstand damage in the event of an earth fault? We have:

$$I = U_{oc}/Z_s = 240/1.2 = 200\ \text{A}$$

From the appropriate curve for the 40 A BS 88 fuse (Figure 35), we obtain a disconnection time t of 2 s. From Table 54C of the Regulations, $k = 115$. Therefore the minimum size of CPC is given by:

$$s = \sqrt{(I^2t)}/k = \sqrt{200^2 \times 2}/115 = 2.46\,\text{mm}^2$$

So our 4 mm^2 CPC is acceptable. Beware of thinking that the answer means that we could change the 4 mm^2 for a 2.5 mm^2. If we did, the loop impedance would be different and hence I and t would change; the answer for s would probably tell us to use a 4 mm^2. In the example shown, s is merely a check on the actual size chosen.

Having discussed each component of the design procedure, we can now put all eight together to form a complete design.

Example of circuit design

A consumer lives in a bungalow with a detached garage and workshop, as shown in Figure 37. The building method is traditional brick and timber.

The mains intake position is at high level, and comprises an 80 A BS 1361 240 V main fuse, an 80 A rated meter and a six-way 80 A consumer unit housing BS 3036 fuses as follows:

Ring circuit	30 A
Lighting circuit	5 A
Immersion heater circuit	15 A
Cooker circuit	30 A
Shower circuit	30 A
Spare way	

The cooker is 40 A, with no socket in the cooker unit.

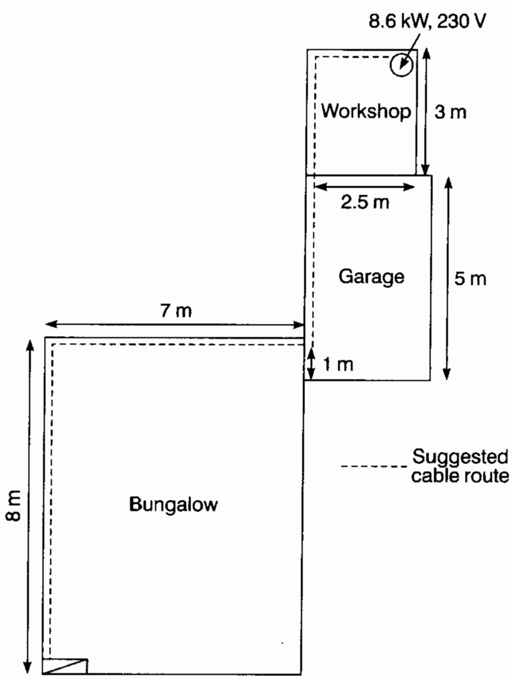


Figure 37

The main tails are 16 mm^2 double-insulated PVC, with a 6 mm^2 earthing conductor. There is no main equipotential bonding. The earthing system is TN–S, with an external loop impedance Z_e of 0.3Ω. The prospective short-circuit current (PSCC) at the origin of the installation has been measured at 800 A. The roof space is insulated to the full depth of the ceiling joists, and the temperature in the roof space has been noted to be no more than 40°C.

The consumer wishes to convert the workshop into a pottery room and install an 8.6 kW, 230 V electric kiln. The design procedure is as follows.

Assessment of general characteristics (IEE Regs Part 3)

Present maximum demand

Applying diversity, we have:

Ring	30 A
Lighting (66% of 5 A)	3.3 A
Immersion heater	15 A
A cooker (10 A + 30% of 30 A)	19 A
Shower	30 A
Total	97.3 A

Reference to Table 4D1A of the Regulations will show that the existing main tails are too small and should be uprated. Also, the consumer unit should be capable of carrying the full load of the installation *without* the application of diversity. So the addition of another 8.6 kW of load is not possible with the present arrangement.

New maximum demand

The current taken by the kiln is 8600/230 = 37.4 A. Therefore the new maximum demand is 97.3 + 37.4 = 134.7 A.

Supply details

Single phase
230 V, 50 Hz
Earthing: TN–S
PSCC at origin (measured): 800 A

Decisions must now be made as to the type of cable, the installation method and the type of protective device. As the existing arrangement is not satisfactory, the supply authority must be informed of the new maximum demand, as a larger main fuse and service cable may be required. It would then seem sensible to disconnect, say, the shower circuit, and to supply it and the new kiln circuit via a new two-way consumer unit, as shown in Figure 38.

Sizing the main tails (IEE Reg 547–02)

1 The new load on the existing consumer unit will be the old load less the shower load: 97.3 – 30 = 67.3 A. From Table 4D1A of the Regulations, the cable size is 16 mm^2.
2 The load on the new consumer unit will be the kiln load plus the shower load: 37.4 + 30 = 67.4 A. From Table 4D1A, the cable size is 16 mm^2.

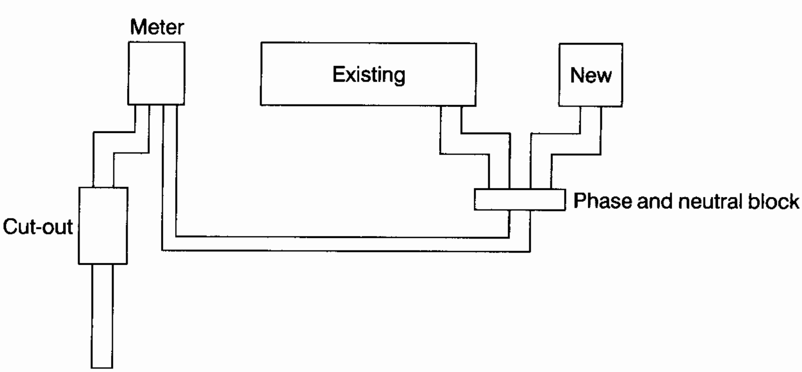


Figure 38

3 The total load is 67.3 + 67.4 = 134.7 A. From Table 4D1A, the cable size is 35 mm^2.
4 The earthing conductor size, from Table 54 G, will be 16 mm^2. The main equipotential bonding conductor size, from Regulation 547–02, will be 10 mm^2.

For a domestic installation such as this, a PVC flat twin cable clipped direct through the loft space and the garage etc. would be most appropriate.

Sizing the kiln circuit cable

Design current

$$I_b = \frac{P}{V} = \frac{8600}{230} = 37.4\,\text{A}$$

Rating and type of protection

In order to show how important this choice is, it is probably best to compare the values of current-carrying capacity resulting from each type of protection.

As we have seen, the requirement for the rating I_n is that $I_n \geqslant I_b$. Therefore, using Table 41B2, I_n will be as follows for the various fuse types:

BS 88	40 A	BS 3036	45 A
BS 1361	45 A	MCB	50 A

Correction factors

C_a 0.87 or 0.94 if fuse is BS 3036
C_g not applicable
C_f 0.725 only if fuse is BS 3036
C_i 0.5 if cable is totally surrounded in thermal insulation

(a)

	BS 88 40A	BS 1361 45 A	BS 3036 45 A	MCB 50 A
Surrounded by thermal insulation	$\dfrac{40}{0.5\times0.87} = 92\,\text{A}$	$\dfrac{45}{0.5\times0.87} = 103.4\,\text{A}$	$\dfrac{45}{0.5\times0.94\times0.725} = 132\,\text{A}$	$\dfrac{50}{0.95\times0.87} = 115\,\text{A}$
Not touching	$\dfrac{40}{0.87} = 46\,\text{A}$	$\dfrac{45}{0.87} = 51.7\,\text{A}$	$\dfrac{45}{0.94\times0.725} = 66\,\text{A}$	$\dfrac{50}{0.87} = 57.5\,\text{A}$

(b)

	BS 88	BS 1361	BS 3036	MCB
Cable size with thermal insulation	25.0 mm^2	25.0 mm^2	35.0 mm^2	35.0 mm^2
Cable size without thermal insulation	6.0 mm^2	10.0 mm^2	16.0 mm^2	10.0 mm^2
Cable size with half thermal insulation*	10.0 mm^2	16.0 mm^2	25.0 mm^2	25.0 mm^2

* See item number 15. Table 4A IEE Regulations.
In method 4, correction has already been made for cables touching thermal insulation on one size only.

Tabulated current-carrying capacity of cable

For each of the different types of protection, the current-carrying capacity I_t will be as shown in Table (a), page 77.

Cable size based on tabulated current-carrying capacity

Table (b) on page 83 shows the sizes of cable for each type of protection (taken from Table 4D2 of the IEE Regulations).

Clearly the BS 88 fuse gives the smallest cable size if the cable is kept clear of thermal insulation, i.e. 6.0 mm^2.

Check on voltage drop

The actual voltage drop is given by:

$$\frac{\text{mV} \times I_b \times \text{L}}{1000} = \frac{7.3 \times 37.4 \times 24.5}{1000} = 6.7\,\text{V}$$

This voltage drop, whilst not causing the kiln to work unsafely, may mean inefficiency, and it is perhaps better to use a 10 mm^2 cable. This also gives us a wider choice of protection type, except BS 3036 rewirable. This decision we can leave until later.

For a 10 mm^2 cable, the voltage drop is checked as:

$$\frac{4.4 \times 37.4 \times 24.5}{1000} = 4.04\,\text{V}$$

So at this point we have selected a 10 mm^2 twin cable. We have at our disposal a range of protection types, the choice of which will be influenced by the loop impedance.

Shock risk

The CPC inside a 10 mm^2 twin 6242Y cable is 4 mm^2. Hence, the total loop impedance will be:

$$Z_s = Z_e + R_1 + R_2$$

For our selected cable, $R_1 + R_2$ for 24.5 m will be (from tables of conductor resistance):

$$\frac{6.44 \times 1.2 \times 24.5}{1000} = 0.189\,\Omega$$

Note: the multiplier 1.2 takes account of the conductor resistance at its operating temperature.

We are given that $Z_e = 0.3\,\Omega$. Hence:

$$Z_s = 0.3 + 0.189 = 0.489\,\Omega$$

This means that all but 50 A types C and D CBs could be used (by comparison of values in Table 41B2 of the Regulations). As only BS EN 60898 types B, C and D will be available in the future, we must use type B.

Thermal constraints

We still need to check that the 4 mm^2 CPC is large enough to withstand damage under earth fault conditions. We have:

$$I = \frac{U_{oc}}{Z_s} = \frac{240}{0.489} = 490\,\text{A}$$

The disconnection time t for each type of protection from the relevant curves in the IEE Regulations are as follows:

40 A	BS 88	0.05 s
45 A	BS 1361	0.18 s
50 A	CB type B	0.01 s

From Table 54C of the Regulations, $k = 115$. Now:

$$s = \sqrt{(I^2 t)}/k$$

Therefore for each type of protection we have the following sizes s:

40 A	BS 88	0.9 mm^2
45 A	BS 1361	1.7 mm^2
50 A	CB type B	0.466 mm^2

Hence, our 4 mm^2 CPC is of adequate size.

Protection

It simply remains to decide on the type of protection. Probably a type B CB is the most economical. However, if this is chosen a check should be made on the shower circuit to ensure that this type of protection is also suitable.

Design problem

In a factory it is required to install, side by side, two three-phase 400 V direct on line motors, each rated at 19 A full load current. There is spare capacity in a three-phase distribution fuseboard housing BS 3036 fuses, and the increased load will not affect the existing installation. The cables are to be PVC-insulated singles installed in steel conduit, and a separate CPC is required (note Regulation 543–1–02). The earthing system is TN–S with a measured external loop impedance of 0.47 Ω, and the length of the cable run is 42 m. The worst conduit section is 7 m long with one bend. The ambient temperature is not expected to exceed 40°C.

Determine the minimum sizes of cable and conduit.

6
TESTING AND INSPECTION

Definitions used in this chapter

Earth electrode A conductor or group of conductors in intimate contact with and providing an electrical connection with earth.

Earth fault loop impedance The impedance of the earth fault loop (phase-to-earth loop) starting and ending at the point of earth fault.

Residual current device An electromechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions.

Ring final circuit A final circuit arranged in the form of a ring and connected to a single point of supply.

Testing sequence (Part 7)

Having designed our installation, selected the appropriate materials and equipment, and installed the system, it now remains to put it into service. However, before the installation is put into service it must be tested and inspected to ensure that it complies, as far as is practicable, with the IEE Regulations. Note the word 'practicable'; it would be unreasonable, for example, to expect the whole length of a circuit cable to be inspected for defects, as this may mean lifting floorboards etc.

Part 7 of the IEE Regulations give details of testing and inspection requirements. Unfortunately, these requirements presuppose that the person carrying out the testing is in possession of all the design data, which is only likely to be the case on the larger commercial or industrial projects. It may be wise for the person who will eventually sign the test certificate to indicate that the test and inspection were carried out as far as was possible in the absence of any design or other information.

However, let us continue by examining the required procedures. The Regulations initially call for a visual inspection, but some items such as correct connection of conductors etc. can be done during the actual testing. A preferred sequence of tests is recommended, where relevant, and is as follows:

1. Continuity of protective conductors.
2. Continuity of ring final circuit conductors.
3. Insulation resistance.
4. Insulation of site-built assemblies.
5. Protection by electrical separation.
6. Protection by barriers and enclosures provided during erection.
7. Insulation of non-conducting floors and walls.
8. Polarity.
9. Earth electrode resistance.
10. Earth fault loop impedance.
11. Prospective fault current.
12. Functional testing.

Not all of the tests may be relevant, of course. For example, in a domestic installation (TN–S or TN–C–S) only tests 1, 2, 3, 8, 9 and 11 would be needed.

The Regulations indicate quite clearly the tests required in Part 7. Let us then take a closer look at some of them in order to understand the reasoning behind them.

Continuity of protective conductors

All protective conductors, including main equipotential and supplementary bonding conductors, must be tested for continuity using a low-reading ohmmeter.

For main equipotential bonding there is no single fixed value of resistance above which the conductor would be deemed unsuitable. Each measured value, if indeed it is measurable for very short lengths, should be compared with the relevant value for a particular conductor length and size. Such values are shown in Table 3.

Where a supplementary equipotential bonding conductor has been installed between *simultaneously accessible* exposed and extraneous conductive parts, because circuit disconnection times cannot be met, then the resistance R of the conductor must be equal to or less than $50/I_a$. So:

$$R \leqslant 50/I_a$$

Where 50 is the voltage, above which exposed metalwork should not rise, and I_a is the minimum current, causing operation of the circuit protective device within 5 s.

For example, suppose a 45 A BS3036 fuse protects a cooker circuit. The disconnection time for the circuit cannot be met, and so a supplementary bonding conductor has been installed between the cooker case and the adjacent metal sink. The resistance R of that conductor should not be greater than $50/I_a$ which in this case is 145 A (IEE Regulations). So:

$$50/145 = 0.34\Omega$$

How then, do we conduct a test to establish continuity of main or supplementary bonding conductors? Quite simple really: just connect the leads from the continuity tester to the ends of the bonding conductor (Figure 39). One end should be disconnected from its bonding clamp, otherwise any measurement may include

Table 3

Conductor size (mm^2)	*Resistance (m✱/m)*
1.0	18.1
1.5	12.1
2.5	7.41
4.0	4.61
6.0	3.08
10.0	1.83
16.0	1.15
25.0	0.727
35.0	0.524

the resistance of parallel paths of other earthed metalwork. Remember to zero the instrument first or, if this facility is not available, record the resistance of the test leads so that this value can be subtracted from the test reading.

IMPORTANT NOTE: If the installation is in operation, then never disconnect main bonding conductors unless the supply can be isolated. Without isolation, persons and livestock are at risk of electric shock.

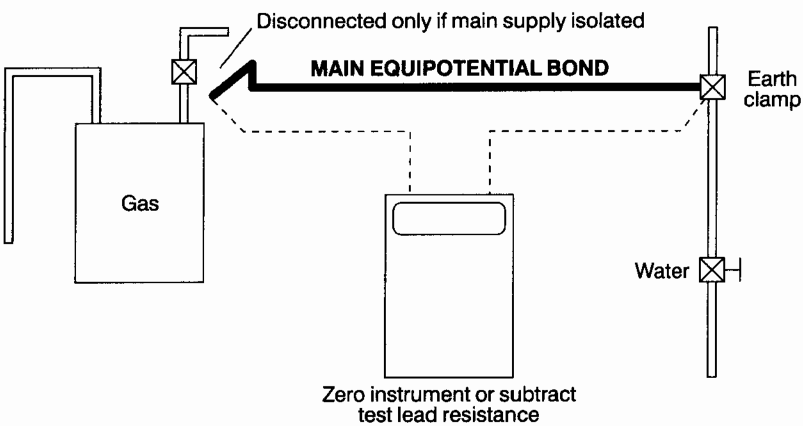


Figure 39

The continuity of circuit protective conductors may be established in the same way, but a second method is preferred, as the results of this second test indicate the value of $(R_1 + R_2)$ for the circuit in question.

The test is conducted in the following manner:

1 Temporarily link together the phase conductor and CPC of the circuit concerned in the distribution board or consumer unit.
2 Test between phase and CPC at each outlet in the circuit. A reading indicates continuity.
3 Record the test result obtained at the furthest point in the circuit. This value is $(R_1 + R_2)$ for the circuit.

Figure 40 illustrates the above method.

There may be some difficulty in determining the $(R_1 + R_2)$ values of circuits in installations that comprise steel conduit and trunking, and/or SWA and mims cables because of the parallel earth paths that are likely to exist. In these cases, continuity tests may have to be carried out at the installation stage before accessories are connected or terminations made off as well as after completion.

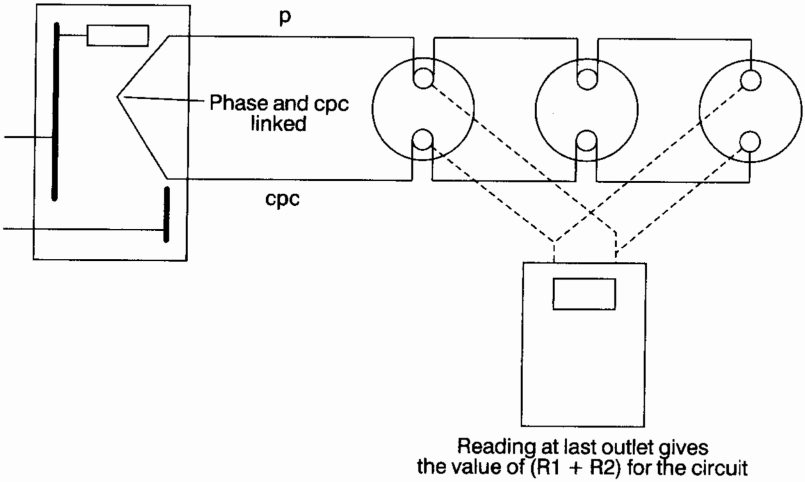


Figure 40

Continuity of ring final circuit conductors

There are two main reasons for conducting this test:

1 To establish that interconnections in the ring do not exist.
2 To ensure that the CPC is continuous, and indicate the value of $(R_1 + R_2)$ for the ring.

What then are interconnections in a ring circuit, and why is it important to locate them? Figure 41 shows a ring final circuit with an interconnection.

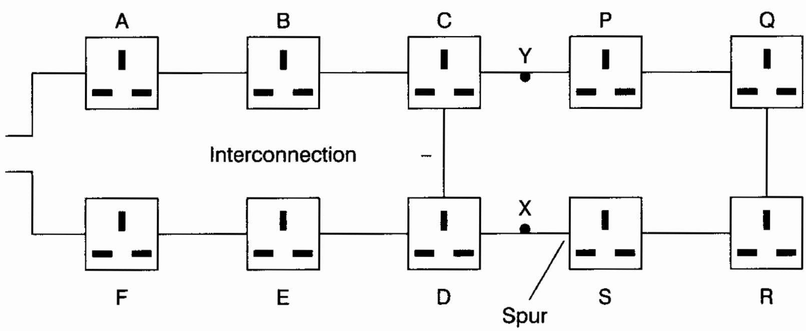


Figure 41

The most likely cause of the situation shown in Figure 41 is where a DIY enthusiast has added sockets P, Q, R and S to an existing ring A, B, C, D, E and F. In itself there is nothing wrong with this. The problem arises if a break occurs at, say, point Y, or the terminations fail in socket C or P. Then there would be four sockets all fed from the point X which would then become a spur. So, how do we identify such a situation with or without breaks at point Y? A simple resistance test between the ends of the phase, neutral or circuit protective conductors will only indicate that a circuit exists, whether there are interconnections or not. The following test method based on the theory that the resistance measured across any diameter of a perfect circle of conductor will always be the same value (Figure 42).

The perfect circle of conductor is achieved by cross-connecting the phase and neutral loops of the ring (Figure 43).

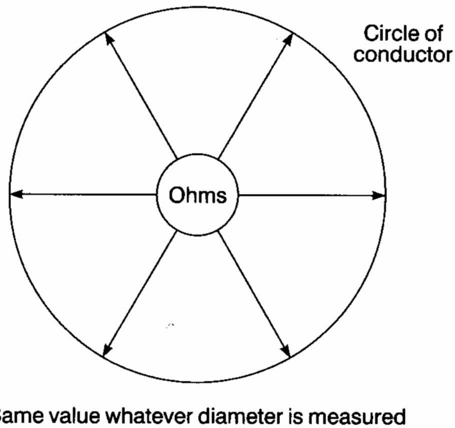


Figure 42

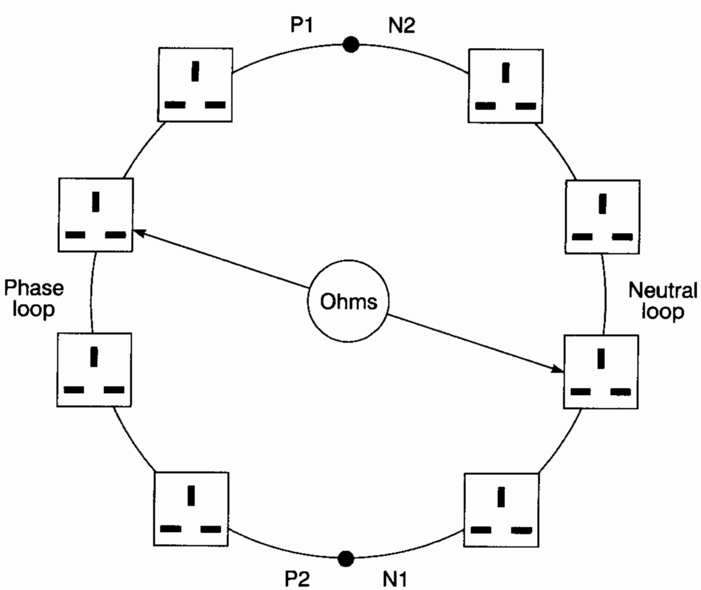


Figure 43

The test procedure is as follows:

1 *Identify the opposite legs of the ring.* This is quite easy with sheathed cables, but with singles, each conductor will have to be identified, probably by taking resistance measurements between each one and the closest socket outlet. This will give three high readings and three low readings, thus establishing the opposite legs.
2 *Take a resistance measurement between the ends of each conductor loop. Record this value.*
3 *Cross connect the ends of the phase and neutral loops (see Figure 44).*
4 *Measure between phase and neutral at each socket on the ring.* The readings obtained should be, for a perfect ring, substantially the same.

If an interconnection existed such as shown in Figure 41 then sockets A to F would all have similar readings, and those beyond the interconnection would have gradually increasing values to approximately the midpoint of the ring, then decreasing values back towards the interconnection. If a break had occurred at point Y then the readings from socket S would increase to a maximum at socket P. One or two high readings are likely to indicate either loose connections or spurs. A null reading, i.e. an open circuit indication, is probably a reverse polarity, either phase-CPC or neutral-CPC reversal. These faults would clearly be rectified and the test at the suspect socket(s) repeated.

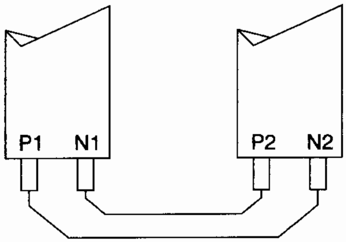


Figure 44

5 *Repeat the above procedure, but in this case cross connect the phase and CPC loops*. In this instance, if the cable is of the flat twin type, the readings at each socket will very slightly increase and then decrease around the ring. This difference, due to the phase and CPC being different sizes, will not be significant enough to cause any concern. The measured value is very important, it is $R_1 + R_2$ for the ring.

As before, loose connections, spurs and, in this case P–N cross polarity, will be picked up.

The details that follow are typical approximate ohmic values for a healthy 70 m ring final circuit wired in 2.5/1.5 flat twin and CPC cable:

Initial measurements:	P1 to P2	N1 to N2	CPC1 to CPC2
Reading at each socket:	0.26	0.26	between 0.32 and 0.34
For spurs, each metre in length will add the following resistance to the above values:	0.015	0.015	0.02

Insulation resistance

This is probably the most used and yet most abused test of them all. Affectionately known as 'meggering', an insulation resistance test is performed in order to ensure that the insulation of conductors, accessories and equipment is in a healthy condition, and will prevent dangerous leakage currents between conductors and between conductors and earth. It also indicates whether any short circuits exist.

Insulation resistance is the resistance measured between conductors and is made up of countless millions of resistances in parallel (Figure 45).

The more resistances there are in parallel, the lower the overall resistance, and in consequence, the longer a cable the lower the insulation resistance. Add to this the fact that almost all installation circuits are also wired in parallel, and it becomes apparent that tests

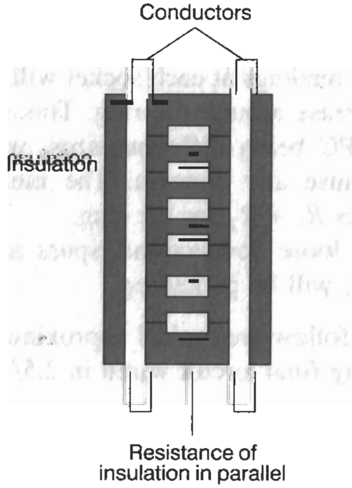


Figure 45

on large installations may give, if measured as a whole, pessimistically low values, even if there are no faults. Under these circumstances, it is usual to break down such large installations into smaller sections, floor by floor, sub-main by sub-main etc. This also helps, in the case of periodic testing, to minimize disruption.

The test procedure then, is as follows:

1 Disconnect all items of equipment such as capacitors and indicator lamps as these are likely to give misleading results. Remove any items of equipment likely to be damaged by the test, such as dimmer switches, electronic timers etc. Remove all lamps and accessories and disconnect fluorescent and discharge fittings. Ensure that the installation is disconnected from the supply, all fuses are in place, and MCBs and switches are in the on position. In some instances it may be impracticable to remove lamps etc. and in this case the local switch controlling such equipment may be left in the off position.
2 Join together all live conductors of the supply and test between this join and earth. Alternatively, test between each live conductor and earth in turn.

3 Test between phase and neutral. For three-phase systems, join together all phases and test between this join and neutral. Then test between each of the phases. Alternatively, test between each of the live conductors in turn. Installations incorporating two-way lighting systems should be tested twice with the two-way switches in alternative positions.

The following Table 4 gives the test voltages and minimum values of insulation resistance for ELV and LV systems.

If a value of less than 2 MΩ is recorded it may indicate a situation where a fault is developing, but as yet still complies with the minimum permissible value. In this case each circuit should be tested separately and each should be above 2 MΩ.

Polarity

This simple test, often overlooked, is just as important as all the others, and many serious injuries and electrocutions could have been prevented if only polarity checks had been carried out.

The requirements are:

- all fuses and single pole switches are in the phase conductor
- the centre contact of an Edison screw type lampholder is connected to the phase conductor
- all socket outlets and similar accessories are correctly wired.

Although polarity is towards the end of the recommended test sequence, it would seem sensible, on lighting circuits, for example, to conduct this test at the same time as that for continuity of CPCs, Figure 46.

Table 4

System	*Test voltage*	*Minimum insulation resistance*
SELV and PELV	250 V DC	0.25 MΩ
LV up to 500 V	500 V DC	0.5 MΩ
Over 500 V	1000 V DC	1.0 MΩ

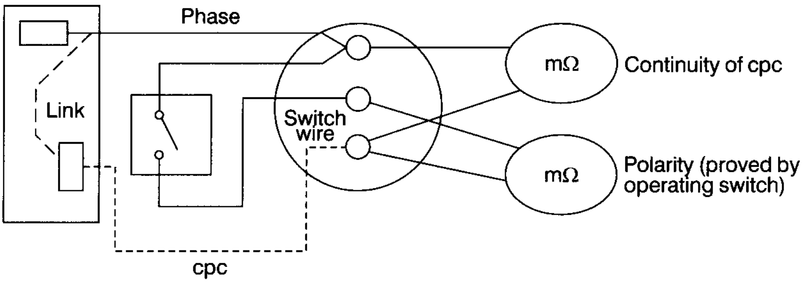


Figure 46

As discussed earlier, polarity on ring final circuit conductors is achieved simply by conducting the ring circuit test. For radial socket outlet circuits, however, this is a little more difficult. The continuity of the CPC will have already been proved by linking phase and CPC and measuring between the same terminals at each socket. Whilst a phase-CPC reversal would not have shown, a phase-neutral reversal would, as there would have been no reading at the socket in question. This would have been remedied, and so only phase-CPC reversals need to be checked. This can be done by linking together phase and neutral at the origin and testing between the same terminals at each socket. A phase-CPC reversal will result in no reading at the socket in question.

Earth electrode resistance

As we know, in many rural areas, the supply system is T–T and hence reliance is placed on the general mass of earth for a return path under earth fault conditions and the connection to earth is made by an electrode, usually of the rod type.

In order to determine the resistance of the earth return path, it is necessary to measure the resistance that the electrode has with earth. In this instance an earth fault loop impedance test is carried out between the incoming phase terminal and the electrode (a standard test for Z_e). The value obtained is added to the CPC resistance of the protected circuits and this value is multiplied by the operating current of the RCD. The resulting value should not exceed 50 V.

Table 5 Values of loop impedance for comparison with test readings

Protection	Disconnection time		RATING OF PROTECTION 5A	6A	10A	15A	16A	20A	25A	30A	32A	40A	45A	50A	60A	63A	80A	100A	125A	160A	200A
BS 3036 fuse	0.4 s	Zs max.	7.5	///////	///////	2	///////	1.38	///////	0.85	///////	///////	0.46								
	5 s	Zs max.	13.9	///////	///////	4.18	///////	3	///////	2.97	///////	///////	1.25	///////	0.87	///////	///////	0.42			
BS 88 fuse	0.4 s	Zs max.	///////	6.66	4	///////	2.11	1.38	1.12	///////	0.82	0.64	///////	0.47							
	5 s	Zs max.	///////	10.5	5.8	///////	3.27	2.28	1.8	///////	1.44	1.05	///////	0.82	///////	0.64	0.45	0.33	0.26	0.2	0.14
BS 1361 fuse	0.4 s	Zs max.	8.17	///////	///////	2.57	///////	1.33	///////	0.9	///////	///////	0.45								
	5 s	Zs max.	12.8	///////	///////	3.9	///////	2.19	///////	1.44	///////	///////	0.75	///////	0.54	///////	0.39	0.28			
BS 3871 MCB Type 1	0.4 & 5 s	Zs max.	9	7.5	4.5	3	2.81	2.25	1.8	1.5	1.41	1.12	1	0.9	///////	0.71					
BS 3871 MCB Type 2	0.4 & 5 s	Zs max.	5.14	4.28	2.57	1.71	1.6	1.28	1.02	0.85	0.8	0.64	0.57	0.51	///////	0.4					
BS 3871 MCB Type 3	0.4 & 5 s	Zs max.	3.6	3	1.8	1.2	1.12	0.9	0.72	0.6	0.56	0.45	0.4	0.36	///////	0.28					
BS EN 60898 MCB Type B	0.4 & 5 s	Zs max.	///////	6	3.6	///////	2.25	1.8	1.44	///////	1.12	0.9	0.8	0.72	///////	0.57					
BS EN 60898 MCB Type C	0.4 & 5 s	Zs max.	3.6	3	1.8	1.2	1.12	0.9	0.72	0.6	0.56	0.45	0.4	0.36	///////	0.28					
BS EN 60898 MCB Type D	0.4 & 5 s	Zs max.	1.8	1.5	0.9	0.6	0.56	0.45	0.36	0.3	0.28	0.22	0.2	0.18	///////	0.14					

Earth fault loop impedance

Overcurrent protective devices must, under earth fault conditions, disconnect fast enough to reduce the risk of electric shock. This is achieved if the actual value of the earth fault loop impedance does not exceed the tabulated maximum values given in the IEE Regulations. The purpose of the test, therefore, is to determine the actual value of the loop impedance Z_s, for comparison with those maximum values, and it is conducted as follows:

1 Ensure that all main equipotential bonding is in place.
2 Connect the test instrument either by its BS4363 plug, or the 'flying leads', to the phase, neutral and earth terminals at the remote end of the circuit under test. (If a neutral is not available, connect the neutral probe to earth.)
3 Press to test and record the value indicated.

It must be understood that this instrument reading is *not valid for direct comparison with the tabulated maximum values*, as account must be taken of the ambient temperature at the time of test, and the maximum conductor operating temperature, both of which will have an effect on conductor resistance. Hence, the $(R_1 + R_2)$ is likely to be greater at the time of fault than at the time of test.

So, our measured value of Z_s must be corrected using correction factors and applying them in a formula.

Clearly this method of correcting Z_s is time-consuming and unlikely to be commonly used. Hence, a rule of thumb method may be applied which simply requires that the measured value of Z_s does not exceed 3/4 of the appropriate tabulated value. Table 7 gives the 3/4 values of tabulated loop impedance for direct comparison with measured values.

In effect, a loop impedance test places a phase/earth fault on the installation, and if an RCD is present it may not be possible to conduct the test, as the device will trip out each time the loop impedance tester button is pressed. Unless the instrument is of a type that has a built-in guard against such tripping, the value of Z_s will have to be determined from measured values of Z_e and $(R_1 + R_2)$.

NEVER SHORT OUT AN RCD IN ORDER TO CONDUCT THIS TEST

As a loop impedance test creates a high earth fault current, albeit for a short space of time, some lower rated MCBs may operate resulting in the same situation as with an RCD, and Z_s will have to be calculated. It is not really good practice to temporarily replace the MCB with one of a higher rating.

External loop impedance Z_e

The value of Z_e is measured at the intake position on the supply side and with all main equipotential bonding disconnected. Unless the installation can be isolated from the supply, this test should not be carried out, as a potential shock risk will exist with the supply on and the main bonding disconnected.

Prospective fault current

Prospective fault current (PFC) has to be determined at the origin of the installation. This is achieved by enquiry, calculation or measurement.

Functional testing

RCD RCBO operation

Where RCDs RCBOs are fitted, it is essential that they operate within set parameters. The RCD testers used are designed to do just this, and the basic tests required are as follows:

1 Set the test instrument to the rating of the RCD.
2 Set the test instrument to half rated trip.
3 Operate the instrument and the RCD should not trip.
4 Set the instrument to deliver the full rated tripping current of the RCD.
5 Operate the instrument and the RCD should trip out in the required time.

Table 6 gives further details.

Table 6

RCD type	*Half rated*	*Full trip current*
BS 4293 and BS 71–88 sockets	no trip	less than 200 ms
BS 4293 with time delay	no trip	$\frac{1}{2}$ time delay + 200 ms
BS EN 61009 or BS EN 61009 RCBO	no trip	300 ms
As above, but type S with time delay	no trip	130–500 ms

When an RCD is used for supplementary protection against direct contact, it must be rated at 30 mA or less and operate within 40 ms when subjected to a tripping current of five times its operating current.

Test instruments have the facility to provide this value of tripping current. There is no point in conducting this so called 'fast trip' test if an RCD has a rating in excess of 30 mA.

All RCDs have a built-in test facility in the form of a test button. Operating this test facility creates an artificial out of balance condition that causes the device to trip. This only checks the mechanics of the tripping operation, it is not a substitute for the tests just discussed.

All other items of equipment such as switchgear, control-gear interlocks etc. must be checked to ensure that they are correctly mounted and adjusted and that they function correctly.

7
SPECIAL LOCATIONS

In this chapter we will deal with locations that require special consideration and in particular, bathrooms, construction sites and agricultural/horticultural situations.

Section 601: Locations containing a bath or shower

This section deals with common locations containing baths, showers and cabinets containing a shower and/or bath. It does not apply to specialist locations. The main feature of this section is the division of the location into zones (0, 1, 2 and 3) in the same way as Section 602 for swimming pools.

Section 602: Swimming pools

The general requirements are similar to those for bathrooms. In the case of swimming pools the zones are zone A, B & C where Zone A is in the pools itself, Zone B extends 2.0 m beyond Zone A and 2.5 m above it, and Zone C extends a further 1.5 m beyond Zone B. Where they are permitted socket outlets must be of the industrial type to BS EN 60309-2.

Section 603: Hot air saunas

The room housing a hot air sauna is divided into temperature zones A, B, C & D in which only equipment suitable for the temperature may be installed.

All equipment should be IP24 rated.

Section 604: Construction site installations

This section does not apply to offices, cloakrooms, meeting rooms, canteens etc.

Clearly a construction site is a hazardous area, and a location where many hand held portable tools are used. Consequently special precautions must be taken.

- 50 V or 25 V SELV would be required for supplying portable hand lamps in damp or confined locations.
- 110 V single or three phase centre tap earth would be needed for general portable lamps or tools. This is the reduced voltage system already mentioned in Chapter 3.
- 230 V is only permitted for fixed floodlighting
- 400 V for fixed and moveable equipment above 3.75 kW.
- Disconnection times are reduced for all voltages above 120 V to earth, the 220 V–277 V range is halved from 0.4 s to 0.2 s, and the associated loop impedance values are also reduced.
- Disconnection times for reduced voltage (110 V cte) systems are 5 s (IEE Regs 471-15-06)
- Touch voltage has also been reduced from 50 V to 25 V.

Section 605: Agricultural and horticultural locations

This section does not apply to farm houses and dwellings for human habitation. The general requirements are very similar to construction sites except for the voltages. Disconnection times are reduced to 0.2 s. Protection against indirect contact may be achieved by EEBADS. 500 mA RCD's are permitted for protection against fire. Electrical equipment in normal use should be to IP44.

Section 606: Restrictive conductive locations

These are locations which are conductive and where freedom of movement is difficult. Such a location would be, for example, a ventilation shaft where an operative may need to enter to work on, say, a fan. Any hand held tools taken into a location must only be supplied by a SELV supply.

Section 607: Installations having high protective conductor currents

These are typically installation in large commercial offices etc where IT equipment is extensively used. No special precautions are needed where leakage currents do not exceed 3.5 mA. This section outlines the requirements when currents exceed 3.5 mA or 10 mA in respect of types of socket outlet and sizes and number of protective conductors and how they should be connected.

Section 608: Caravans

Generally speaking, the electrical contractor will have little input to the installation in a caravan as they are pre-wired at construction stage. If, however, re-wiring is needed this section details the wiring systems permitted, the types and positions of inlets and notices to be displayed.

Section 609: Caravan parks

Generally this section deals with the site supplies to the individual caravan pitches and outlines the type of wiring system (overhead or underground) to be used and the type of socket outlet (BS EN60309-2) permitted.

Section 611: Highway supplies and street located equipment

This section deals with lamp-posts, illuminated road signs etc. Generally such locations are treated as ordinary installations but with extra details regarding identification of supply cables and temporary supplies.

BS 7671 2001
THE CHANGES

The new BS 7671 2001 contains many small editorial and Regulation number alterations; some substantial revisions and amendments; two new chapters and associated regulations; three new sections and the inclusion of the revised section 601 for bathrooms.

The bulk of the original BS 7671 1992 remains unaffected and the changes will not significantly effect the work of the electrical operative. The feel and look (apart from the colour) of the new edition is unchanged and the extent of additions, amendments and re-written regulations etc., are indicated by vertical lines in the margins of each page.

So, as the story teller says, let us begin at the beginning!

Part 1: Scope, object and fundamental principals

The whole of the original Part 1 has been re-written, rearranged etc. and three new sections ***131, 132*** and ***133*** added. These outline the general requirements for ***Design (131), Selection of electrical equipment (132) and Erection and Inspection and Testing of installations (133).***

Part 2: Definitions

There are only six significant changes to the list of definitions, two are deletions (earth leakage and hazardous live part), one (residual

current) is re-written and three are new (***mobile & offshore installations, leakage current and protective conductor current***).

Protective conductor current replaces Earth leakage current and is defined as ***Electric current which flows in a protective conductor under normal operating conditions.*** This is clearly not a fault current and is typical of the current flowing in the cpc's of IT equipment installations.

Leakage current on the other hand flows, ***under normal operating conditions, in an unwanted conductive path*** e.g. pipework which is not intended as cpc.

Part 3: Assessment of general characteristics

This part remains unchanged with the exception of Regulation 331-01-01 Compatibility, where there are some small editorial changes and the addition of ***Power factor, Undervoltage*** and ***Unbalanced loads*** to the list of harmful effects.

Part 4: Protection for safety

This part contains by far the most amendments and additions and include:

- (i) A change in test current requirements for residual current devices.
- (ii) Changes to Loop impedance tables.
- (iii) Change of pvc to ***Thermoplastic*** and the addition of ***Thermosetting*** to rubber cables.
- (iv) A new chapter on ***Overvoltage***.
- (v) New regulations regarding conductors in parallel.
- (vi) A new chapter regarding ***Protective measures as a function of external influences***.

(i) 412-06-02 (ii): When a residual current device is used as supplementary protection against Direct Contact it should have a rating $I\Delta n$ not exceeding 30 mA and should operate in

40 ms at a residual current of *5 × IΔn not* 150 mA (except for 30 mA devices).

(ii) In tables 41B2, 41C and 471 (also 604B2 and 605B2) all reference to miniature circuit breakers to ***BS 3871 types 1, 2 and 3*** has been removed and ***RCBO's to BS EN 61009*** included.

(iii) In table 43A and elsewhere in BS7671, pvc has been replaced by ***Thermoplastic (pvc)*** and rubber is now shown as ***Thermosetting (rubber)***.

(iv) New ***Chapter 44 Protection against Overvoltage***. This outlines the requirements for protecting electrical installations against overvoltages due to switching surges or from an atmospheric origin (lightning!!). Tables ***44A*** and ***44B*** give examples of equipment that withstand voltages and the categories of equipment. It is unlikely that this chapter will be of any real significance in the UK, as most equipment used is to a relevant British Standard, and the number of thunderstorm days anywhere are unlikely to exceed 25 per year.

(v) New Regulations ***473-01-06, 07 & 08*** and ***473-07-05*** incorporate and add to the old regulations regarding conductors in parallel.

(vi) New ***Chapter 48 Choice of protective measures as a function of External Influences***. This chapter deals with protection where there is a risk of fire due to the ***nature of processed or stored materials (482-02)***, and in locations with ***combustible constructional materials (482-03)***.

Part 5: Selection and erection

There are few significant changes in this part, most are editorial or re-written sentences.

514-10-01 Voltage warning notices should now read ***230 V*** *not* 250 V.

Part 6: Special installations or locations

The changes in this part are mainly editorial with a few additions.

Section 601: Bathrooms etc

The old AMD 3 has been incorporated with one or two minor amendments.

Section 604: Construction sites etc.

There are three new regulations ***604-01-02*** and ***03*** which give greater detail of the scope of this section and ***604-10-03*** which indicates the requirements for the selection of flexible cables i.e. ***Low temperature 300/500 V thermoplastic cable for reduced voltage systems*** and ***HO7 RN-F 400/750 V rated cables for 230/400 V systems.***

Section 607: High protective conductor current installations

Whilst this section has been completely re-written the content is generally unchanged. Where the protective conductor current is likely to exceed 10 mA, the requirement for two separate protective conductor terminals in BS EN 60309-2 plugs has been deleted but where high integrity protective conductors and connections are required ***accessories must have two earthing terminals.***

RCD's, should not operate at ***expected protective conductor currents.***

Section 611: Highway power supplies etc.

Once again this section is generally unchanged with only one new regulation ***611-05-02*** which requires a degree of protection for all electrical equipment of ***IP33.***

Regulation 611-02 has been added to with the requirements that ***access doors less than 2.5 m above the ground be locked or secured by the use of a key or tool.***

Regulation 611-02-02 also requires the use of a tool to remove barriers or enclosures to ***gain access to light sources of luminaires located less than 2.8 m above the ground.***

Regulation 611-04-03 has been added to, and includes the need for ***colour coded marker tape or cable tiles to be used with power supply cables.***

Part 7: Inspection and testing

Not a great deal of change here, just 2 new regulations and some modifications.

It is now required that for an initial verification, every installation be inspected and tested during ***and*** on completion.

New regulation ***713-12-01*** requires that the ***Prospective short circuit current and Prospective earth fault current at the origin and at other relevant points be ascertained by measurement, calculation or other method.***

New regulation ***732-01-02*** concerns Periodic Inspection and Testing and suggests that this may be replaced by ***an adequate regime of monitoring and maintenance provided this is carried out by skilled persons, and that the installation is under effective supervision.***

Both Electrical Installation Certificates and Periodic Test Reports must be accompanied by a schedule of test results ***and an inspection schedule.***

New regulation 742-01-02 requires every circuit to be identified on a schedule of test results.

Appendices

Appendix 1 and 2 have been updated with regards to new and amended standards and revised and new legislation.

Appendix 3, Time/Current graphs, have had all reference to BS 3871 mcb's deleted and RCBO's to BS EN61009 added.

Appendix 4 Current ratings etc. has Table 4A changed to 4A1 and another table, 4A2 added, which lists all the appropriate current rating tables.

Appendix 6 now includes samples of inspection and test schedules.

ANSWERS TO PROBLEMS

Chapter 2

1 0.152Ω.
2 18 m.
3 0.56Ω.
4 No.
5 Yes. Change the cooker control unit to one without a socket, thus converting the circuit to fixed equipment.

Chapter 5

For the factory design problem, the values obtained are as follows:

I_b = 19 A;
I_n = 20 A;
C_f = 0.725;
C_a = 0.94;
C_g = 0.8;
I_t = 36.6 A;
cable size = 6.0 mm^2;
CPC size = 2.5 mm^2;
Z_s = 1Ω;
I = 240 A;
t = 1 s;
k = 115;
conduit size = 32 mm.

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16 EDITION IEE WIRING REGULATIONS

DESIGN & VERIFICATION

OF ELECTRICAL INSTALLATIONS

Covers BS 7671: 2001

IEE Wiring Regulations

Design and Verification of Electrical Installations

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1
DESIGN

Any design to the 16th Edition of the IEE Wiring Regulations BS 7671 must be primarily concerned with the safety of persons, property and livestock. All other considerations such as operation, maintenance, aesthetics, etc., while forming an essential part of the design, should never compromise the safety of the installation.

The selection of appropriate systems and associated equipment and accessories is an integral part of the design procedure, and as such cannot be addressed in isolation. For example, the choice of a particular type of protective device may have a considerable effect on the calculation of cable size, or shock risk or the integrity of conductor insulation under fault conditions.

Perhaps the most difficult installations to design are those involving additions and/or alterations to existing systems, especially where no original details are available, and those where there is a change of usage or a refurbishment of a premises, together with a requirement to utilize as much of the existing wiring system as possible.

So, let us investigate those parts of the Wiring Regulations that need to be considered in the early stages of the design procedure.

Assessment of general characteristics

Regardless of whether the installation is a whole one, an addition, or an alteration, there will always be certain design criteria to be considered before calculations are carried out. Part 3 of the 16th Edition, 'Assessment of General Characteristics', indicates four main headings under which these considerations should be addressed. These are:

1 Purpose, supplies and structure
2 External influences
3 Compatibility
4 Maintainability.

Let us look at these headings in a little more detail.

Purpose, supplies and structure

- For a new design, will the installation be suitable for its intended purpose?
- For a change of usage, is the installation being used for its intended purpose?
- If not, can it be used safely and effectively for any other purpose?
- Has the maximum demand been evaluated?
- Can diversity be taken into account?
- Are the supply and earthing characteristics suitable?
- Are the methods for protection for safety appropriate?
- If standby or safety supplies are used, are they reliable?
- Are the installation circuits arranged to avoid danger and facilitate safe operation?

External influences

Appendix 5 of the IEE Regulations classifies external influences which may affect an installation. This classification is divided into three sections, the environment (A), how that environment is utilized (B) and construction of buildings (C). The nature of any influence within each section is also represented by a number. The following gives examples of the classification:

Environment	*Utilization*	*Building*
Water	Capability	Materials
AD6 Waves	**BA3** Handicapped	**CA1** Non-combustible

With external influences included on drawings and in specifications, installations and materials used can be designed accordingly.

Compatibility

It is of great importance to ensure that damage to, or mal-operation of equipment cannot be caused by harmful effects generated by other equipment even under normal working conditions. For example, MIMS cable should not be used in conjunction with discharge lighting, as the insulation can break down when subjected to the high starting voltages; the operation of RCDs may be impaired by the magnetic fields of other equipment; computers, PLCs, etc., may be affected by normal earth leakage currents from other circuits.

Maintainability

All installations require maintaining, some more than others, and due account of the frequency and quality of maintenance must be taken at the design stage. It is usually the industrial installations that are mostly affected by the need for regular maintenance, and consultation with those responsible for the work is essential in order to ensure that all testing, maintenance and repair can be effectively and safely carried out. The following example may serve to illustrate an approach to consideration of design criteria with regards to a change of usage.

EXAMPLE 1

A vacant two-storey light industrial workshop, 12 years old, is to be taken over and used as a Scout/Guide HQ. New shower facilities are to be provided. The supply is three-phase 400/230 V and the earthing system is TN–S.

The existing electrical installation on both floors comprises steel trunking at a height of 2.5 m around all perimeter walls, with steel conduit, to all socket outlets and switches (metal-clad), to numerous isolators and switch-fuses once used to control single and three-phase machinery, and to the lighting, fluorescent luminaires suspended by chains from the ceilings. The ground floor is to be used as the main activity area and part of the top floor at one end is to be converted to house separate male and female toilet and shower facilities accommodating two 8 kW/230 V shower units in each area.

If the electrical installation has been tested and inspected and shown to be safe:

1 Outline the design criteria, having regard for the new usage, for
   (a) The existing wiring system, and
   (b) The wiring to the new showers.
2 What would be the total assumed current demand of the shower units?

Suggested approach/solution 1

(a) Existing system

Purpose, supplies and structure

Clearly the purpose for which the installation was intended has changed, however, the new usage is unlikely, in all but a few instances, to have a detrimental effect on the existing system. It will certainly be under-loaded, nevertheless this does not preclude the need to assess the maximum demand.

The supply and earthing arrangements will be satisfactory, but there may be a need to alter the arrangement of the installation, in order to rebalance the load across the phases now that machinery is no longer present.

External influences

The new shower area will probably have a classification AD3 or 4 and will be subject to Section 601, IEE Regulations. Hence all metal conduit and trunking should be removed together with any socket outlets. The trunking could be replaced with PVC, alternatively it could be boxed in using insulating material and screw-on lids to enable access. Suspended fluorescent fittings should be replaced with the enclosed variety, with control switches preferably located outside the area.

The activities in the ground-floor area will almost certainly involve various ball games giving it a classification of AG2 (medium impact). Conduit drops are probably suitable, but old isolators and switch-fuses should be removed, and luminaires fixed to the ceiling and caged, or be replaced with suitably caged spotlights on side walls at high level.

As the whole building utilization can now be classified BA2 (children), it is probably wise to provide supplementary protection against direct contact by installing 30 mA RCDs on all accessible circuits.

Compatibility

Unlikely to be any compatibility problems with the new usage.

Maintainability

Mainly periodic test and inspection with some maintenance of lighting, hence suitable access equipment should be available, together with spare lamps and tubes. Lamp disposal facilities should be considered.

(b) New shower area (BS7691 Section 601)

Purpose, supplies and structure

As this is a new addition, the installation will be designed to fulfil all the requirements for which it is intended. The supply and earthing system should be suitable, but a measurement of the PSCC and Z_e should be taken. The loading of the showers will have been accounted for during the assessment of maximum demand.

In the unlikely event of original design and installation details being available, it may be possible to utilize the existing trunking without exceeding space factors or de-rating cables due to the application of grouping factors. However, it is more probable that a re-evaluation of the trunking installation would need to be undertaken, or alternatively, install a completely separate system. Whichever the method adopted, a sub-main supplying a four-way distribution board located outside the area would be appropriate, the final circuits to each shower being run via individual control switches also outside, and thence to the units using a PVC conduit system. Protection against indirect contact would be by earthed equipotential bonding and automatic disconnection, by CBs backed up by RCDs.

External influences

These have already been addressed in 1(a) above.

Compatibility

There will be no incompatibility between any equipment in this area.

Maintainability

Afforded by the individual switches and/or CBs allowing isolation to maintain or repair/replace defective units.

Suggested approach/solution 2

Design current I_b for each unit = 8000/230 = 35 A applying diversity:

1st unit	100% of 35	=	35
2nd unit	100% of 35	=	35
3rd unit	25% of 35	=	8.75
4th unit	25% of 35	=	8.75
Total assumed current demand		=	87.5 A

As an answer to a C&G 2400 examination question, this suggested approach is more comprehensive than time constraints would allow, and hence an abbreviated form is acceptable. The solutions to the questions in Chapter 3 of this book illustrate such shortened answers.

Protection for safety

Part 4 of the 16th Edition details the methods and applications of *protection for safety*, and consideration of these details must be made as part of the design procedure. Areas that the designer needs to address are: protection against shock, thermal effects, overcurrent and undervoltage, and the requirements for isolation and switching. Let us now deal, in broad terms, with each of these areas.

Protection against shock

There are two ways that persons or livestock may be exposed to the effects of electric shock, these are (a) by touching live parts of electrical equipment, 'Direct Contact' or (b) by touching exposed-conductive-parts of electrical equipment or systems, which have been made live by a fault, 'Indirect Contact'. Chart 1 indicates the common methods of protecting against either of these situations.

Barriers and enclosures

One method used to protect against direct contact is to place live parts in enclosures and/or behind barriers. In order to ensure that such protection will be satisfactory, the enclosures/barriers must

Chart 1 Common methods of protection against shock

Protection by	*Protection against*	*Applications and comments*
SELV (separated extra low voltage)	Direct and Indirect contact	Used for circuits in environments such as bathrooms, swimming pools, restrictive conductive locations, agricultural and horticultural situations, and for 25 V hand lamps in damp situations on construction sites. Also useful for circuits in schools, or college laboratories.
Insulation of live parts	Direct contact	This is simply 'basic insulation'.
Barriers and enclosures	Direct contact	Except where otherwise specified, such as swimming pools, hot air saunas, etc., placing LIVE PARTS behind barriers or in enclosures to at least IP2X is the norm. Two exceptions to this are: 1 Accessible horizontal top surfaces of, for example, distribution boards or consumer units, where the protection must be to at least IP4X, and 2 Where a larger opening than IP2X is necessary, e.g. entry to lampholders where replacement of lamps is needed. Access past a barrier or into an enclosure should only be possible by the use of a tool, or after the supply has been disconnected, or if there is an intermediate barrier to at least IP2X. This does not apply to ceiling roses or ceiling switches with screw-on lids.

Chart 1 Continued

Protection by	*Protection against*	*Applications and comments*
Obstacles	Direct contact	Restricted to areas only accessible to skilled persons, e.g. sub-stations with open fronted busbar chambers, etc.
Placing out of reach	Direct contact	Restricted to areas only accessible to skilled persons, e.g. sub-stations with open fronted busbar chambers, etc. Overhead travelling cranes or overhead lines.
RCDs (residual current devices)	Direct contact	These may only be used as supplementary protection against direct contact, and must have an operating current of 30 mA or less, and an operating time of 40 ms or less at a residual current of $5 \times I\Delta n$.
	Indirect contact	Used when the loop impedance requirements for EEBADS cannot be met or for protecting S/O circuits supplying portable equipment used outdoors. Preferred method of earth fault protection for TT systems.
EEBADS (earthed equipotential bonding and automatic disconnection of supply)	Indirect contact	The most common method in use. Relies on the co-ordination of the characteristics of the earthing, impedance of circuits, and operation of protective devices such that no danger is caused by earth faults occurring anywhere in the installation.

Chart 1 Continued

Protection by	*Protection against*	*Applications and comments*
Class II equipment	Indirect contact	Sometimes referred to as double insulated equipment and marked with the BS symbol ⧈. Supplying such equipment via a class II 'All insulated' installation incorporating S/Os may NOT be used as the sole means of protection against Indirect Contact.
Non-conducting location	Indirect contact	Rarely used – only for very special installations under strict supervision.
Earth-free local equipotential bonding	Indirect contact	Rarely used – only for very special installations under strict supervision.
Electrical separation	Indirect contact	Rarely used – only for very special installations under strict supervision.

conform to BS EN 60529, commonly referred to as the IP code. This details the amount of protection an enclosure can offer to the ingress of mechanical objects, foreign solid bodies and moisture. Table 1 shows part of the IP code. The X in a code simply means that protection is not specified, for example, in the code IP2X, only the protection against mechanical objects is specified, not moisture.

Table 1

First numeral	*Mechanical protection*
0	No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.
1	Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example, a hand, not for protection against deliberate access to such parts. Protection against ingress of large solid foreign bodies.
2	Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium-sized solid foreign bodies.
3	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small foreign bodies.
4	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small foreign bodies.
5	Complete protection against contact with live or moving parts inside the enclosures. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed.
6	Complete protection against contact with live or moving parts inside the enclosures. Protection against ingress of dust.

Table 1 Continued

Second numeral	*Liquid protection*
0	No protection.
1	Protection against drops of condensed water. Drops of condensed water falling on the enclosure shall have no effect.
2	Protection against drops of liquid. Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical.
3	Protection against rain. Water falling in rain at an angle equal to or smaller than 60° with respect to the vertical shall have no harmful effect.
4	Protection against splashing. Liquid splashed from any direction shall have no harmful effect.
5	Protection against water jets. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect.
6	Protection against conditions on ships' decks (deck with watertight equipment). Water from heavy seas shall not enter the enclosures under prescribed conditions.
7	Protection against immersion in water. It must not be possible for water to enter the enclosure under stated conditions of pressure and time.
8	Protection against indefinite immersion in water under specified pressure. It must not be possible for water to enter the enclosure.

Earthed equipotential bonding and automatic disconnection of supply (EEBADS)

As Chart 1 indicates, EEBADS is the most common method of providing protection against electric shock through Indirect Contact, and hence it is important to expand on this topic.

There are two basic ways of receiving an electric shock by Indirect Contact:

1 Via parts of the body and the general mass of earth (typically hands and feet) Figure 1, and
2 Via parts of the body and simultaneously accessible *Exposed and Extraneous conductive parts* (typically hand to hand) Figure 2.

Clearly, the conditions shown in Figures 1 and 2 would provide no protection, as the installation is not earthed. However, if it can be ensured that protective devices operate fast enough by providing low impedance paths for earth fault currents, and that main equipotential bonding is carried out, then the magnitude and duration of earth faults will be reduced to such a level as not to cause danger.

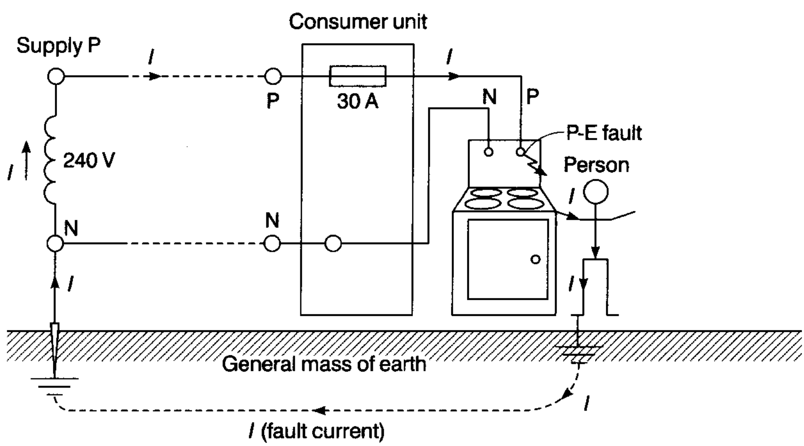


Figure 1

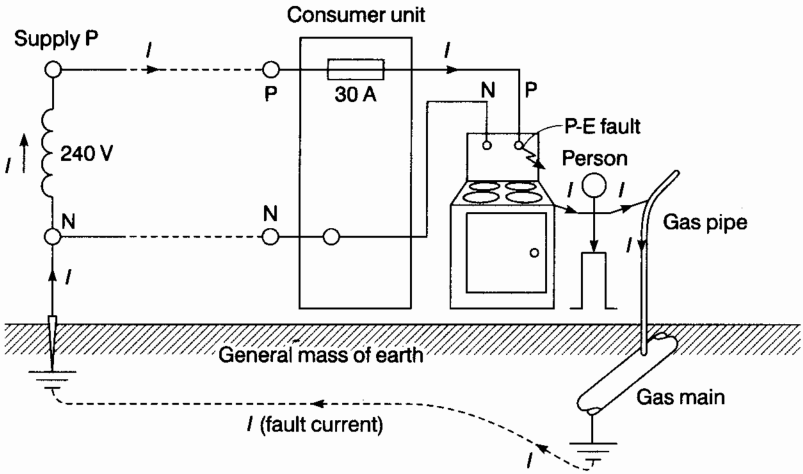


Figure 2

Experience has shown that it is reasonable to allow earth faults to persist on circuits feeding fixed or stationary equipment, for durations up to 5 s, and up to 0.4 s on circuits feeding socket outlets intended to supply portable appliances. These times are further reduced to 0.2 s, in agricultural and horticultural situations and on construction sites. The nominal voltage to earth (U_0) in all these cases being 230 V to 277 V.

The connection of main equipotential bonding conductors has the effect of creating a zone in which, under earth fault conditions, all exposed and extraneous conductive parts rise to a substantially equal potential. There may be differences in potential between simultaneously accessible conductive parts, but provided the design and installation is correct, the level of shock voltage will not be harmful.

Figure 3 shows the earth fault system which provides protection against indirect contact.

The low impedance path for fault currents, the *earth fault loop path*, comprises that part of the system external to the installation, i.e. the impedance of the supply transformer, distributor and

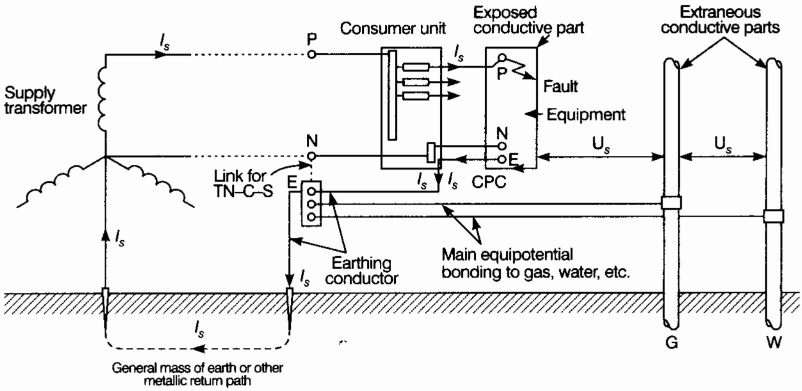


Figure 3

service cables Z_e, and the resistance of the phase conductor R_1, and CPC R_2, of the circuit concerned.

The total value of loop impedance Z_s is therefore the sum of these values:

$$Z_s = Z_e + (R_1 + R_2)\ \Omega$$

Provided that this value of Z_s does not exceed the maximum value given for the protective device in question in Tables 41B1, 41B2 or 41D of the Regulations, the protection will operate within the prescribed time limits.

It must be noted that the actual value of $(R_1 + R_2)$ is determined from:

$$\frac{\text{Tabulated value of } (R_1 + R_2) \times \text{Circuit length} \times \text{Multiplier}}{1000}$$

Note: The multiplier corrects the resistance at 20°C to the value at conductor operating temperature.

External loop impedance Z_e

The designer obviously has some measure of control over the values of R_1 and R_2, but the value of Z_e can present a problem when the premises, and hence the installation within it, are at drawing board stage. Clearly Z_e cannot be measured, and although a test made in an adjacent installation would give some indication of a likely value, the only recourse would either be to request supply network details from the supply authority and calculate the value of Z_e, or use the maximum likely values quoted by the electricity boards, which are:

TT system	21 Ω
TN–S system	0.8 Ω
TNC–S system	0.35 Ω

These values are pessimistically high and may cause difficulty in even beginning a design calculation. For example, calculating the size of conductors (considering shock risk) for, say, a sub-main cable protected by a 160 A, BS88 fuse and supplied via a TNC–S system, would present great difficulties, as the maximum value of Z_s (Table 41D(b)) for such a fuse is 0.27 Ω and the quoted likely value of Z_e is 0.35 Ω. In this case the supply authority would need to be consulted.

Supplementary equipotential bonding

This still remains a contentious issue even though the Regulations are quite clear on the matter.

Supplementary bonding is only required under the following conditions:

1 When the requirements for loop impedance and associated disconnection times cannot be met (RCDs may be installed as an alternative), and
2 The exposed and/or extraneous conductive parts are *simultaneously* accessible, or
3 The location is an area of increased risk such as detailed in Part 6 of the Regulations, and other areas such as industrial kitchens, laundry rooms, etc.

Other equipotential bonding

There are occasions when a distribution board houses circuits with significantly different disconnection times. In the event of an earth fault occurring on equipment supplied by the circuit with the longer time, a fault voltage could appear on the exposed conductive parts of equipment supplied by the circuit with the shorter time.

This situation can be resolved by connecting a local equipotential bonding conductor from the earth terminal of the distribution board to the same extraneous conductive parts that have been bonded at the intake position. Perhaps the better method of overcoming the problem is to design all the circuits for the lower disconnection time of 0.4 s.

Protection against thermal effects

The provision of such protection requires, in the main, a common-sense approach. Basically, ensure that electrical equipment that generates heat is so placed as to avoid harmful effects on surrounding combustible material. Terminate or join all live conductors in approved enclosures, and where electrical equipment contains in excess of 25 litres of flammable liquid, make provision to prevent the spread of such liquid, for example, a retaining wall round an oil-filled transformer.

In order to protect against burns from equipment not subject to a British Standard limiting temperature, conform to the requirements of Table 42A, IEE Regulations.

Precautions where there is a particular risk of fire (IEE Regs Chapter 48)

This chapter outlines details of locations and situations where there may be a particular risk of fire. These would include locations where combustible materials are stored or could collect and where a risk of ignition exists. This section does not include locations where there is a risk of explosion.

Protection against overcurrent

The term overcurrent may be sub-divided into:

1 Overload current, and
2 Fault current.

The latter being further sub-divided to:

(a) Short-circuit current (between live conductors), and
(b) Earth fault current (between phase and earth)

Overloads are overcurrents occurring in healthy circuits and caused by, for example, motor starting, inrush currents, motor stalling, connection of more loads to a circuit than it is designed for, etc.

Fault currents, on the other hand, typically occur when there is mechanical damage to circuits and/or accessories causing insulation failure or breakdown leading to 'bridging' of conductors. The impedance of such a 'bridge' is assumed to be negligible.

Clearly, significant overcurrents should not be allowed to persist for any length of time, as damage will occur to conductors and insulation.

Chart 2 indicates some of the common types of protective device.

Protection against overload

Protective devices used for this purpose have to be selected to conform with the following requirements:

1 The nominal setting of the device I_n must be greater than or equal to the design current I_b.

$$I_n \geqslant I_b$$

2 The current carrying capacity of the conductors, I_z must be less than or equal to the nominal setting of the device I_n.

$$I_z \geqslant I_n$$

3 The current causing operation of the device I_2 must be less than or equal to 1.45 times the current carrying capacity of the conductors I_z.

$$I_2 \leq 1.45 \times I_z$$

Chart 2 Commonly used protective devices

Device	*Application*	*Comments*
Semi-enclosed re-wireable fuse BS3036	Mainly domestic consumer units	Gradually being replaced by other types of protection. Its high fusing factor results in lower cable current carrying capacity or, conversely, larger cable sizes. Does not offer good short-circuit current protection. Ranges from 5 A to 200 A.
HRC fuse links BS88 Parts 2 and 6	Mainly commercial and industrial use	Give excellent short-circuit current protection. Does not cause cable de-rating. 'M' types used for motor protection. Ranges from 2 A to 1200 A.
HRC fuse links BS1361	House service and consumer unit fuses	Not popular for use in consumer units, however, gives good short-circuit current protection, and does not result in cable de-rating. Ranges from 5 A to 100 A.
MCBs (miniature circuit breakers) BS3871, now superseded by BS EN 60898 CBs	Domestic consumer units commercial/ industrial distribution boards.	Very popular due to ease of operation. Some varieties have locking-off facilities. Range from 1 A to 63 A single and three phase. Old types 1, 2, 3 and 4 now replaced by types B, C and D with breaking capacities from 3 kA to 25 kA.
MCCBs (moulded case circuit breakers) BS EN 609472	Industrial situations where high current and breaking capacities are required	Breaking capacity, 22 kA to 50 kA in ranges 16 A to 1200 A. 2, 3 and 4 pole types available.

For fuses to BS88 and BS1361, and MCBs or CBs, compliance with (2) above automatically gives compliance with (3). For fuses to BS3036 (re-wireable) compliance with (3) is achieved if the nominal setting of the device I_n is less than or equal to $0.725 \times I_z$.

$$I_n \leq 0.725 \times I_z$$

This is due to the fact that a re-wireable fuse has a fusing factor of 2, and 1.45/2 = 0.725.

Overload devices should be located at points in a circuit where there is a reduction in conductor size or anywhere along the length of a conductor, providing there are no branch circuits. The Regulations indicate circumstances under which overload protection may be omitted, one such example is when the characteristics of the load are not likely to cause an overload, hence there is no need to provide protection at a ceiling rose for the pendant drop.

Protection against fault current

Short-circuit current

When a 'bridge' of negligible impedance occurs between live conductors (remember, a neutral conductor is a live conductor) the short-circuit current that could flow is known as the 'prospective short circuit current' (PSCC), and any device installed to protect against such a current must be able to break the PSCC at the point at which it is installed without the scattering of hot particles or damage to surrounding materials and equipment. It is clearly important therefore to select protective devices that can meet this requirement.

It is perhaps wise to look in a little more detail at this topic. Figure 4 shows PSCC over one half-cycle, t_1 is the time taken to reach 'cut-off' when the current is interrupted, and t_2 the total time taken from start of fault to extinguishing of the arc.

During the 'pre-arcing' time t_1, electrical energy of considerable proportions is passing through the protective device into the conductors. This is known as the 'pre-arcing let-through' energy and is given by $I_f^2 t_1$, where I_f is the short-circuit current at 'cut-off'.

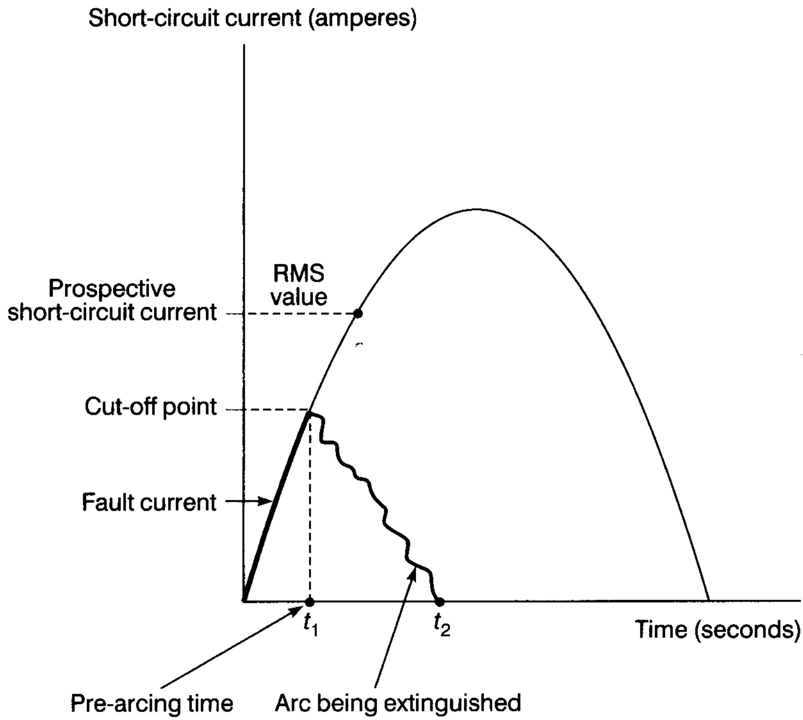


Figure 4

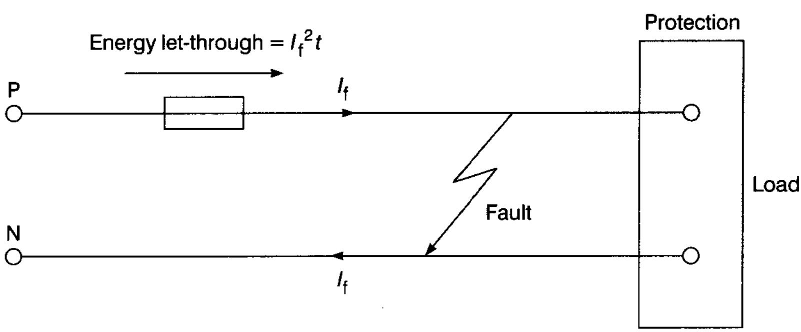


Figure 5

The total amount of energy let through into the conductors is given by $I_f^2 t_2$ in Figure 5.

For faults up to 5 s duration, the amount of heat and mechanical energy that a conductor can withstand is given by $k^2 s^2$, where k is a factor dependent on the conductor and insulation materials (tabulated in the Regulations), and s is the conductor csa. Provided the energy let-through by the protective device does not exceed the energy withstand of the conductor, no damage will occur. Hence, the limiting situation is when $I_f^2 t = k^2 s^2$. If we now transpose this formula for t, we get $t = k^2 s^2 / I_f^2$, which is the maximum disconnection time (t in seconds).

When an installation is being designed, the PSCC at each relevant point in the installation has to be determined, unless the breaking capacity of the lowest rated fuse in the system is greater than the PSCC at the intake position. For supplies up to 100 A the supply authorities quote a value of PSCC at the point at which the service cable is joined to the distributor cable, of 16 kA. This value will decrease significantly over only a short length of service cable.

Earth fault current

We have already discussed this topic with regards to shock risk, and although the protective device may operate fast enough to prevent shock, it has to be ascertained that the duration of the fault, however small, is such that no damage to conductors or insulation will result. This may be verified in two ways:

1 If the protective conductor conforms to the requirements of Table 54G (IEE Regulations), or if
2 The csa of the protective conductor is not less than that calculated by use of the formula

$$s = \frac{\sqrt{I^2 t}}{k}$$

which is another rearrangement of the formula $I^2 t = k^2 s^2$.

For flat, twin and three-core cables the formula method of verification will be necessary, as the circuit protective conductor (CPC) incorporated in such cables is always smaller than the associated phase conductor. It is often desirable when choosing a CPC size to use the calculation, as invariably, the result leads to smaller CPCs and hence greater economy. This topic will be expanded further in the section 'Design calculations'.

Chart 3 $I_f^2\,t$ characteristics: 2–800 A fuse links. Discrimination is achieved if the total $I_f^2\,t$ of the minor fuse does not exceed the pre-arcing $I_f^2\,t$ of the major fuse

Rating (A)	*$I_f^2\,t$ pre-arcing*	*$I_f^2\,t$ total at 415 V*
2	0.9	1.7
4	4	12
6	16	59
10	56	170
16	190	580
20	310	810
25	630	1 700
32	1 200	2 800
40	2 000	6 000
50	3 600	11 000
63	6 500	14 000
80	13 000	36 000
100	24 000	66 000
125	34 000	120 000
160	80 000	260 000
200	140 000	400 000
250	230 000	560 000
315	360 000	920 000
350	550 000	1 300 000
400	800 000	2 300 000
450	700 000	1 400 000
500	900 000	1 800 000
630	2 200 000	4 500 000
700	2 500 000	5 000 000
800	4 300 000	10 000 000

Discrimination

It is clearly important that, in the event of an overcurrent, the protection associated with the *circuit in question* should operate, and not other devices upstream. It is not enough to simply assume that a device one size lower will automatically discriminate with one a size higher. All depends on the 'let-through' energy of the devices. If the *total* 'let-through' energy of the lower rated device does not exceed the *pre-arcing* 'let-through' energy of the higher rated device, then discrimination is achieved. Chart 3 shows the 'let-through' values for a range of BS88 fuse links, and illustrates the fact that devices of consecutive ratings do not necessarily discriminate. For example, a 6 A fuse will *not* discriminate with a 10 A fuse.

Protection against undervoltage

In the event of a loss of, or significant drop in voltage, protection should be available to prevent either damage or danger when the supply is restored. This situation is most commonly encountered in motor circuits, and in this case the protection is provided by the contactor coil via the control circuit. If there is likely to be damage or danger due to undervoltage, standby supplies could be installed and in the case of computer systems, uninterruptible power supplies (UPS).

Protection against overvoltage (IEE Regs Chapter 44)

This chapter deals with the requirements of an electrical installation to withstand overvoltages caused by lightning or switching surges. It is unlikely that installations in the UK will be affected by the requirements of this section as the number of thunderstorm days per year is not likely to exceed 25.

Isolation and switching

Let us first be clear about the difference between isolators and switches. An isolator is, by definition, 'A mechanical switching device which provides the function of cutting off, for reasons of safety, the supply to all or parts of an installation, from every source. Whereas a *switch* is a mechanical switching device which is capable of making, carrying and breaking normal load current, and some overcurrents. It may not break short-circuit currents.'

So, a switch may be used for isolation, but not vice versa. Basically an isolator is operated after all loads are switched off, in order to prevent energization while work is being carried out. Isolators are off-load devices, switches are on-load devices. Chart 4 indicates some of the common devices.

Chart 4 Common types of isolators and switches

Device	*Application*	*Comments*
Isolator or disconnector	Performs the function of isolation	Not designed to be operated on load. Isolation can also be achieved by the removal of fuses, pulling plugs, etc.
Functional switch	Any situation where a load needs to be frequently operated, i.e. light switches, switches on socket outlets, etc.	A functional switch could be used as a means of isolation, i.e. a one-way light switch provides isolation for lamp replacement provided the switch is under the control of the person changing the lamp.
Switch-fuse	At the origin of an installation or controlling sub-mains or final circuits	These can perform the function of isolation while housing the circuit protective devices.
Fuse-switch	As for switch-fuse	Mainly used for higher current ratings and have their fuses as part of the moving switch blades.
Switch disconnector	Main switch on consumer units and distribution fuse boards	These are ON LOAD devices but can still perform the function of isolation.

Design calculations

Basically, all designs follow the same procedure:

1 Assessment of general characteristics
2 Determination of design current I_b
3 Selection of protective device having nominal rating or setting I_n
4 Selection of appropriate correction factors
5 Calculation of tabulated conductor current I_t
6 Selection of suitable conductor size
7 Calculation of voltage drop
8 Evaluation of shock risk
9 Evaluation of thermal risks to conductors.

Let us now consider these steps in greater detail. We have already dealt with 'assessment of general characteristics', and clearly one result of such assessment will be the determination of the type and disposition of the installation circuits. Chart 5 gives details of common wiring systems and cable types. Having made the choice of system and cable type, the next stage is to determine the design current.

Design current I_b

This is defined as '*the magnitude of the current to be carried by a circuit in normal service*', and is either determined directly from manufacturers' details or calculated using the following formulae:

Single phase:

$$I_b = \frac{P}{V} \quad \text{or} \quad \frac{P}{V \times \text{Eff\%} \times PF}$$

Three phase:

$$I_b = \frac{P}{\sqrt{3} \times V_L} \quad \text{or} \quad \frac{P}{\sqrt{3} \times V_L \times \text{Eff\%} \times PF}$$

where:
P = power in watts
V = phase to neutral voltage in volts
V_L = phase to phase voltage in volts
EFF% = efficiency
PF = power factor.

Chart 5 Common wiring systems and cable types

System/cable type	*Applications*	*Comments*
1 Flat twin and three-core cable with CPC; PVC sheathed, PVC insulated, copper conductors	Domestic and commercial fixed wiring	Used clipped direct to surface or buried in plaster either directly, or encased in oval conduit or top-hat section, also used in conjunction with PVC mini-trunking.
2 PVC mini-trunking	Domestic and commercial fixed wiring	Used with (1) above for neatness when surface wiring is required.
3 PVC conduit with single-core PVC insulated copper conductors	Commercial and light industrial	Easy to install high impact, vermin proof, self-extinguishing, good in corrosive situations. When used with 'all insulated' accessories, provides a degree of protection against indirect contact on the system.
4 PVC trunking: square, rectangular, skirting, dado, cornice, angled bench. With single-core PVC insulated copper conductors	Domestic, commercial and light industrial	When used with all insulated accessories provides a degree of protection against indirect contact on the system. Some forms come pre-wired with copper busbars and socket outlets. Segregated compartment type good for housing different band circuits.
5 Steel conduit and trunking with single-core PVC insulated copper conductors	Light and heavy industry, areas subject to vandalism	Black enamelled conduit and painted trunking used in non-corrosive, dry environments. Galvanized finish good for moist/damp or corrosive situations. May be used as CPC, though separate one is preferred.

Chart 5 Continued

System/cable type	*Applications*	*Comments*
6 Busbar trunking	Light and heavy industry, rising mains in tall buildings	Overhead plug-in type ideal for areas where machinery may need to be moved. Arranged in a ring system with section switches provides flexibility where regular maintenance is required.
7 Mineral insulated copper sheathed (MICS) cable exposed to touch or PVC covered. Clipped direct to a surface or perforated tray or in trunking or ducts	All industrial areas, especially chemical works, boiler houses, petrol filling stations, etc., where harsh conditions exist such as extremes of heat, moisture, corrosion, etc., also used for fire alarm circuits	Very durable, long-lasting, can take considerable impact before failing. Conductor current carrying capacity greater than same in other cables. May be run with circuits of different categories in un-segregated trunking. Cable reference system as follows: CC – Bare copper sheathed MI cable V – PVC covered M – Low smoke and fume (LSF) material covered L – Light duty (500 V) H – Heavy duty (750 V) Hence a two-core 2.5 mm^2 light duty MI cable with PVC oversheath would be shown: CCV 2L 2.5.
8 F.P. 200. PVC sheathed aluminium screened silicon-rubber insulated, copper conductors. Clipped direct to surface or on perforated tray or run in trunking or ducts	Fire alarm and emergency lighting circuits	Specially designed to withstand fire. May be run with circuits of different categories in non-segregated trunking.

Chart 5 Continued

System/cable type	*Applications*	*Comments*
9 Steel wire armoured. PVC insulated PVC sheathed with copper conductors, clipped direct to a surface or on cable tray or in ducts or underground	Industrial areas, construction sites, underground supplies, etc.	Combines a certain amount of flexibility with mechanical strength and durability.
10 As above but insulation is XLPE. Cross (X) linked (L) poly (P) ethylene (E)	For use in high temperature areas	As above.
11 HOFR sheathed cables (heat, oil, flame retardant)	All areas where there is a risk of damage by heat, oil or flame	These are usually flexible cords.

Diversity

The application of diversity to an installation permits, by assuming that not all loads will be energized at the same time, a reduction in main or sub-main cable sizes. The IEE Regulations guidance notes or On-Site Guide tabulate diversity in the form of percentages of full load for various circuits in a range of installations. However it is for the designer to make a careful judgement as to the exact level of diversity to be applied.

Nominal rating or setting of protection I_n

We have seen earlier that the first requirement for I_n is that it should be greater than or equal to I_b. We can select for this condition from IEE Regulations Tables 41B1, 41B2 or 41D. For types and sizes outside the scope of these tables, details from the manufacturer will need to be sought.

Correction factors

There are several conditions which may have an adverse effect on conductors and insulation, and in order to protect against this, correction factors (CFs) are applied. These are:

C_a	Factor for ambient temperature	(From IEE Regulations Tables 4C1 or 4C2)
C_g	Factor for groups of cables	(From IEE Regulations Table 4B)
C_f	Factor if BS 3036 re-wireable fuse is used	(Factor is 0.725)
C_i	Factor if cable is surrounded by thermally insulating material	(IEE Regulations Table 52A)

Application of correction factors

The factors are applied as divisors to the setting of the protection I_n, the resulting value should be less than or equal to the tabulated current carrying capacity I_t of the conductor to be chosen.

It is unlikely that all of the adverse conditions would prevail at the same time along the whole length of the cable run and hence only the relevant factors would be applied. Unconsidered application of correction factors can result in unrealistically large conductor sizes. Item 6.4, Appendix 4, IEE Regulations refers to this situation, so consider the following:

1 If the cable in Figure 6 ran for the whole of its length, grouped with others of the same size in a high ambient temperature, and was totally surrounded with thermal insulation, it would seem logical to apply all the CFs, as they all affect the whole cable run. Certainly the factors for the BS3036 fuse, grouping and thermal insulation should be used. However, it is doubtful if the ambient temperature will have any effect on the cable, as the thermal insulation, if it is efficient, will prevent heat reaching the cable. Hence apply C_g, C_f and C_i.

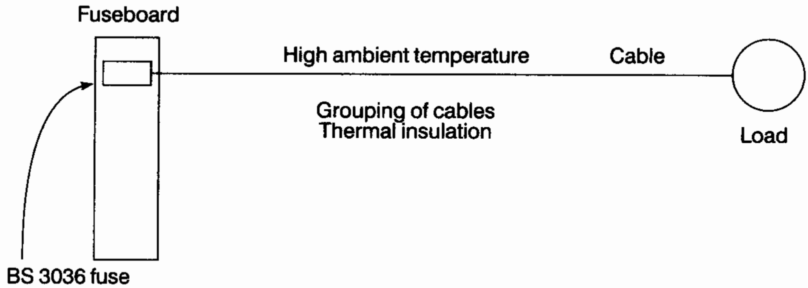


Figure 6

2 In Figure 7(a) the cable first runs grouped, then leaves the group and runs in high ambient temperature, and finally is enclosed in thermal insulation. We therefore have three different conditions, each affecting the cable in different areas. The BS3036 fuse affects the whole cable run and therefore C_f

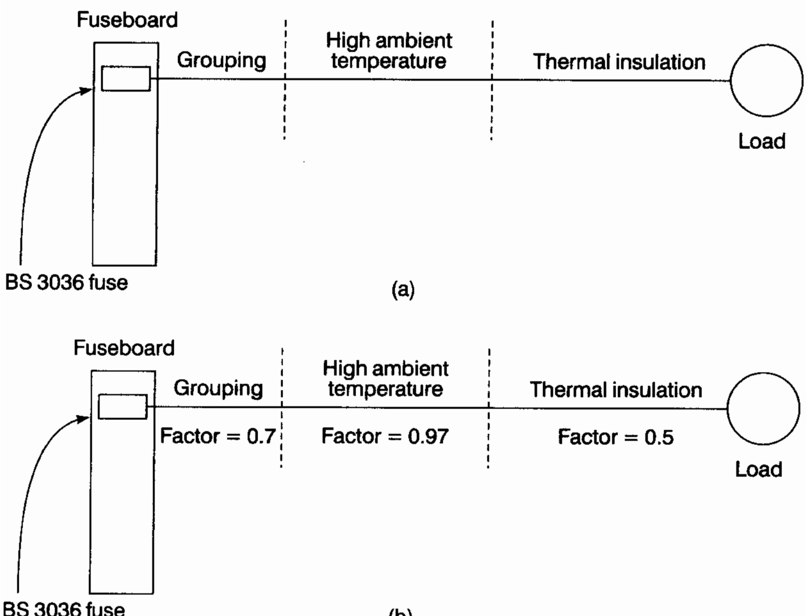


Figure 7

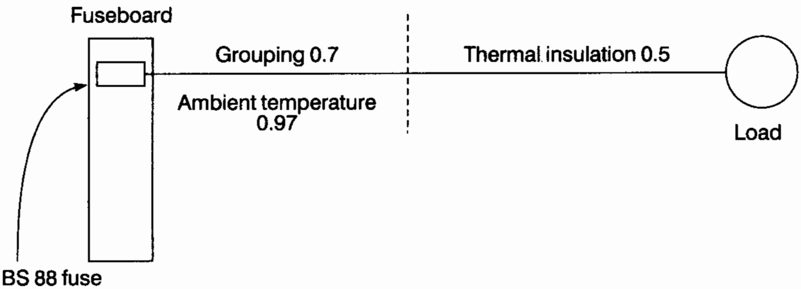


Figure 8

must be used, but there is no need to apply all of the remaining factors as the worst one will automatically compensate for the others. The relevant factors are shown in Figure 7(b) and apply only if C_f = 0.725 and C_i = 0.5. If protection was *not* by BS3036 fuse, then apply only C_i = 0.5.

3 In Figure 8 a combination of cases 1 and 2 is considered. The effect of grouping and ambient temperature is $0.7 \times 0.97 = 0.679$. The factor for thermal insulation is still worse than this combination, and therefore C_i is the only one to be used.

Tabulated conductor current carrying capacity I_t

$$I_t \geqslant \frac{I_n}{C_a \times C_g \times C_f \times C_i}$$

Remember, only the relevant factors are to be used!

As we have seen when discussing overload protection, the Regulations permit the omission of such protection in certain circumstances (473–01–04), in these circumstances, I_n is replaced by I_b and the formula becomes:

$$I_t \geqslant \frac{I_b}{C_a \times C_g \times C_i}$$

Selection of suitable conductor size

During the early stages of the design, the external influences will have been considered, and a method of circuit installation chosen. Appendix 4, IEE Regulations Table 4A1 gives examples of installation methods, and it is important to select the appropriate method in the current rating tables. For example, from IEE Regulations Table 4D2A the tabulated current ratings I_t for reference method 3 are less than those for method 1. Having selected the correct cable rating table and relevant reference method, the conductor size is determined to correspond with $I_t \geqslant$ the corrected value of I_n or I_b as is the case.

Voltage drop

In many instances this may well be the most onerous condition to affect cables sizes. The Regulations require that the voltage at the terminals of fixed equipment should be greater than the lower limit permitted by the British Standard for that equipment, or in the absence of a British Standard, that the safe functioning of the equipment should not be impaired. These requirements are fulfilled if the voltage drop between the origin of the installation and the equipment does not exceed 4% of the supply voltage. This means a permitted drop of 9.2 V for a single-phase 230 V supply and 16 V for a 400 V three-phase supply.

Accompanying the cable current rating tables are tabulated values of voltage drop based on the milli-volts (mV) dropped for every ampere of design current (A), for every metre of conductor length (m), i.e.

$$\text{Volt drop} = \text{mV/A/m}$$

or fully translated with I_b for A and L (length in metres):

$$\text{Volt drop} = \frac{\text{mV} \times I_b \times \text{length voltss}}{1000}$$

For conductor sizes in excess of 16 mm^2 the impedance values of volt drop (columns headed z) should be used. The columns headed r and x indicate the resistive and reactive components of the impedance values.

Evaluation of shock risk

This topic has been discussed earlier, suffice to say that the calculated value of loop impedance should not exceed the tabulated value quoted for the protective device in question.

Evaluation of thermal constraints

As we know, the 'let-through' energy of a protective device under fault conditions can be considerable and it is therefore necessary to ensure that the CPC is large enough either by satisfying the requirements of IEE Regulations Table 54G or by comparing its size with the minimum derived from the formula:

$$s = \frac{\sqrt{I^2 t}}{k}$$

where: s = minimum csa of the CPC
I = fault current
t = disconnection time in seconds
k = factor taken from IEE Regulations Tables 54B to 54F

The following examples illustrate how this design procedure is put into practice.

EXAMPLE 2

A consumer has asked to have installed a new 9 kW/230 V shower unit in a domestic premises. The existing eight-way consumer unit houses BS3871 MCBs and supplies two ring final circuits, one cooker circuit, one immersion heater circuit and two lighting circuits, leaving two spare ways. The earthing system is TN–C–S with a measured value of Z_e of 0.18 ohms, and the length of the run from consumer unit to shower is approximately 28 m. The installation reference method is method 1, and the ambient temperature will not exceed 30°C. If flat twin cable with CPC is to be used, calculate the minimum cable size.

1 Assessment of general characteristics

In this case, the major concern is the maximum demand. It will need to be ascertained whether or not the increased load can be accommodated by the consumer unit and the supplier's equipment.

2 Design current I_b (based on rated values)

$$I_b = \frac{P}{V} = \frac{9000}{230} = 39\ \text{A}$$

3 Choice and setting of protection

The type of MCB most commonly found in domestic installations over 10 years old is a Type 2, and the nearest European standard to this is a Type B. So from IEE Regulations Table 41B2, the protection would be a 40 A Type B MCB with a corresponding maximum value of loop impedance Z_e of 1.2 Ω.

4 Tabulated conductor current carrying capacity I_t

As a shower is unlikely to cause an overload, I_b may be used instead of I_n.

$$I_t \geqslant \frac{I_b}{C_a \times C_g \times C_f \times C_i}$$

but as there are no correction factors,

$$I_t \geqslant I_b \qquad I_t \geqslant 39$$

5 Selection of conductor size

As the cable is to be PVC Twin with CPC, the conductor size will be selected from IEE Regulations Table 4D2A column 6. Hence I_t will be 46 A and the conductor size 6.0 mm^2.

6 Voltage drop

From IEE Regulations Table 4D2B column 3, the mV drop is 7.3, so:

$$\text{Volt drop} = \frac{\text{mV} \times I_b \times L}{1000}$$

$$= \frac{7.3 \times 39 \times 28}{1000} = 7.96\,\text{V (acceptable)}$$

7 Evaluation for shock risk

The phase conductor of the circuit has been calculated as 6.0 mm^2, and a twin cable of this size has a 2.5 mm^2 CPC. So, using the tabulated values of R_1 and R_2 given in tabulated values of resistance at the end of this book, 28 m of cable would have a resistance under operating conditions of:

$$\frac{28 \times (3.08 + 7.41) \times 1.2}{1000} = 0.35\,\Omega$$

(1.2 = multiplier for 70°C conductor operating temperature) and as Z_e is 0.18 Ω, then:

$$\begin{aligned} Z_s &= Z_e + R_1 + R_2 \\ &= 0.18 + 0.35 \\ &= 0.53\,\Omega \end{aligned}$$

Which is clearly less than the maximum value of 1.2 Ω.

8 Evaluation of thermal constraints

Fault current I is found from:

$$I = \frac{U_{oc}}{Z_s}$$

Where: U_{oc} = open circuit voltage at supply transformer
Z_s = calculated value of loop impedance

$$I = \frac{240}{0.53} = 453\,\text{A}$$

t for 450 A from IEE Regulations curves, Figure 3.4 for a 40 A CB is less than 0.1 sec. k from IEE Regulations Table 54C is 115.

$$s = \frac{\sqrt{I^2 t}}{k} = \frac{\sqrt{453^2 \times 0.1}}{115} = 1.24\,\text{mm}^2$$

Which means that the 2.5 mm^2 CPC is perfectly adequate. It does not mean that a 1.24 mm^2 CPC could be used.

Hence, provided the extra demand can be accommodated, the new shower can be wired in 6.0 mm^2 flat twin cable with a 2.5 mm^2 CPC and protected by a 40 A Type B CB.

EXAMPLE 3

Four industrial single-phase fan assisted process heaters are to be installed adjacent to each other in a factory. Each one is rated at 50 A/230 V. The furthest heater is some 32 m from a distribution board, housing BS88 fuses, located at the intake position. It has been decided to supply the heaters with PVC singles in steel trunking (reference method 3), and part of the run will be through an area where the ambient temperature may reach 35°C. The earthing system is TN–S with a measured Z_e of 0.3 Ω. There is spare capacity in the distribution board, and the maximum demand will not be exceeded. Calculate the minimum size of live conductors and CPC.

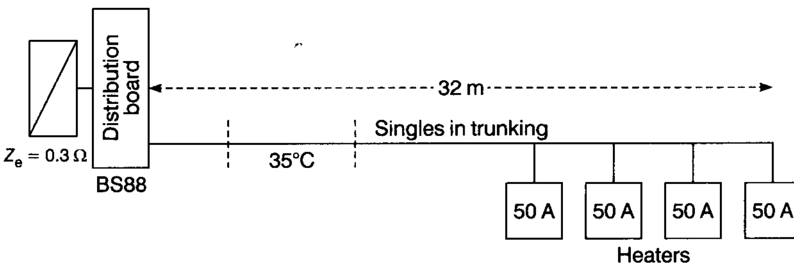
Calculations will be based on the furthest heater. Also, only one common CPC need be used (IEE Regulations 543–01–02(1)).

Design current I_b

$$I_b = 50\,\text{A}$$

Type and setting of protection I_n

$I_n \geqslant I_b$ so, from IEE Regulations Table 41D, a BS 88 50 A fuse would be used with a corresponding value of Z_s of 1.09 Ω.



Correction factors

As the circuits will be grouped and, for part of the run, in a high ambient temperature, both C_a and C_g will need to be used.

C_a for 35°C	0.94 (Table 4C1)
C_g for four circuits	0.65 (Table 4B1)

Tabulated current carrying capacity I_t

As the heaters are fan assisted, they are susceptible to overload, hence I_n is used.

$$I_t \geqslant \frac{I_n}{C_a \times C_g}$$

$$\geqslant \frac{50}{0.94 \times 0.65}$$

$$\geqslant 82\,\text{A}$$

Selection of conductor size

From IEE Regulations Table 4D1A column 4, I_t = 101 A, and the conductor size is $25.00\,mm^2$.

Voltage drop

From IEE Regulations Table 4D1B, the mV drop for $25.0\,mm^2$ is 1.8 mV.

$$\text{Volt drop} = \frac{1.8 \times 50 \times 32}{1000} = 2.88\,\text{V (acceptable)}$$

Evaluation of shock risk

In this case, as the conductors are singles, a CPC size has to be chosen either from IEE Regulations Table 54G, or by calculation. The former method will produce a size of $16\,mm^2$, whereas calculation tends to produce considerably smaller sizes. The calculation involves the rearrangement of the formula:

$$Z_s = Z_e + \frac{(R_1 + R_2) \times L \times 1.2}{1000}$$

to find the maximum value of R_2 and selecting a CPC size to suit. The value of Z_s used will be the tabulated maximum which in this case is $1.09\,\Omega$. The rearranged formula is:

$$R_2 = \left[\frac{(Z_s - Z_e) \times 1000}{L \times 1.2}\right] - R_1$$

$$= \left[\frac{(1.09 - 0.3) \times 1000}{32 \times 1.2}\right] - 0.727$$

$$= 19.84\,m\Omega$$

The nearest value to this maximum is 18.1 mΩ giving a CPC size of 1.0 mm^2. This will satisfy the shock risk requirements, but we will still have to know the actual value of Z_s, so:

$$Z_s = 0.3 + \frac{(0.727 + 18.1) \times 1.2 \times 32}{1000}$$

$$= 1.0\,\Omega$$

Evaluation of thermal constraints

$$\text{Fault current } I = \frac{U_{oc}}{Z_s} = \frac{240}{1} = 240\,\text{A}$$

t from 50 A BS88 curve = 3 s
k = 115 (IEE Regulations Table 54C)

$$s = \frac{\sqrt{I^2 t}}{k}$$

$$= \frac{\sqrt{240^2 \times 3}}{115}$$

$$= 3.6\,\text{mm}^2$$

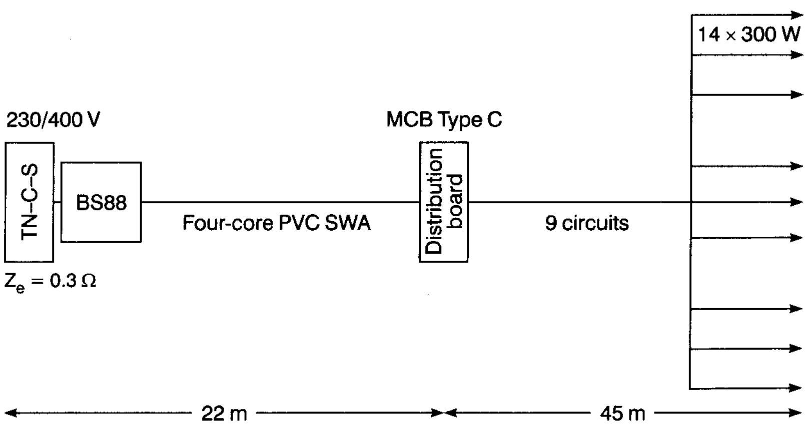
Hence, our 1.0 mm^2 CPC is too small to satisfy the thermal constraints, and hence a 4.0 mm^2 CPC would have to be used. So the heaters would be supplied using 25 mm^2 live conductors, a 4.0 mm CPC and 50 A BS88 protection.

EXAMPLE 4

Part of the lighting installation in a new warehouse is to comprise a sub-main supply to a three-phase lighting distribution board from which nine single-phase final circuits are to be fed. The sub-main, protected by BS88 fuses, is to be four-core PVC SWA cable and is

22 m long. The armouring will provide the function of the CPC. The distribution board will house BS EN 60898 Type C CBs, and each final circuit is to supply fourteen 300 W discharge luminaires. The longest run is 45 m, and the wiring system will be singles in trunking, the first few metres of which will house all nine final circuits. The earthing system is TN-C-S and the value of Z_e calculated to be 0.2 Ω. The ambient temperature will not exceed 30°C.

Determine all relevant cable/conductor sizes



Design current of each final circuit I_b

As each row comprises fourteen 300 W/230 V discharge fittings:

$$I_b = \frac{14 \times 300 \times 1.8}{230}$$ (The 1.8 is the multiplier for discharge lamps)

$$= 32.8\,\text{A}$$

As the nine circuits will be balanced over three phases, each phase will feed three rows of fittings.

I_b per phase $= 3 \times 32.8 = 98.4\,\text{A}$

Sub-main design current I_b

Sub-main I_b per phase = 98.4 A

Nominal rating of protection I_n

$I_n \geqslant I_b$ so, from IEE Regulations Table 41D the protection will be 100 A with a maximum loop impedance Z_s of 0.44 Ω.

Correction factors

Not applicable.

Tabulated current carrying capacity I_t

Discharge units do cause short duration overloads at start-up, so it is perhaps best to use I_n rather than I_b.

$$I_t \geqslant I_n$$
$$\geqslant 100\,\text{A}$$

Cable selection

From IEE Regulations Table 4D4A column 3, I_t = 102 A, giving a cable size of 25 mm^2.

Voltage drop

From IEE Regulations Table 4D4B column 4, the mV drop is 1.5.

$$\text{Volt drop} = \frac{1.5 \times 98.4 \times 22}{1000} = 3.23\,\text{V (acceptable)}$$

This is the three-phase drop, the single phase being:

$$\frac{3.23}{\sqrt{3}} = 1.87\,\text{V}$$

Evaluation of shock risk

Cable manufacturer's information shows that the resistance of the armouring on a 25 mm^2 four-core cable is 2.1 mΩ/m. Hence, $R_1 = 0.727\,\text{m}\Omega$, and $R_2 = 2.1\,\text{m}\Omega$.

$$Z_s = 0.2 + \frac{(0.727 + 2.1) \times 22 \times 1.2}{1000} = 0.274\,\Omega$$

Clearly ok, as Z_s maximum is 0.44 Ω.

Thermal constraints

$$I = \frac{U_{OC}}{Z_s} = \frac{240}{0.274} = 875\text{ A}$$

$t = 0.6$ (from BS88 curve for 100 A)

$k = 51$ (IEE Regulations Table 54D)

$$s = \frac{\sqrt{875^2 \times 0.6}}{51} = 13.3\,\text{mm}^2$$

Manufacturer's information gives the gross csa of 25 mm^2 four-core SWA cable as 76 mm^2. Hence the armouring provides a good CPC.

If we had chosen to use IEE Regulations Table 54G to determine the minimum size it would have resulted in:

$$s = \frac{16 \times k_1}{k_2} = \frac{16 \times 115}{51} = 36\,\text{mm}^2$$

which still results in a smaller size than will exist.

Final circuits design current I_b

$I_b = 32.8$ A (calculated previously)

Setting of protection I_n

From IEE Regulations Table 41B2 (h) $I_n \geqslant I_b = 40\,\text{A}$ with a corresponding value for Z_s of $0.6\,\Omega$.

Correction factors

Only grouping needs to be considered:

C_g for nine circuits = 0.5 (IEE Regulations Table 4B1)

Tabulated current carrying capacity I_t

$$I_t \geqslant \frac{I_n}{C_g} \geqslant \frac{40}{0.5} \geqslant 80\,\text{A}$$

Cable selection

From IEE Regulations Table 4D1A $I_t \geqslant 80\,\text{A} = 101\,\text{A}$ and conductor size will be $16\,\text{mm}^2$.

Voltage drop

The assumption that the whole of the design current of 32.8 A will flow in the circuit would be incorrect, as the last section will only draw:

$$\frac{32.8}{14} = 2.34\ \text{A}$$

the section previous to that 4.68 A, the one before that 7.02 A and so on, the total volt drop being the sum of all the individual volt drops. However, this is a lengthy process and for simplicity the volt drop in this case will be based on 32.8 A over the whole length.

From IEE Regulations Table 4D1B column 3, the mV drop for a $25\,\text{mm}^2$ conductor is 2.8 mV.

$$\text{Volt drop} = \frac{1.8 \times 32.8 \times 45}{1000} = 2.6\,\text{V}$$

Add this to the sub-main single-phase drop, and the total will be:

$$1.87 + 2.6 = 4.47\,\text{V (acceptable)}$$

Shock risk constraints

$$Z_s = Z_c + \frac{(R_1 + R_2) \times L \times 1.2}{1000}$$

In this case Z_e will be the Z_s value for the sub-main.

Rearranging as before, to establish a minimum CPC size, we get:

$$R_2 = \left[\frac{(Z_s - Z_e) \times 1000}{\text{length} \times 1.2}\right] - R_2 \text{ (for } 25\,\text{mm}^2\text{)}$$

$$= \frac{(0.6 - 0.262) \times 1000}{45 \times 1.2} - 0.727$$

$$= 5.53\,\text{m}\Omega$$

Therefore, the nearest value below this gives a size of $4.0\,\text{mm}^2$:

$$\text{Actual } Z_s = 0.262 + \frac{(0.727 + 4.61)}{1000} \times 45 \times 1.2$$

$$= 0.55\,\Omega \text{ (less than the maximum of } 0.75\,\Omega\text{)}$$

Thermal constraints

$$I = \frac{U_{OC}}{Z_s} = \frac{240}{0.55} = 436\,\text{A}$$

t from Type C CB curve for 32 A = is less than 0.1 s
k = 115 (IEE Regulations Table 54C)

$$s = \frac{\sqrt{436^2 \times 0.1}}{115} = 1.19\,\text{mm}$$

Hence our $4.0\,\text{mm}^2$ CPC is adequate.

So, the calculated cable design details are as follows:

Sub-main protection	100 A BS88 fuses
Sub-main cable	25 mm^2 four-core SWA with armour as the CPC
Final circuit protection	32 A Type C, BS EN 60898 MCB
Final circuit cable	25 mm^2 singles with 4.0 mm^2 CPC

Conduit and trunking sizes

Part of the design procedure is to select the correct size of conduit or trunking. The basic requirement is that the space factor is not exceeded and in the case of conduit, that cables can be easily drawn in without damage.

For conduit, the requirement is that the space occupied by conductors should not exceed 40% of the internal conduit area. For trunking, the figure is 45%. The IEE Regulations Guidance Notes/ On-Site-Guide give a series of tables which enable the designer to select appropriate sizes by the application of conductor/conduit/ trunking terms. This is best illustrated by the following examples.

EXAMPLE 5

What size straight 2.5 m long conduit would be needed to accommodate ten 2.5 mm^2 and 5 1.5 mm^2 stranded conductors?

Tabulated cable term for 1.5 mm^2 stranded = 31
Tabulated cable term for 2.5 mm^2 stranded = 43

$$31 \times 5 = 155$$
$$43 \times 10 = \underline{430}$$
$$\text{Total} = \overline{\overline{585}}$$

The corresponding conduit term must be equal to or greater than the total cable term. Hence the nearest conduit term to 585 is 800 which gives a conduit size of 25 mm^2.

EXAMPLE 6

How many 4.0 mm^2 stranded conductors may be installed in a straight 3 m run of 25 mm conduit?

Tabulated conduit term for 25 mm^2 = 800
Tabulated cable term for 4.0 mm^2 = 58

$$\text{Number of cables} = \frac{800}{58} = 13.79$$

Hence thirteen 4.0 mm conductors may be installed.

EXAMPLE 7

What size conduit 6 m long and incorporating two bends would be needed to house eight 6.0 mm^2 conductors?

Tabulated cable term for 6.0 mm^2 = 58
Overall cable term = 58 × 8 = 464

Nearest conduit term above this is 600, giving 32 mm^2 conduit.

EXAMPLE 8

What size trunking would be needed to accommodate twenty-eight 10 mm^2 conductors?

Tabulated cable term for 10 mm^2	36.3
Overall cable term	36.3 × 28 = 1016.4

Nearest trunking term above this is 1037, giving 50 mm × 50 mm trunking.

EXAMPLE 9

What size of trunking would be required to house the following conductors:

20–1.5 mm^2 stranded
35–2.5 mm^2 stranded
28–4.0 mm^2 stranded

Tabulated cable term for $1.5\,mm^2$ = 8.1
Tabulated cable term for $2.5\,mm^2$ = 11.4
Tabulated cable term for $4.0\,mm^2$ = 15.2

$$
\begin{aligned}
\text{Hence}\quad 8.1 \times 20 &= 162 \\
11.4 \times 35 &= 399 \\
15.2 \times 28 &= \underline{425.6} \\
\text{Total} &= 986.6
\end{aligned}
$$

The nearest trunking term is 993 giving 100 mm × 225 mm trunking, but it is more likely that the more common 50 mm × 250 mm would be chosen.

Note

It is often desirable to make allowance for future additions to trunking systems, but care must be taken to ensure that extra circuits do not cause a change of grouping factor which could then de-rate the existing conductors below their original designed size.

Drawings

Having designed the installation it will be necessary to record the design details either in the form of a schedule for small installations or on drawings for the more complex installation. These drawings may be of the block, interconnection, layout, etc., type. The following figures indicate some typical drawings.

Note the details of the design calculations shown on Figure 11, all of which is essential information for the testing and inspection procedure.

With the larger types of installation, an alphanumeric system is very useful for cross reference between block diagrams and floor plans showing architectural symbols. Figure 12 shows such a system.

Distribution board 3 (DB3) under the stairs would have appeared on a diagram such as Figure 10, with its final circuits indicated. The floor plan shows which circuits are fed from DB3, and the number and phase colour of the protection. For example,

Figure 9
Layout of industrial installation

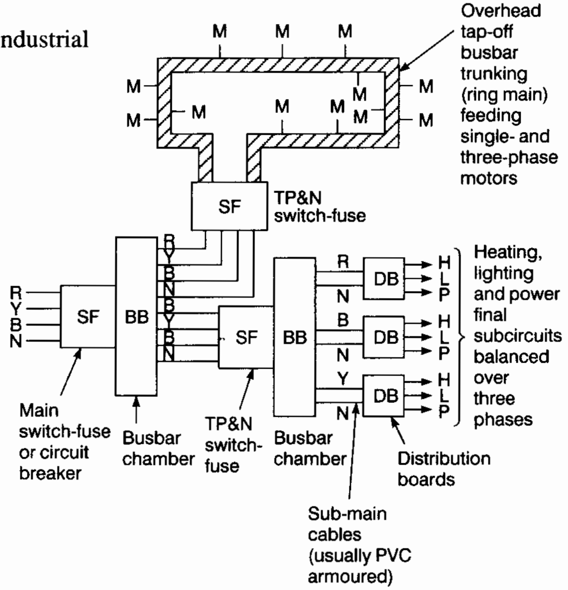
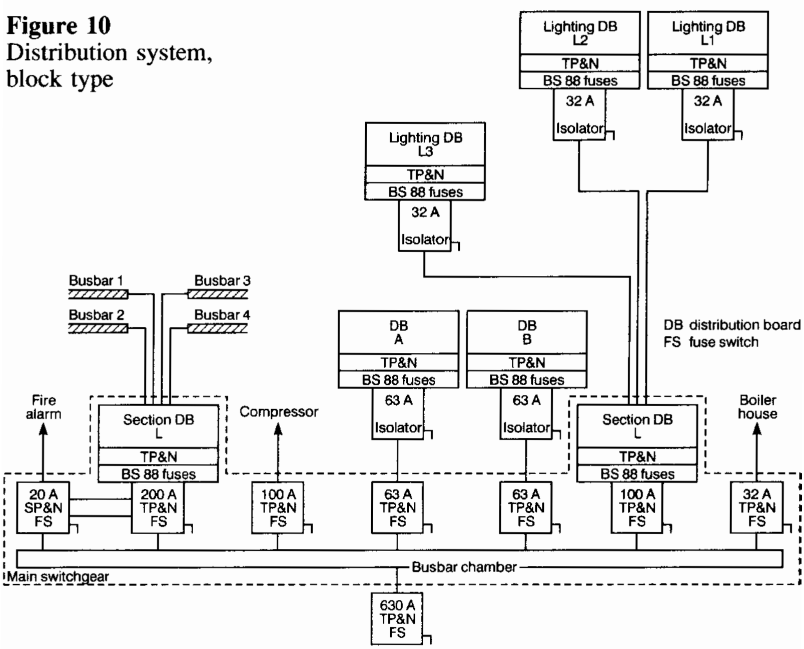


Figure 10
Distribution system, block type



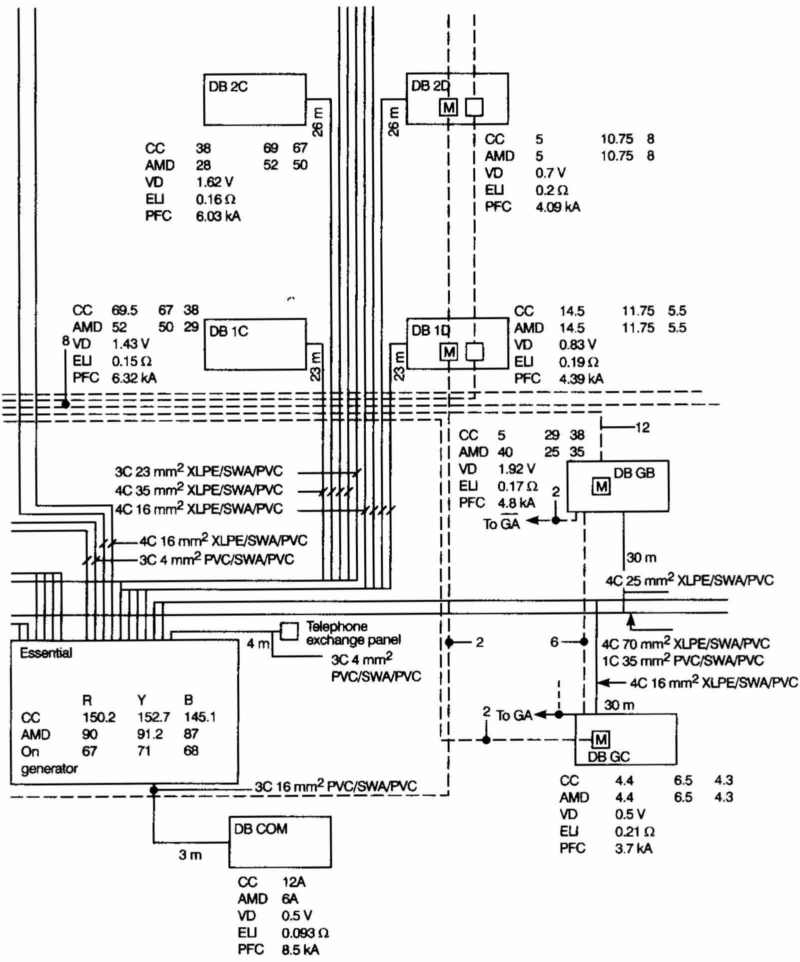


Figure 11 Distribution system, interconnection type

CC = Circuit current
AMD = Assumed maximum demand
VD = Volt drop
ELI = Earth loop impedance
PFC = Prospective fault or short-circuit current

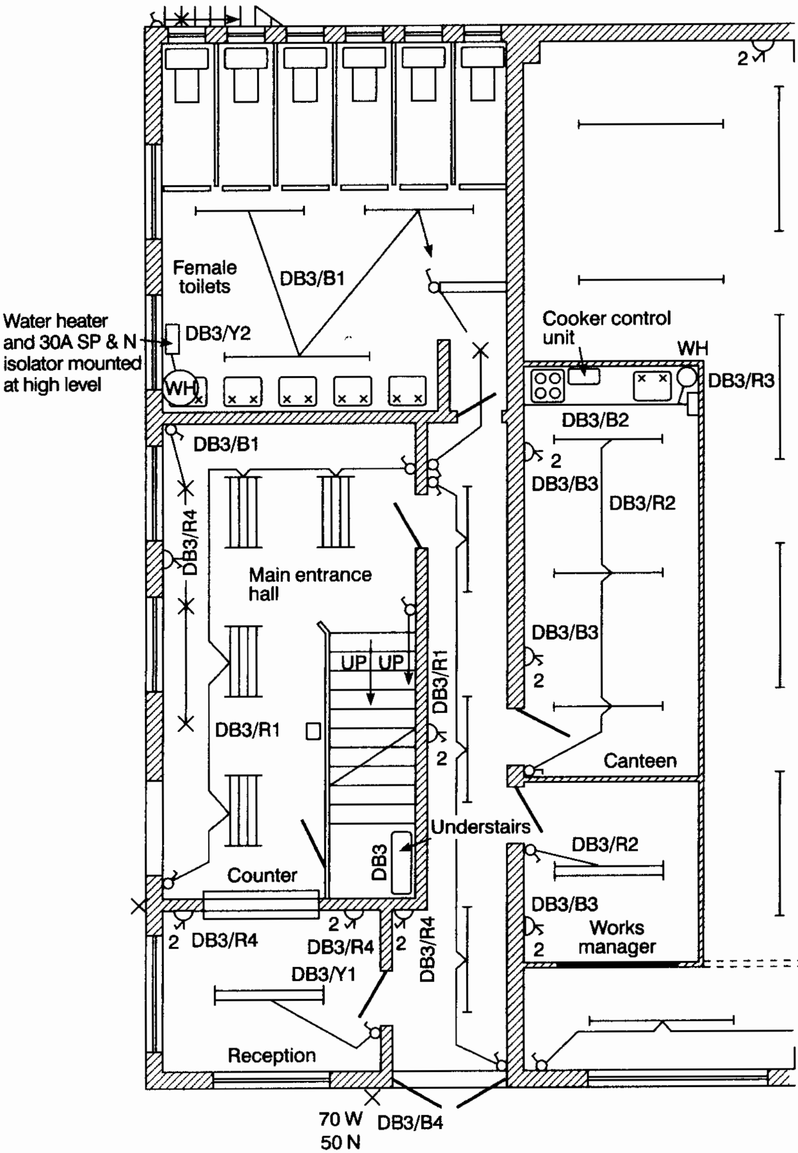


Figure 12 Example floor plan

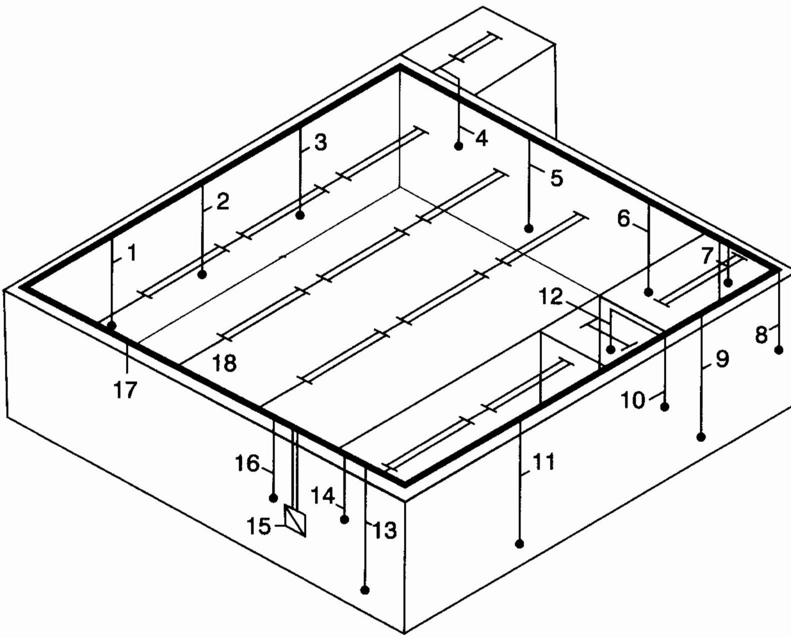


Figure 13 Isometric drawing for garage/workshop

1 Three-phase supply to ramp: 20 mm^2 conduit
2 Single-phase supply to double sockets: 20 mm^2 conduit. Also 3, 5, 6, 9, 11, 13
4 Single-phase supply to light switch in store: 20 mm^2 conduit
7 Single-phase supply to light switch in compressor: 20 mm^2 conduit
8 Three-phase supply to compressor: 20 mm^2 conduit
10 Single-phase supply to heater in WC: 20 mm^2 conduit
12 Single-phase supply to light switch in WC: 20 mm^2 conduit
14 Single-phase supply to light switch in office: 20 mm^2 conduit
15 Main intake position
16 Single-phase supplies to switches for workshop lights: 20 mm^2 conduit
17 50 mm × 50 mm steel trunking
18 Supplies to fluorescent fittings: 20 mm^2 conduit

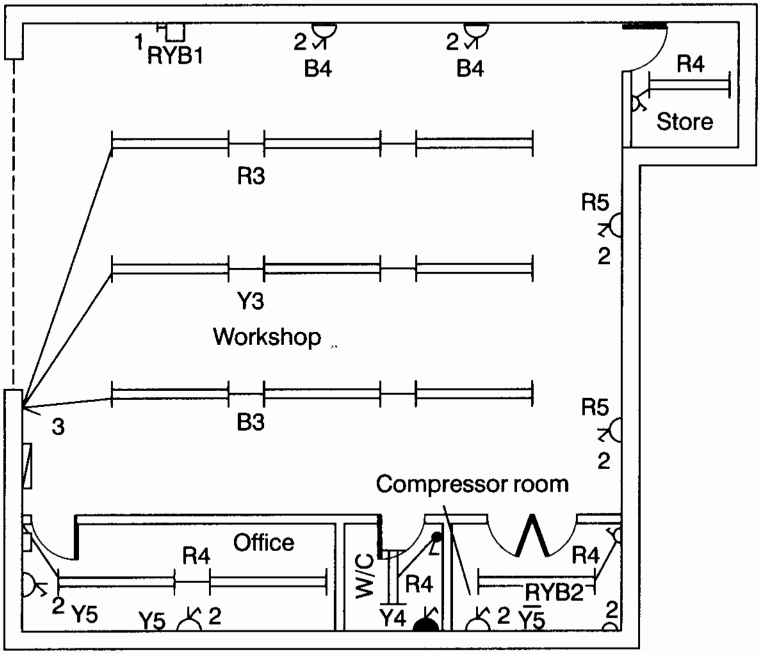


Figure 14 Floor plan for garage/workshop

the fluorescent lighting in the main entrance hall is fed from fuse or MCB 1 on the red phase of DB3, and is therefore marked DB3/R1. Similarly, the water heater circuit in the female toilets is fed from fuse or MCB 2 on the yellow phase, i.e. DB3/Y2.

Figures 13, 14, and 15 illustrate a simple but complete scheme for a small garage/workshop. Figure 13 is an isometric drawing of the garage and the installation, from which direct measurements for materials may be taken. Figure 14 is the associated floor plan, which cross-references with the DB schedule and interconnection details shown on Figure 15.

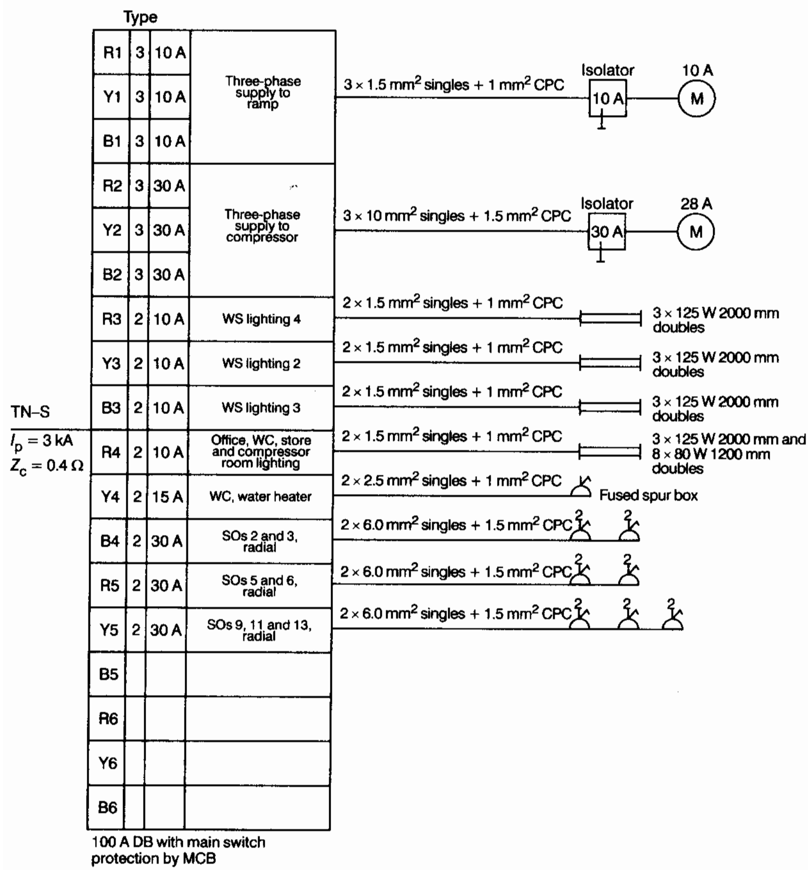


Figure 15 Details of connection diagram for garage/workshop

2
INSPECTION AND TESTING

This is the subject of Part 7 of the IEE Regulations, and opens with the statement to the effect that it must be verified that *all* installations, before being put into service, comply with the Regulations, i.e. BS 7671. The author interprets the comment 'before being put into service by the user' as before being handed over to the user, not, before the supply is connected. Clearly a supply is needed to conduct some of the tests.

The opening statement also indicates that verification of compliance be carried out during the erection of the installation and after it has been completed. In any event, certain criteria must be observed.

1 The test procedure must not endanger persons, livestock or property.
2 Before any inspection and testing can even start, the person carrying out the verification must be in possession of all the relevant information and documentation. In fact the installation will fail to comply without such information (IEE Regulations 712–01–03 xvii). How, for example, can a verifier accept that the correct size conductors have been installed, without design details (IEE Regulations 712–01–03 iv)?

So, let us start, as they say, at the beginning. Armed with the results of the Assessment of General Characteristics, the designer's details, drawings, charts, etc., together with test instruments, the verification process may proceed.

Inspection

Usually referred to as a visual inspection, this part of the procedure is carried out against a check list as detailed in the IEE Regulations, section 712 (Appendix 6), and in the Guidance Notes 3 for inspection and testing. Much of the initial inspection will involve access to enclosures housing live parts, hence, those parts of the installation being tested should be isolated from the supply.

Naturally, any defects found must be rectified before instrument tests are performed.

Testing

This involves the use of test equipment and there are several important points to be made in this respect.

1 Electronic instruments must conform to BS4743 and electrical instruments to BS5458.
2 The Electricity at Work Regulations 1989 state an *absolute* requirement in Regulation 4(4), that test equipment be maintained in good condition. Hence it is important to ensure that regular calibration is carried out.
3 Test leads should have shrouded/recessed ends and/or when one end is a probe, it should be insulated to within 2 mm of the tip and have finger guards.
4 Test lamps should be of the approved type.

Selection of test equipment

As has been mentioned, instruments must comply with the relevant British Standard, and provided they are purchased from established bona fide instrument manufacturers, this does not present a

Chart 6

Test	*Range*	*Type of instrument*
1 Continuity of ring final conductors	0.05 to 0.8 Ω	Low resistance ohmmeter
2 Continuity of protective conductors	2 to 0.005 Ω or less	Low resistance ohmmeter
3 Earth electrode resistance	Any value over about 3 to 4 Ω	Special ohmmeter
4 Insulation resistance	Infinity to less than 1 mΩ	High resistance ohmmeter
5 Polarity	None	Ohmmeter, bell, etc.
6 Earth fault loop impedance	0 to 2000 Ω	Special ohmmeter
7 Operation of RCD	5 to 500 mA	Special instrument
8 Prospective short-circuit current	2 A to 20 kA	Special instrument

problem. There is a range of instruments needed to carry out all the standard installation tests, and some manufacturers produce equipment with dual functions, indeed there are now single instruments capable of performing all the fundamental tests.

Chart 6 indicates the basic tests and the instruments required.

Approved test lamps and indicators

Search your tool boxes: find, with little difficulty one would suspect, your 'neon screwdriver' or 'testascope'; locate a very deep pond; and drop it in!

Imagine actually allowing electric current at low voltage (50 to 1000 V ac) to pass through one's body in order to activate a test lamp! It only takes around 10 to 15 mA to cause severe electric shock, and 50 mA (1/20th of an ampere) to kill.

Apart from the fact that such a device will register any voltage from about 5 V upwards, the safety of the user depends entirely on the integrity of the current limiting resistor in the unit. An electrician received a considerable shock when using such an instrument after his apprentice had dropped it in a sink of water, simply wiped it dry and replaced it in the tool box. The water had seeped into the device and shorted out the resistor.

An approved test lamp should be of similar construction to that shown in Figure 16.

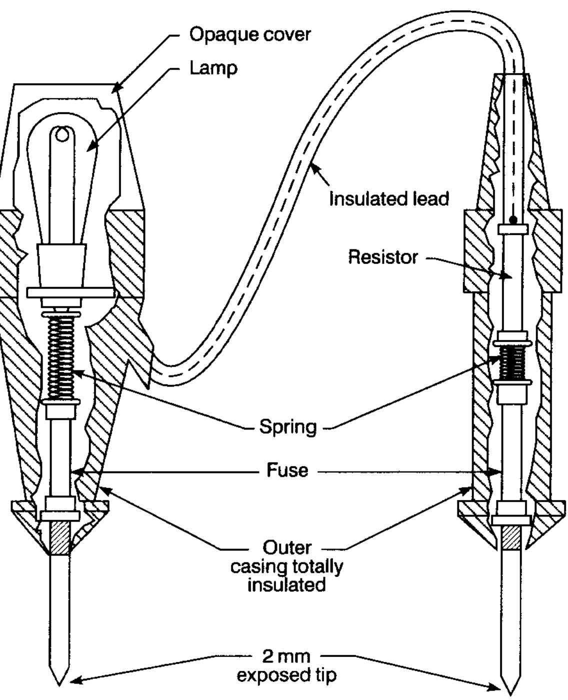


Figure 16 Approved test lamp

The following procedure is recommended when using approved test lamps to check that live parts have been made dead:

1 Check that the test lamp is in good condition and the leads are undamaged. (This should be done regardless of the purpose of use.)
2 Establish that the lamp is sound by probing onto a known supply. This is best achieved by using a proving unit. This is simply a pocket-sized device which electronically produces 230 V dc.
3 Carry out the test to verify the circuit is dead.
4 Return to the proving unit and check the lamp again.

It has long been the practice when using a test lamp to probe between phase and earth for an indication of a live supply on the phase terminal. However, this can now present a problem where RCDs exist in the circuit, as of course the test is applying a deliberate phase-to-earth fault.

Some test lamps have LED indicators, and the internal circuitry of such test lamps limits the current to earth to a level below that at which the RCD will operate. The same limiting effect applies to multimeters. However, it is always best to check that the testing device will have no effect on RCDs.

Calibration, zeroing and care of instruments

Precise calibration of instruments is usually well outside the province of the electrician, and would normally be carried out by the manufacturer or local service representative. A check, however, can be made by the user to determine whether calibration is necessary by comparing readings with an instrument known to be accurate, or by measurement of known values of voltage, resistance, etc. However, as we have already seen, regular calibration is a legal requirement.

It may be the case that readings are incorrect simply because the instrument is not zeroed before use, or because the internal battery needs replacing. Most modern instruments have battery condition indication, and of course this should never be ignored.

Always adjust any selection switches to the off position after testing. Too many instrument fuses are blown when, for example, a multimeter is inadvertently left on the ohms range and then used to check for mains voltage.

The following set procedure may seem rather basic but should ensure trouble-free testing:

1 Check test leads for obvious defects.
2 Zero the instrument.
3 Select the correct range for the values anticipated. If in doubt, choose the highest range and gradually drop down.
4 Make a record of the test results.
5 When a no reading is expected and occurs (or, in the case of insulation resistance, an infinite reading), make a quick check on the test leads just to ensure that they are not open circuited.
6 Return switches/selectors to the off position.
7 Replace instrument and leads in carrying case.

The tests

The IEE Regulations indicate a preferred sequence of tests and state that if, due to a defect, compliance cannot be achieved, the defect should be rectified and the test sequence started from the beginning. The tests for 'Site applied insulation', 'Protection by separation', and 'Insulation of non-conducting floors and walls' all require specialist high voltage equipment and in consequence will not be discussed here. The sequence of tests for an initial inspection and test is as follows:

1 Continuity of protective conductors
2 Continuity of ring final circuit conductors
3 Insulation resistance
4 Protection against direct contact by barriers or enclosures
5 Polarity
6 Earth electrode resistance
7 Earth fault loop impedance
8 Prospective fault current.
9 Functional testing.

One other test not included in Part 7 of the IEE Regulations but which nevertheless has to be carried out, is external earth fault loop impedance.

Continuity of protective conductors

These include the CPCs of radial circuits, main and supplementary bonding conductors. Two methods are available, either can be used for CPCs, but bonding can only be tested by the second.

Method 1

At the distribution board, join together the phase conductor and its associated CPC. Using a low resistance ohmmeter, test between phase and CPC at all the outlets in the circuit. The reading at the farthest point will be $(R_1 + R_2)$ for that circuit. Record this value, as after correction for temperature, it may be compared with the designer's value (more about this later).

Method 2

Connect one test instrument lead to the main earthing terminal, and a long test lead to the earth connection at all the outlets in the circuit. Record the value after deducting the lead resistance. An idea of the length of conductor is valuable, as the resistance can be calculated and compared with the test reading. Table 2 gives resistance values already calculated for a range of lengths and sizes.

It should be noted that these tests are applicable only to 'all insulated' systems, as installations using conduit, trunking, MICC and SWA cables will produce spurious values due to the probable parallel paths in existence. This is an example of when testing needs to be carried out during the erection process before final connections and bonding are in place.

If conduit, trunking or SWA is used as the CPC, then the verifier has the option of first inspecting the CPC along its length for soundness then conducting the long-lead resistance test. If the inspector is not happy with the result, he would carry

Table 2 Resistance (Ω) of copper conductors at 20°C

csa	*Length (metres)*									
(mm^2)	5	10	15	20	25	30	35	40	45	50
1.0	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.82	0.90
1.5	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.55	0.61
2.5	0.04	0.07	0.11	0.15	0.19	0.22	0.26	0.30	0.33	0.37
4.0	0.023	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.21	0.23
6.0	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.13	0.14	0.16
10.0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
16.0	0.006	0.01	0.02	0.023	0.03	0.034	0.04	0.05	0.051	0.06
25.0	0.004	0.007	0.01	0.015	0.02	0.022	0.026	0.03	0.033	0.04
35.0	0.003	0.005	0.008	0.01	0.013	0.016	0.019	0.02	0.024	0.03

out a high current test using a proprietary instrument that delivers a test current of 1.5 times the design current up to 25 A at a voltage of 50 V.

Continuity of ring final circuit conductors

The requirement of this test is that each conductor of the ring is continuous. It is, however, not sufficient to simply connect an ohmmeter, a bell, etc., to the ends of each conductor and obtain a reading or a sound.

So what is wrong with this procedure? A problem arises if an interconnection exists between sockets on the ring, and there is a break in the ring beyond that interconnection. From Figure 17 it will be seen that a simple resistance or bell test will indicate continuity via the interconnection. However, owing to the break, sockets 4 to 11 are supplied by the spur from socket 12 – not a healthy situation. So how can one test to identify interconnections?

There are at present three methods of conducting such a test. Two are based on the principle that resistance changes with a change in length or csa; the other relies on the fact that the resistance measured across any diameter of a circular loop of conductor is the same. Let us now consider the first two.

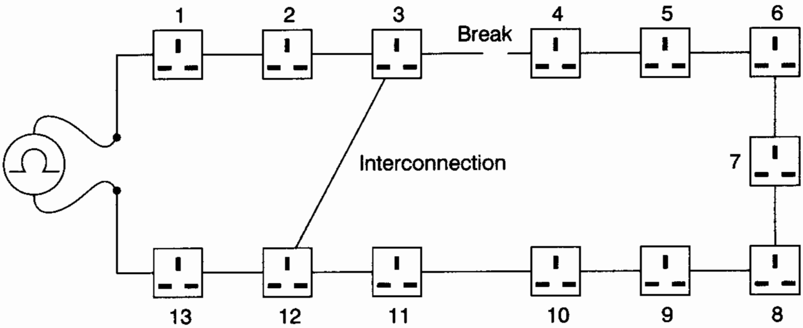


Figure 17 Ring circuit with interconnection

Method 1

If we were to take a length of conductor XYZ and measure the resistance between its ends (Figure 18), then double it over at Y, join X and Z, and measure the resistance between XZ and Y (Figure 19), we would find that the value was approximately a quarter of the original. This is because the length of the conductor is halved and hence so is the resistance, and the csa is doubled and so the resistance is halved again.

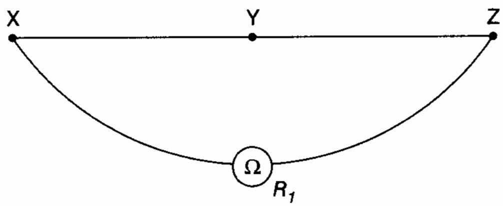


Figure 18

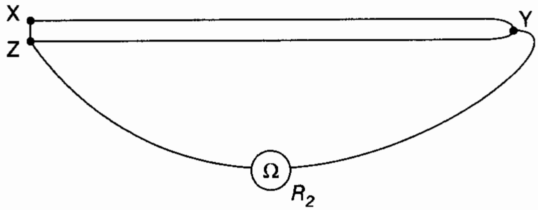


Figure 19

In order to apply this principle to a ring final circuit, it is necessary to know the position of the socket nearest the mid-point of the ring. The test procedure is then as follows for each of the conductors of the ring:

1 Measure the resistance of the ring conductor under test between its ends before completing the ring in the fuse board. Record this value, say R_1.
2 Complete the ring.
3 Using long test leads, measure between the completed ends and the corresponding terminal at the socket nearest the mid-point of the ring. Record this value, say R_2. (The completed ends correspond to point XZ in Figure 19, and the mid-point to Y.)
4 Measure the resistance of the test leads, say R_3, and subtract this value from R_2, i.e. $R_2 - R_3 = R_4$ say.
5 A comparison between R_1 and R_4 should reveal, if the ring is healthy, that R_4 is approximately a quarter of R_1.

Method 2

The second method tests two ring circuit conductors at once, and is based on the following.

Take two conductors XYZ and ABC and measure their resistances (Figure 20). Then double them both over, join the ends XZ and AC and the mid-points YB, and measure the resistance between XZ and AC (Figure 21). This value should be a quarter of that for XYZ plus a quarter of that for ABC.

If both conductors are of the same length and csa, the resultant value would be half that for either of the original resistances.

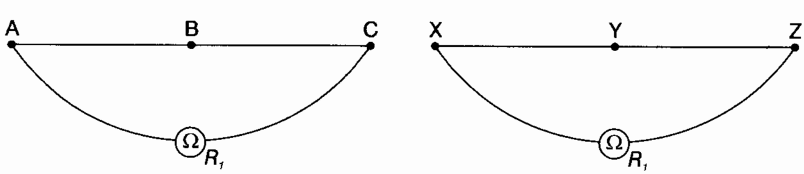


Figure 20

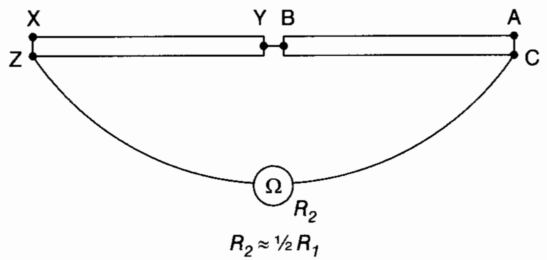


Figure 21

Applied to a ring final circuit, the test procedure is as follows:

1 Measure the resistance of both phase and neutral conductors before completion of the ring. They should both be the same value, say R_1.
2 Complete the ring for both conductors, and bridge together phase and neutral at the mid-point socket (this corresponds to point YB in Figure 21). Now measure between the completed phase and neutral ends in the fuse board (points XZ and AC in Figure 21). Record this value, say R_2.
3 R_2 should be, for a healthy ring, approximately half of R_1 for either phase or neutral conductor. When testing the continuity of a CPC which is a different size from either phase or neutral, the resulting value R_2 should be a quarter of R_1 for phase or neutral plus a quarter of R_1 for the CPC.

Method 3

The third method is based on the measurement of resistance at any point across the diameter of a circular loop of conductor (Figure 22).

As long as the measurement is made across the diameter of the ring, all values will be the same. The loop of conductor is formed by crossing over and joining the ends of the ring circuit conductors at the fuse board. The test is conducted as follows:

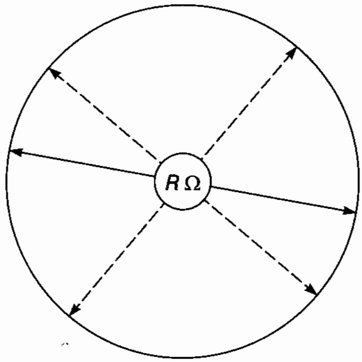


Figure 22

1 Identify both 'legs' of the ring.
2 Join one phase and one neutral conductor of opposite legs of the ring.
3 Obtain a resistance reading between the other phase and neutral (Figure 23). (A record of this value is important.)
4 Join these last two conductors (Figure 24).
5 Measure the resistance value between P and N at each socket on the ring. All values should be the same, approximately a quarter of the reading in (3) above.

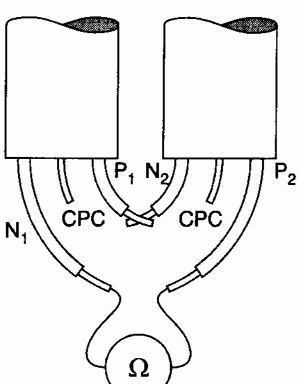


Figure 23

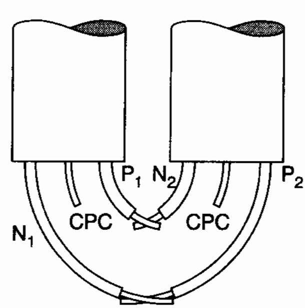


Figure 24

The test is now repeated but the neutral conductors are replaced by the CPCs. If the cable is twin with CPC, the CPC size will be smaller than the phase conductor, and although the readings at each socket will be substantially the same, there will be a slight increase in values towards the centre of the ring, decreasing back towards the start. The highest reading represents $R_1 + R_2$ for the ring.

The basic principle of this method is that the resistance measured between any two points, equidistant around a closed loop of conductor, will be the same.

Such a loop is formed by the phase and neutral conductors of a ring final circuit (Figure 25).

Let the resistance of conductors be as shown.

R measured between P and N on socket A will be:

$$\frac{0.2 + 0.5 + 0.2 + 0.3 + 0.4 + 0.1 + 0.3}{2} = \frac{2}{2} = 1\,\Omega$$

R measured between P and N at socket B will be:

$$\frac{0.3 + 0.2 + 0.5 + 0.2 + 0.3 + 0.4 + 0.1}{2} = \frac{2}{2} = 1\,\Omega$$

Hence all sockets on the ring will give a reading of 1 Ω between P and N.

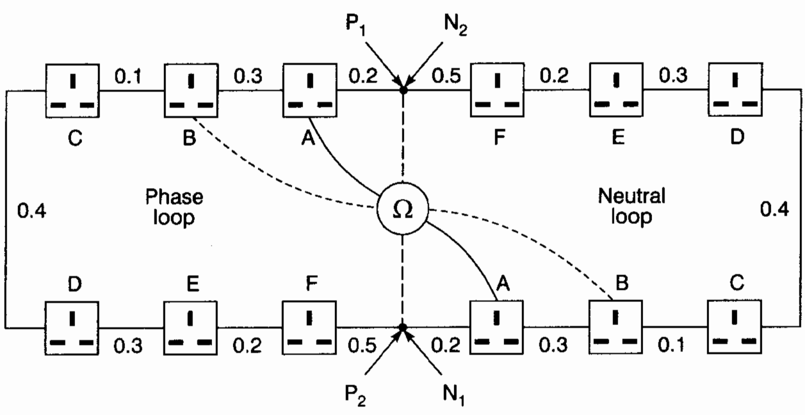


Figure 25

If there were a break in the ring in, say, the neutral conductor, all measurements would have been 2 Ω, incorrectly indicating to the tester that the ring was continuous. Hence step 3 in the test procedure which at least indicates that there is a continuous P–N loop, even if an interconnection exists. Figure 26 shows a healthy ring with interconnection.

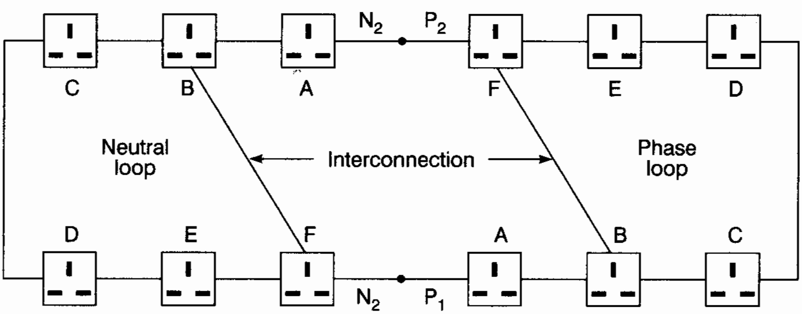


Figure 26 Healthy ring with interconnection. Sockets A, B and F will give identical readings. C, E and D will not.

Here is an example that shows the slight difference between measurements on the phase/CPC test. Consider a 30 m ring final circuit wired in 2.5 mm^2 with a 1.5 mm^2 CPC. Figure 27 illustrates this arrangement when cross-connected for test purposes.

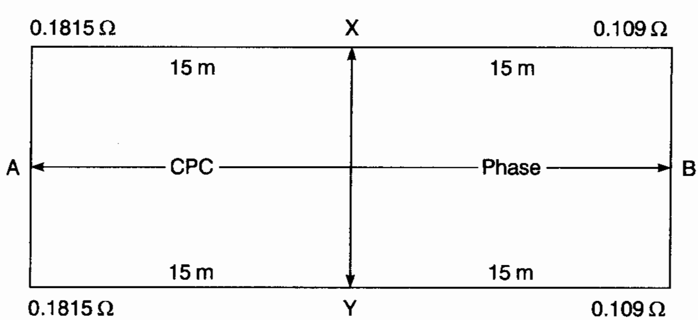


Figure 27

From the resistance tables, 1.5 mm^2 conductor is seen to have a resistance of 12.1 mΩ/m, and 2.5 mm^2, 7.27 mΩ/m. This gives the resistance from X to A as $15 \times 12.1/1000 = 0.1815\,\Omega$ and from X to B as $15 \times 7.27/1000 = 0.109\,\Omega$. The same values apply from Y to A and Y to B.

So measuring across X and Y we have $2 \times 0.1815 = 0.363$ in parallel with $2 \times 0.109 = 0.218/(0.37 + 0.218)$ product over sum = $0.137\,\Omega$.

Measuring across A and B (the mid-point) gives $0.1815 + 0.109 = 0.29$, in parallel with the same value, i.e. 0.29, which gives $0.29/2 = 0.145\,\Omega$.

While there is a difference ($0.008\,\Omega$) the amount is too small to suggest any faults on the ring.

Protection against direct contact by barriers or enclosures

If an enclosure/barrier is used to house or obscure live parts, and is not a factory-built assembly, it must be ascertained whether or not it complies with the requirements of the IP codes IP2X, IPXXB or IP4X. For IP2X and IPXXB, the test is made using the

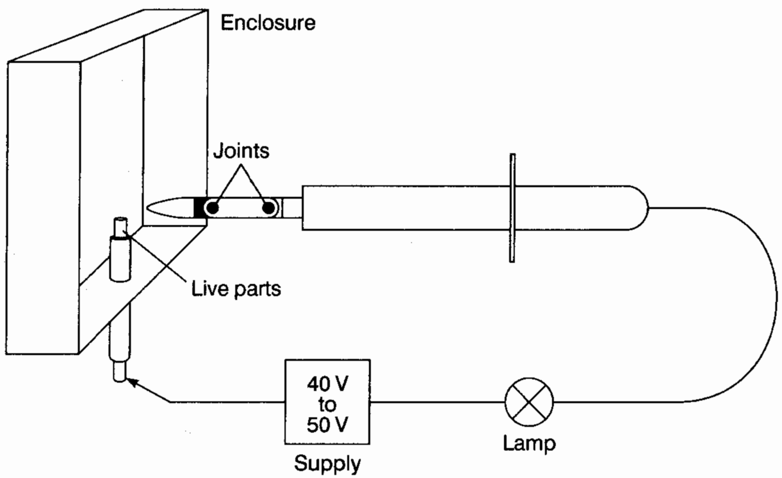


Figure 28

British Standard Finger, which is connected in series with a lamp and a supply of not less than 40 V and not more than 50 V. The test finger is pushed into or behind the enclosure/barrier and the lamp should not light (Figure 28).

The test for IP4X is made with a 1.0 mm diameter wire with its end bent at right angles. The wire should not enter the enclosure.

Insulation resistance

An insulation resistance tester, which is a high resistance ohmmeter, is used for this test. The test voltages and minimum MΩ values are as follows:

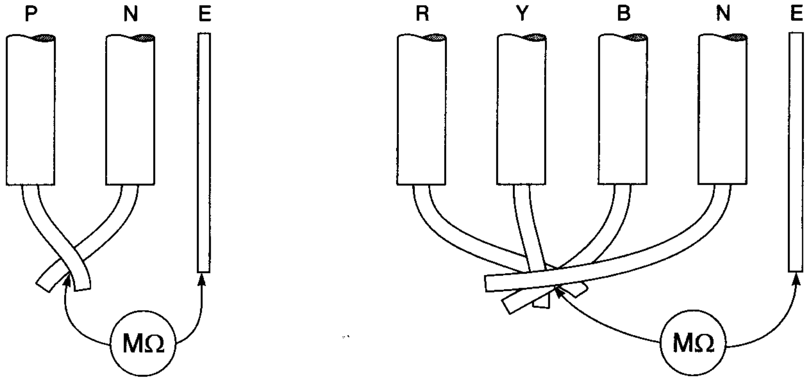
ELV circuits (SELV and PELV)		*LV circuits up to 500 V*		*LV circuits above 500 V*	
V	M	V	M	V	M
250	0.25	500	0.5	1000	1

Clearly with voltages of these levels, there are certain precautions to be taken prior to the test being carried out. Persons should be warned, and sensitive electronic equipment disconnected or unplugged. A common example of this is the dimmer switch. Also, as many accessories have indicator lamps, and items of equipment such as fluorescent fittings have capacitors fitted, these should be disconnected as they will give rise to false readings.

The test procedure is as follows:

Poles to earth (Figure 29)

1 Isolate supply
2 Ensure that all protective devices are in place and all switches are closed
3 Link all poles of the supply together (where appropriate)
4 Test between the linked poles and earth.



Single phase

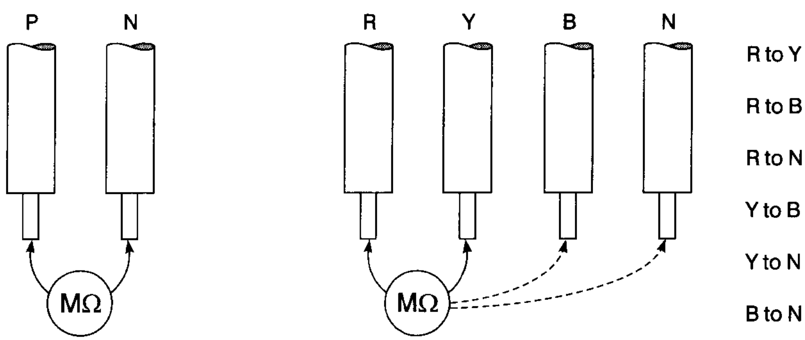
Three phase

Figure 29

Between poles (Figure 30)

1 As previous test
2 As previous test
3 Remove all lamps, equipment, etc.
4 Test between poles.

Test results on disconnected equipment should conform to the relevant British Standard for that equipment. In the absence of a British Standard, the minimum value is 0.5 mΩ.



Single phase

Three phase

Figure 30

For small installations, the tests are performed on the whole system, whereas for larger complex types, the installation may be sub-divided into sections and tests performed on each section. The reason for this is that as conductor insulation and the circuits they supply are all in parallel, a test on the whole of a large installation would produce pessimistically low readings even though no faults exist.

Although for standard 400 V/230 V installations the minimum value of insulation resistance is 0.5 mΩ, a reading of less than 2 mΩ should give rise to some concern. Circuits should be tested individually to locate the source of such a low reading. If this test reveals all circuits to be above 2 MΩ, this is satisfactory.

Polarity

It is required that all fuses and single-pole devices such as single-pole MCBs and switches are connected in the phase conductor only. It is further required that the centre contact of Edison screw lamp holders be connected to the phase conductor and that socket outlets and similar accessories are correctly connected.

Ring final circuits

If method 3 for testing ring circuit conductor continuity was performed, then any cross polarity would have shown itself and been rectified. Hence no further test is necessary. However, if method 1 or 2 were used, and the mid-point socket was correct, reversals elsewhere in the ring would not be detected and therefore two tests are needed.

1 Link completed phase and CPC loops together at the fuse board and test between P and E at each socket. A nil reading will indicate a reversed polarity (Figure 31).
2 Repeat as in 1, but with P and N linked.

Radial circuits

For radial circuits, the test method 1 for continuity of protective conductors will have already proved correct polarity. It just remains to check the integrity of the neutral conductor for socket

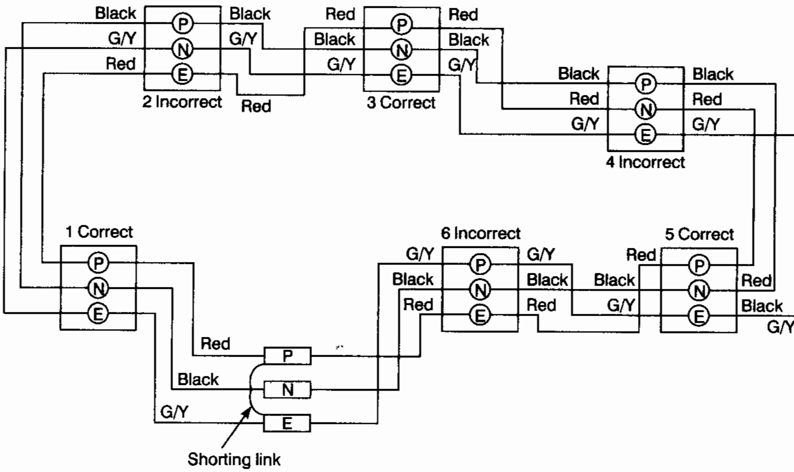


Figure 31

outlet circuits, and that switch wires and neutrals are not mixed at lighting points. This is done by linking P and N at the fuse board and testing between P and N at each outlet and between N and switch wire at each lighting point.

Also for lighting circuits, to test for switches in phase conductors, etc., link P and E at the fuse board and test as shown in Figure 32.

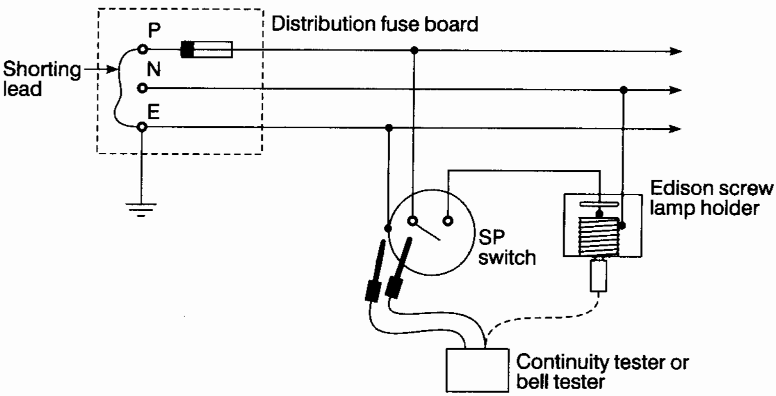


Figure 32 Polarity test on lighting circuit

Earth fault loop impedance

External loop impedance Z_e

This is carried out by connecting an earth fault loop impedance tester between the phase conductor and the main earthing terminal at the intake position with the main bonding conductors disconnected. This ensures that parallel resistance paths will not affect the reading. Great care must be taken when conducting this test, as the installation has to be energized and probes and/or clips are used to make contact, also the installation is not earthed for the duration of the test. When the test is completed reconnect the bonding.

Total loop impedance Z_s

This has to be measured in order to ensure that protective devices will operate in the specified time under fault conditions. As the value of $(R_1 + R_2)$ for a particular circuit will have already been established, Z_s may be found by simply adding the $(R_1 + R_2)$ value to Z_e. Alternatively, it may be measured directly at the extremity of a particular circuit. Whichever method is used, the value obtained will need to be corrected for ambient and conductor operating temperatures before a comparison is made with the tabulated values of Z_s in the Regulations.

In practice, it would be unusual to take temperature measurements on site an in consequence a 'rule of thumb' method is adopted. This simply requires that measured values of loop impedance do not exceed $\frac{3}{4}$ of tabulated values.

Note: All main equipotential and supplementary bending must be in place during this test.

Earth electrode resistance

If we were to place an electrode in the earth and measure the resistance between the electrode and points at increasingly larger distances from it, we would notice that the resistance increased with distance until a point was reached (usually around 2.5 m) beyond which no increase in resistance was noticed (Figure 33).

It is a requirement of the Regulations that for a TT system, exposed conductive parts be connected via protective conductors

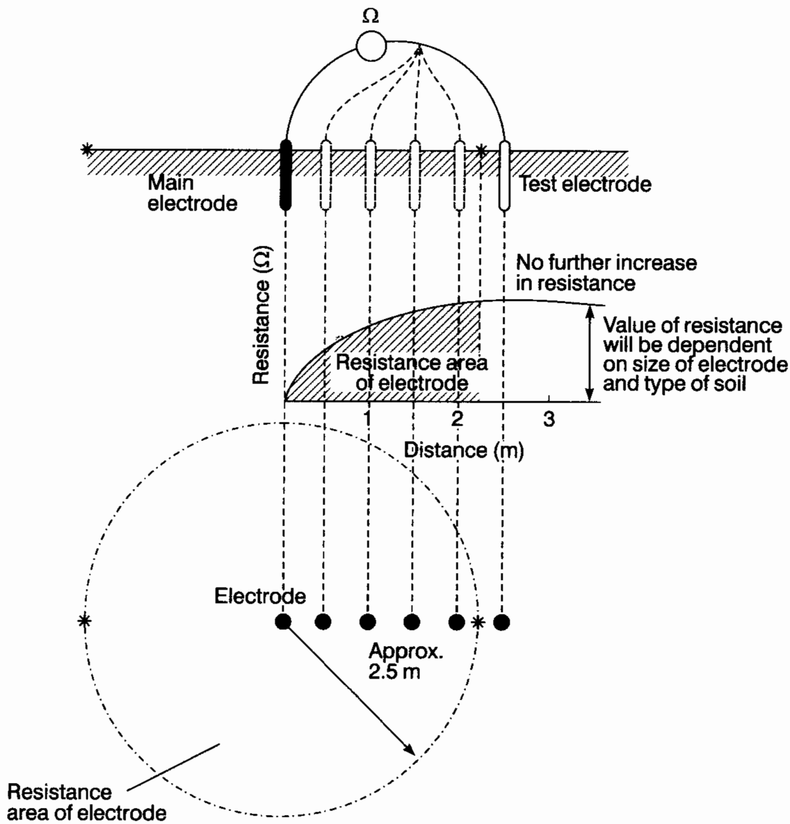


Figure 33 Resistance area of electrode

to an earth electrode, and that the protection is by either an RCD or an overcurrent device, the RCD being preferred. Conditional on this is the requirement that the product of the sum of the resistances of the earth electrode and protective conductors, and the operating current of the protective device, shall not exceed 50 V, i.e. $R_a \times I_a \leqslant 50\,\mathrm{V}$ (R_a is the sum of the resistances of the earth electrode and the protective conductors connecting it to the exposed conductive part).

Clearly then, there is a need to measure the resistance of the earth electrode. This may be done in either of two ways.

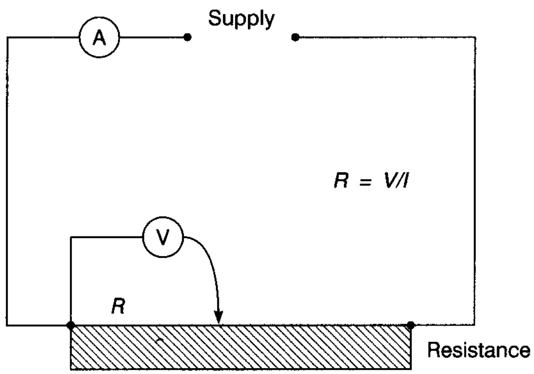


Figure 34

1 Based on the principle of the potential divider (Figure 34), an earth resistance tester is used together with test and auxiliary electrodes spaced as shown in Figure 35. This spacing ensures that resistance areas do not overlap.

The method of test is as follows:

1 Place the current electrode (C2) away from the electrode under test, approximately 10 times its length, i.e. 30 m for a 3 m rod.

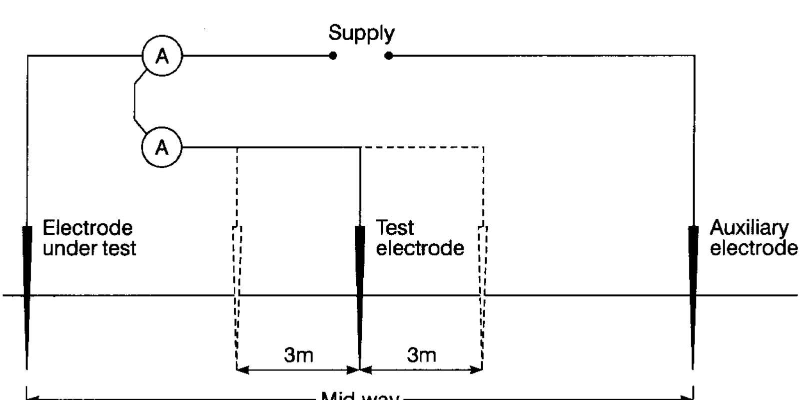


Figure 35

2 Place the potential electrode mid-way.
3 Connect test instrument as shown.
4 Record resistance value.
5 Move the potential electrode approximately 3 m either side of the mid position, and record these two readings.
6 Take an average of these three readings (this is the earth electrode resistance).
7 Determine the maximum deviation or difference of this average from the three readings.
8 Express this deviation as a percentage of the average reading.
9 Multiply this percentage deviation by 1.2.
10 Provided this value does not exceed a figure of 5 per cent then the accuracy of the measurement is considered acceptable.

Three readings obtained from an earth electrode resistance test were 181 Ω, 185 Ω and 179 Ω. What is the value of the electrode resistance and is the accuracy of the measurement acceptable?

$$\text{Average value} = \frac{181 + 185 + 179}{3} = 181.67\,\Omega$$

$$\text{Maximum deviation} = 185 - 181.67 = 3.33$$

$$\text{Expressed as a percentage of the average} = \frac{3.33 \times 100}{181.67}$$

$$= 1.83\%$$

$$\text{Measurement accuracy} = 1.83\% \times 1.2$$

$$= 2.2\% \quad \text{(which is acceptable)}$$

For TT systems the result of this test will indicate compliance if the product of the electrode resistance and the operating current of the overcurrent device does not exceed 50 V.

2 On TT systems protected by an RCD, a loop impedance tester is used, and effectively measures Z_e which is taken as the earth electrode resistance.

Functional testing

Prospective short-circuit current

A PSCC tester, usually incorporated with a loop impedance tester, is used for this. When testing at the intake position, probes and/or clips will be needed and hence great care needs to be taken when connecting to live terminals, etc. Measurements are taken between P and N.

Residual current devices

Only the basic type of RCD will be considered here. Clearly, such devices must operate to their specification, an RCD tester will establish this. As with loop impedance testing, care must be taken when conducting this test as an intentional earth fault is created in the installation.

It is important to know why an RCD has been installed as this has direct effect on the tests performed. The tests are as follows:

1 With the tester set to the RCD rating, half the rated tripping current is passed through the device. It should not trip.
2 With full rated tripping current passed through the device, it should trip within 200 ms.
3 All RCDs have a test button which should be operated to ensure the integrity of the tripping mechanism. It does not check any part of the earthing arrangements. As part of the visual inspection, it should be verified that a notice, indicating that the device should be tested via the test button quarterly, is on or adjacent to the RCD.

There seems to be a popular misconception regarding the ratings and uses of RCD's in that they are the panacea for all electrical ills and the only useful rating is 30 mA!!

Firstly, RCD's are not fail safe devices, they are electro-mechanical in operation and can malfunction. Secondly, general purpose RCD's are manufactured in ratings from 5 mA to 100 mA and have many uses. Let us first deal with RCD's rated at 30 mA or less. The accepted lethal level of shock current is 50 mA and hence RCD's rated at 30 mA or less would be appropriate for use where shock is an increased risk. BS7671 indicates that RCD's of 30 mA or less should be used in the following situations:

1 To protect circuits supplying hand held equipment outside the equipotential zone.
2 To protect all socket outlet circuits in a TT system installation.
3 To protect all socket outlets in a caravan park.
4 To provide supplementary protection against Direct contact.
5 For fixed current using equipment in bathrooms.

In all these cases and apart from conducting the tests already mentioned, it is required that the RCD be injected with a current five times its operating current and the tripping time should not exceed 40 ms.

Where loop impedence values cannot be met, RCD's of an appropriate rating can be installed. Their rating can be determined from

$$I\,n = 50/Zs$$

Where I n is the rated operating current of the device
50 is the touch voltage
Zs is the measured loop impedence

RCD's can also be used for:

1 Discrimination e.g. a 100 mA device to protect the whole installation and a 30 mA for the sockets.
2 Protection against fire use, say, a 500 mA device.

Tests on assemblies

These are carried out on a switchgear, interlock, controlgear, etc., to ensure that they are mounted and installed according to the Requirements of the 16th Edition.

Periodic inspection and testing

After an installation has had an initial verification and been put into service, there is a requirement for regular periodic verification to take place. In some cases where for example a Local Authority is involved, the interval between tests is mandatory. In other cases the interval is only a recommendation. For example the recommended time between tests on domestic installations is 10 years whereas places of public entertainment have a mandatory interval of one year.

Clearly, periodic tests may prove difficult, as premises are usually occupied and in full service and hence careful planning and consultation are needed in order to minimize any disruption. A thorough visual inspection should be undertaken first as this will indicate to the experienced inspector the depth to which he or she need go with the instrument tests, and an even more rigorous investigation may be required if drawings/design data are not available.

The visual inspection will need to take into account such items as safety, wear and tear, corrosion, signs of overloading, mechanical damage, etc. In many instances, a sample of items inspected may be taken, for example a minimum of 10 per cent of switching devices may be taken. If, however, the sample indicates considerable deterioration then all items must be inspected.

The test sequence where relevant is as follows:

1 Continuity of protective conductors and bonding. (In this case, unless the supply can be isolated these conductors must not be disconnected.)
2 Polarity
3 Earth fault loop impedance
4 Insulation resistance
5 Operation of switching and isolating devices
6 Operation of RCDs
7 Continuity of ring circuit conductors
8 Earth electrode resistance
9 Operation of MCBs
10 Separation of circuits
11 Non-conducting floors and walls.

As with visual inspection, sample tests may be made, usually 10 per cent, with the proviso that this is increased in the event of faults being found. In the light of previous comments regarding sampling, it is clear that periodic verification is subjective, varying from installation to installation. It is also more dangerous and difficult and hence requires the inspector to have considerable experience. Accurate and coherent records must be made and given to the person/s ordering the work. Such records/reports must indicate any departures from or non-compliances with the Regulations, any restrictions in the testing procedure, any dangerous situations, etc., if the installation was erected according to an earlier edition of the Regulations, it should be tested as far as possible to the requirements of the 16th Edition, and a note made to this effect on the test report.

It should be noted that if an installation is effectively supervised in normal use, then Periodic Inspection and Testing can be replaced by regular maintenance by skilled persons. This would only apply to, say, factory installations where there are permanent maintenance staff.

3
SPECIAL LOCATIONS

In this chapter we will deal with locations that require special consideration and in particular, bathrooms, construction sites and agricultural/horticultural situations.

Section 601: Locations containing a bath or shower

This section deals with common locations containing baths, showers and cabinets containing a shower and/or bath. It does not apply to specialist locations. The main feature of this section is the division of the location into zones (0, 1, 2 and 3) in the same way as Section 602 for swimming pools.

Section 602: Swimming pools

The general requirements are similar to those for bathrooms. In the case of swimming pools the zones are zone A, B & C where Zone A is in the pools itself, Zone B extends 2.0 m beyond Zone A and 2.5 m above it, and Zone C extends a further 1.5 m beyond Zone B. Where they are permitted socket outlets must be of the industrial type to BS EN 60309-2.

Section 603: Hot air saunas

The room housing a hot air sauna is divided into temperature zones A, B, C & D in which only equipment suitable for the temperature may be installed.

All equipment should be IP24 rated.

Section 604: Construction site installations

This section does not apply to offices, cloakrooms, meeting rooms, canteens etc.

Clearly a construction site is a hazardous area, and a location where many hand held portable tools are used. Consequently special precautions must be taken.

- 50 V or 25 V SELV would be required for supplying portable hand lamps in damp or confined locations.
- 110 V single or three phase centre tap earth would be needed for general portable lamps or tools. This is the reduced voltage system already mentioned in Chapter 3.
- 230 V is only permitted for fixed floodlighting
- 400 V for fixed and moveable equipment above 3.75 kW.
- Disconnection times are reduced for all voltages above 120 V to earth, the 220 V–277 V range is halved from 0.4 s to 0.2 s, and the associated loop impedance values are also reduced.
- Disconnection times for reduced voltage (110 V cte) systems are 5 s (IEE Regs 471-15-06)
- Touch voltage has also been reduced from 50 V to 25 V.

Section 605: Agricultural and horticultural locations

This section does not apply to farm houses and dwellings for human habitation. The general requirements are very similar to construction sites except for the voltages. Disconnection times are reduced to 0.2 s. Protection against indirect contact may be achieved by EEBADS. 500 mA RCD's are permitted for protection against fire. Electrical equipment in normal use should be to IP44.

Section 606: Restrictive conductive locations

These are locations which are conductive and where freedom of movement is difficult. Such a location would be, for example, a ventilation shaft where an operative may need to enter to work on, say, a fan. Any hand held tools taken into a location must only be supplied by a SELV supply.

Section 607: Installations having high protective conductor currents

These are typically installation in large commercial offices etc where IT equipment is extensively used. No special precautions are needed where leakage currents do not exceed 3.5 mA. This section outlines the requirements when currents exceed 3.5 mA or 10 mA in respect of types of socket outlet and sizes and number of protective conductors and how they should be connected.

Section 608: Caravans

Generally speaking, the electrical contractor will have little input to the installation in a caravan as they are pre-wired at construction stage. If, however, re-wiring is needed this section details the wiring systems permitted, the types and positions of inlets and notices to be displayed.

Section 609: Caravan parks

Generally this section deals with the site supplies to the individual caravan pitches and outlines the type of wiring system (overhead or underground) to be used and the type of socket outlet (BS EN60309-2) permitted.

Section 611: Highway supplies and street located equipment

This section deals with lamp-posts, illuminated road signs etc. Generally such locations are treated as ordinary installations but with extra details regarding identification of supply cables and temporary supplies.

4
SAMPLE QUESTIONS AND ANSWERS

In this chapter we will look at typical C&G 2400 examination questions and give suggested solutions (pages 81 to 89) expected by the examiners. Clearly, in many instances there is not always one correct answer, and the examiner will have a range of alternatives from which to award marks. Owing to the time constraints, approximately 18 minutes per question, the candidate is not expected to, and nor can he or she, write an essay in answer to descriptive questions. All that is required are reasoned statements which indicate a knowledge and understanding of the subject matter, and if time allows, specific reference to relevant parts of the 16th Edition, although this is not essential unless asked for. It is not sufficient to simply quote Regulation numbers or Parts in answer to a question. In fact no marks are awarded for such answers.

EXAMPLE 11

A factory manufacturing chemical products is situated close to the supply transformer feeding an industrial estate. The earthing system is TNC–S with a measured loop impedance of 0.015 Ω and PSCC of 16 kA. It is required to increase the level of lighting by installing 26 400 W/230 V high-bay discharge luminaires. The existing wiring system is a mixture of PVC/SWA cables and galvanized trunking and conduit. There is no spare capacity in any of the existing distribution fuse boards.

Outline the design considerations for the new lighting, with regards to:

1 Maximum demand and diversity
2 Maintainability
3 External influences
4 Wiring system
5 Control and protective devices.

EXAMPLE 12

A consumer is having major alterations to their premises, one part of which is to convert an existing kitchen extension to a pottery room housing a 9 kW/230 V fan-assisted kiln and it is proposed to utilize the existing cooker circuit to supply it. The cabling is 6.0 mm^2 twin with 2.5 mm^2 CPC, clipped direct throughout its 25 m run and protected by a 32 A BS3871 Type 2 MCB and there are no adverse conditions prevailing. The external value of loop impedance has been measured as 0.3 Ω. Show by calculation what changes, if any, are required to enable the existing system to be used.

EXAMPLE 13

You are to provide the temporary electrical installation for a construction site on which the site huts and offices together with the main supply point are on the opposite side of the access road to the building under construction. The services required are supplies for:

1 The site huts and offices
2 High level fixed floodlighting around the site perimeter
3 Portable tools
   (a) Indicate a suitable method of running supplies from the site hut area to the construction area. What type of sockets and cable couplers should be used?

(b) State the voltages and disconnection times for 1, 2 and 3 above.

(c) If one of the circuits for the portable tools is protected by a 15 A Type B MCB, what is the maximum value of the loop impedance Z_s for that circuit?

EXAMPLE 14

Part of a farm complex supplied by a TT system is to be converted for use as a poultry incubation area. The existing wiring is some 30 years old and incorporates a voltage operated earth leakage circuit breaker. Outline the design criteria to be considered with regards to:

1 The wiring system
2 Protection against shock
3 Protection against thermal effects.

EXAMPLE 15

A single-phase sub-main circuit to a distribution board housing BS88 fuses is wired in 6.0 mm^2 SWA XLPE cable.

A radial lighting circuit wired in 1.5 mm^2 PVC copper cable with a 1.5 mm^2 CPC and protected by a 10 A fuse is fed from the board. The length of the lighting circuit is 40 m.

The measured values of Z_s at the distribution board is 2.1 Ω, and the ambient temperature at the time of measurement was 20°C.

(a) What would be the minimum gross size of the sub-main cable armouring if it is to be used as the CPC?

(b) Calculate the value of Z_s at the extremity of the lighting circuit. Is this value acceptable?

EXAMPLE 16

During a periodic test and inspection of the installation in a butcher's shop, it is revealed that the circuit supplying an electrically operated compressor does not meet the maximum earth fault loop impedance requirements. The circuit is protected by a

16 A Type C MCB, and the unit is situated 1 m from a steel sink. Explain how, under certain conditions, this situation may be resolved by the use of supplementary bonding. Support your answer with calculation.

EXAMPLE 17

A 2.5 mm^2 ring final circuit 60 m long is wired in singles in PVC conduit, the CPC is 1.5 mm^2. A ring circuit continuity test is performed involving measurements at each socket.

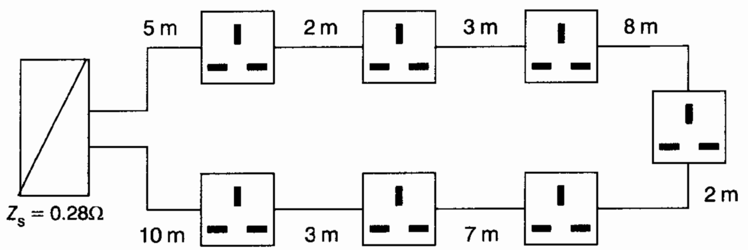
1 What is the purpose of this test?
2 Explain a method of identifying the opposite 'legs' of the ring.
3 What would be the reading between P and E at the socket nearest the mid-point of the ring?
4 What is the significance of this mid-point reading?

EXAMPLE 18

1 Give three examples for the use of an RCD, indicating residual operating currents, and operating times.
2 How often should a consumer operate an RCD via its test button. What does this test achieve.
3 Give one example for the use of a time delayed RCD.

EXAMPLE 19

The diagram shows a ring final circuit wired in flat twin with CPC cable (2.5 mm^2 + 1.5 mm^2). The protection is by 32 A Type B



MCB. If a test for continuity was performed at 15°C using the measurement at each socket method, calculate:

1 The reading at each socket between P and N.
2 The value of $(R_1 + R_2)$.
3 The value of Z_s for comparison with the tabulated maximum value. Is this value acceptable?

(2.5 mm^2 copper has a resistance of 7.41 mΩ/m, 1.5 mm^2 is 12.1 mΩ/m and the value of Z_e is measured as 0.28 Ω.)

EXAMPLE 20

A small three-storey commercial office complex is due to have a periodic test and inspection. Outline the major steps you would take regarding:

1 Disturbance to office routine.
2 Meeting the requirements of the Electricity at Work Regulations 1989.
3 Measuring the continuity of main bonding conductors.
4 Reporting defects and issuing certificates.

EXAMPLE 21

1 Give two reasons, when conducting an insulation resistance test on a large complex installation, for breaking it down into smaller sections. What precautions should be taken before commencing the tests?
2 The test results for each section of such an installation are 50 MΩ, 20 MΩ, 100 MΩ and 4 MΩ. Show by calculation the expected overall insulation resistance at the intake position.

EXAMPLE 22

1 A wiring system employing the use of singles in steel trunking is to be installed. Outline the main design and installation considerations with regards to this installation.

2 The trunking at one point will accommodate the following single stranded conductors:

28	$1.5\,mm^2$
20	$2.5\,mm^2$
12	$6.0\,mm^2$
10	$10.0\,mm^2$

Determine the minimum size of trunking to be used.

Suggested solutions

EXAMPLE 11

1 Determine the new maximum demand by calculating the increase in load and adding to the existing maximum demand. Check that suppliers' equipment and main switchgear/busbars, etc., can accommodate the extra load.

$$\text{Increase in load} = \frac{\text{power} \times 1.8 \text{ (for discharge lamps)}}{240}$$

$$= \frac{26 \times 400 \times 1.8}{230}$$

$$= 81.4\,\text{A}$$

No diversity would be allowed as it is likely that the lamps will be on all the time.

2 Luminaires need to be accessible for cleaning, repair, lamp replacement, etc.
- Access equipment should be available
- Spare lamps, chokes, etc., should be kept
- Luminaires supplied via plug and socket arrangement to facilitate easy removal, and without losing supply to the other lamps

3 As chemicals are being produced the atmosphere could be corrosive, and there may be a fire risk, external influences classification would be AF2 and BE2.

4 If valid documentation exists it is possible for a decision to be made to use at least in part, the existing trunking system. If not, and this is most likely, a new system should be installed using either singles in galvanized steel trunking and conduit, or PVC sheathed material insulated cable, or PVC sheathed SWA cable, with circuits spread over three phases. Protect against indirect contact by EEBADS.
5 Control by switch operating a three-phase 80 A contactor feeding a three-phase distribution board housing BS88 fuses to cater for the high PSCC at the intake. Contactor and DB must also be able to handle the PSCC.

EXAMPLE 12

$$\text{Kiln design current} = \frac{P}{V}$$

$$= \frac{9000}{230}$$

$$= 39\ \text{A}$$

MCB setting I_n, such that $I_n \geqslant I_b = 40\text{A}$

No correction factors hence $I_t \geqslant 40$ A

$$I_t = 46\ \text{A}$$

Cable size $= 6.0\,\text{mm}^2$

$$\text{Volt drop} = \frac{\text{mV} \times I_b \times L}{1000}$$

$$= \frac{7.3 \times 37.5 \times 25}{1000}$$

$$= 6.8\,\text{V ok.}$$

Shock risk $Z_s = Z_e + (R_1 + R_2)$

$$= 0.3 + \frac{(3.08 + 7.41) \times 25 \times 1.2}{1000}$$

$$= 0.615\,\Omega\text{, ok, as } Z_s \text{ maximum}$$

Thermal constraints $I = \dfrac{U_{OC}}{Z_s}$

$$= \frac{240}{0.615}$$

$$= 390\,\text{A}$$

$$k = 115$$

$$S = \frac{\sqrt{I^2 t}}{k}$$

$$= 0.415\,\text{mm}^2$$

So the 2.5 mm^2 CPC is ok. The only change to the existing installation would be to uprate the 32 A MCB to 40 A.

EXAMPLE 13

(a) PVC sheathed SWA cable supported over the access road on a catenary wire at a minimum height of 5.8 m. Cable couplers and sockets should be to BS4343 (BS EN 60309–2).

(b)

Site huts and offices	Fixed floodlights	Portable tools
230 V 0.4 s & 5 s	230 V 0.2 s	110 V CTE 5 s

(c) From Table 471A, IEE Regulations, Z_s = 0.73 or, calculate from:

$$Z_s = \frac{U_{OC}}{I_a}$$

I_a for a 15 A Type B MCB from Figure 7 in IEE Regulation curves = 75 A

$$\text{So} \quad Z_s = \frac{55}{75} = 0.73\,\Omega$$

EXAMPLE 14

1 It is unlikely that the existing wiring will meet the new requirements, and due to its age it would be best to replace with a new all insulated system, for example, singles in PVC conduit out of reach of livestock and supplied by a manufacturer who specifies resistance to the onerous conditions found on farms.

2 Remove the voltage-operated ELCB. These are not permitted. Socket outlets, except those used for equipment essential for the welfare of livestock, should be protected by an RCD rated at 30 mA or less and which will operate within 40 ms at a residual current of 150 mA.

Protection against indirect would be by EEBADS with supplementary equipotential bonding. Disconnection time for 230 V supplies is reduced to 0.2 s.

3 Protection against fire may be achieved by using an RCD rated up to 500 mA, except where equipment essential to the welfare of livestock is involved.

Incubation and subsequent hatching involves the use of infra-red lamps to maintain a stable temperature. The enclosures of such lamps may become hot and hence must be located in positions that will not cause fire or burns.

EXAMPLE 15

(a) Referring to Table 54G:

$$Sp = \frac{k1.S}{k2} \text{ (Sp is the csa of the protective conductor)}$$

As XLPE is thermosetting:

$$k1 = 143 \quad \text{and} \quad k2 = 46$$

$$Sp = \frac{143 \times 6}{46}$$

$$= 18.6\,\text{mm}^2$$

(b) Sub-main $Z_s = 2.1\,\Omega$.

$$\text{Final circuit } (R_1 + R_2) = \frac{(12.1 + 12.1) \times 40 \times 1.2}{1000}$$

$$= 1.16\,\Omega$$

$$\text{So total } Z_s = 2.1 + 1.16$$

$$= 3.26\,\Omega$$

Ok, as Z_s maximum for a 10 A BS88 fuse for fixed equipment is 7.74 Ω.

EXAMPLE 16

Provided that the value of loop impedance allows a fast enough disconnection time to protect against thermal effects, then compliance with the Regulations may be achieved by connecting a supplementary bonding conductor between the exposed conductive parts of the compressor and the sink. The resistance of such a conductor must be less than or equal to:

$\frac{50}{I_a}$, I_a, the current causing operation of the protection within 5 s, is 160 A for a Type C MCB.

$$\text{So, } R \leqslant \frac{50}{160}$$

$$= 0.313\,\Omega$$

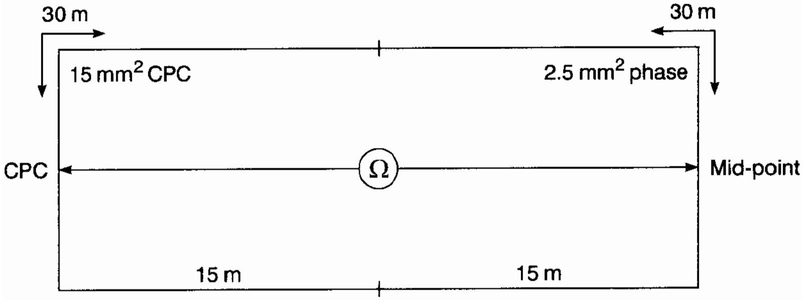
EXAMPLE 17

1 To identify breaks in the ring and/or interconnections across the ring.
2 Test with a low reading ohmmeter between each P, N and E leg and the corresponding terminal at the nearest socket. A low value indicates the short leg, a high value, the long leg.
3 Reading at mid-point $= \dfrac{30\,\text{m of } 2.5\,\text{mm}^2 + 30\,\text{m of } 1.5\,\text{mm}^2}{2}$

$$= \frac{30 \times 0.00741 + 30 \times 0.0121}{2}$$

$$= 0.293\,\Omega$$

4 This value is $(R_1 + R_2)$ for the ring.



EXAMPLE 18

1 (a) When the loop impedance value for an overcurrent device cannot be met. The product of the residual operating current of the device and the loop impedance should not exceed 50 V. The device should trip within 200 ms at the rated residual current.

(b) If supplementary protection against direct current is required. RCD should be rated at 30 mA or less, and trip within 40 ms at a residual operating current of 150 mA.

(c) In agricultural situations, for protection against fire. The RCD should not be rated above 500 mA, and used for circuits other than those essential for the welfare of livestock. The tripping time would be within 200 ms at a rated residual current.

2 The RCD should be tested quarterly via the test button. This only checks the operating mechanism not any earthing arrangements.

3 On a TT system where the whole installation is protected by, say, a 100 mA device and the sockets by a 30 mA device. A time delay on the 100 mA RCD will give discrimination with the 30 mA RCD.

EXAMPLE 19

1 The ring is 40 m long, so the P to N reading at each socket would be:

$$\frac{2 \times 40 \times 7.41}{100 \times 4} = 0.148\,\Omega.$$

2 The mid-point $R_1 + R_2$ is 20 m of 2.5 mm + 20 m of 1.5 mm in parallel:

$$= \frac{20 \times (7.41 + 12.1)}{1000 \times 2}$$

$$= 0.195\,\Omega.$$

3 $(R_1 + R_2)$ corrected for 15°C $= 0.195 \times 1.02$
$= 0.199\,\Omega$

Correction for operating temperature $= 0.199 \times 1.2$
$= 0.239\,\Omega$

so, $Z_s = 0.28 + 0.239$
$= 0.52\,\Omega$

This is ok as tabulated maximum value is $1.5\,\Omega$.

EXAMPLE 20

1 Careful planning and consultation will be required before any work commences. It may be the case that access to the premises is better suited to a weekend, or evenings when no staff are present. If this is not possible, then the installation should be tested in small sections, all the tests required in each section being done at that time.

Clearly, in the modern office, computers play a major role, and unless UPS are present, advice should be sought before isolating any supplies.

2 The inspector is a duty holder and as such must take all precautions to safeguard himself and others. Visual inspection can involve entry into enclosures housing live parts, and unless it is completely impracticable, supplies must be isolated and locked off. Testing on or near live equipment is prohibited unless it is unreasonable for it to be dead, for example, loop impedance and RCD tests. All test equipment must be suitable for the use intended and should be in a safe condition. All test results must be recorded.

3 It is usual for both ends of the bonding conductor to be disconnected for test purposes. Unless all supplies to the complete installation can be isolated, bonding conductors must not be disconnected.

4 All test results must be entered on to a schedule and a report given to the person ordering the work. The report should include details of the extent of the work, any dangerous situations prevailing, restrictions to the inspection and test, and serious defects.

Any certificate issued should indicate and explain departures from the 16th Edition especially those due to installations constructed before the current Regulations.

EXAMPLE 21

1 Large installations may have circuits in parallel which can result in pessimistically low values of insulation resistance even though there are no defects. Dividing the installation into smaller sections will overcome these low readings.

Subdivision of the installation, especially on periodic inspections, will enable minimum disruption of work processes.

All persons must be informed that the test is to take place, all supplies isolated from the part of the installation in question, all electronic devices, capacitors, neon indicators, etc., should be disconnected, and ensure that no electrical connection exists between any live conductor and earth.

2 The overall value will be the sum of the individual insulation resistances in parallel, hence:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{50} + \frac{1}{20} + \frac{1}{100} + \frac{1}{4}$$

$$= 0.02 + 0.05 + 0.01 + 0.25$$

$$= 0.33$$

$$R = \frac{1}{0.33} = 3$$

EXAMPLE 22

1 The design should embrace grouping of circuits, space factor if trunking sizes are outside the scope of tabulated sizes, and external influences which may affect the choice of trunking finish.

Table 3 Resistance of copper conductors at 20°C

Conductor csa (mm^2)	*Resistance ($m\Omega/m$)*
1.0	18.1
1.5	12.1
2.5	7.41
4.0	4.61
6.0	3.08
10.0	1.83
16.0	1.15
25.0	0.727
35.0	0.524

With regards to the installation, supports must be at the correct spacing, joints should be bridged with an earth strap, and where trunking passes through walls, ceilings, etc., it should be externally and internally sealed to the level of the fire resistance required for the building construction.

2 Using the tabulated conductor and trunking terms, we have:

$$\begin{aligned} 28 \times 8.1 &= 226.8 \\ 20 \times 11.4 &= 228 \\ 12 \times 22.9 &= 274.8 \\ 10 \times 36.3 &= 363 \\ \text{Total} \quad & \ \ 1092.6 \end{aligned}$$

Hence trunking size is $75 \times 37.5\,mm^2$.

BS 7671 2001 THE CHANGES

The new BS 7671 2001 contains many small editorial and Regulation number alterations; some substantial revisions and amendments; two new chapters and associated regulations; three new sections and the inclusion of the revised section 601 for bathrooms.

The bulk of the original BS 7671 1992 remains unaffected and the changes will not significantly effect the work of the electrical operative. The feel and look (apart from the colour) of the new edition is unchanged and the extent of additions, amendments and re-written regulations etc., are indicated by vertical lines in the margins of each page.

So, as the story teller says, let us begin at the beginning!

Part 1: Scope, object and fundamental principals

The whole of the original Part 1 has been re-written, rearranged etc. and three new sections ***131, 132*** and ***133*** added. These outline the general requirements for ***Design (131), Selection of electrical equipment (132) and Erection and Inspection and Testing of installations (133).***

Part 2: Definitions

There are only six significant changes to the list of definitions, two are deletions (earth leakage and hazardous live part), one (residual

current) is re-written and three are new (***mobile & offshore installations, leakage current and protective conductor current***).

Protective conductor current replaces Earth leakage current and is defined as ***Electric current which flows in a protective conductor under normal operating conditions.*** This is clearly not a fault current and is typical of the current flowing in the cpc's of IT equipment installations.

Leakage current on the other hand flows, ***under normal operating conditions, in an unwanted conductive path*** e.g. pipework which is not intended as cpc.

Part 3: Assessment of general characteristics

This part remains unchanged with the exception of Regulation 331-01-01 Compatibility, where there are some small editorial changes and the addition of ***Power factor, Undervoltage*** and ***Unbalanced loads*** to the list of harmful effects.

Part 4: Protection for safety

This part contains by far the most amendments and additions and include:

- (i) A change in test current requirements for residual current devices.
- (ii) Changes to Loop impedance tables.
- (iii) Change of pvc to ***Thermoplastic*** and the addition of ***Thermosetting*** to rubber cables.
- (iv) A new chapter on ***Overvoltage***.
- (v) New regulations regarding conductors in parallel.
- (vi) A new chapter regarding ***Protective measures as a function of external influences***.

(i) 412-06-02 (ii): When a residual current device is used as supplementary protection against Direct Contact it should have a rating IΔn *not* exceeding 30 mA and should operate in

40 ms at a residual current of ***5 × IΔn*** *not* 150 mA (except for 30 mA devices).

(ii) In tables 41B2, 41C and 471 (also 604B2 and 605B2) all reference to miniature circuit breakers to ***BS 3871 types 1, 2 and 3*** has been removed and ***RCBO's to BS EN 61009*** included.

(iii) In table 43A and elsewhere in BS7671, pvc has been replaced by ***Thermoplastic (pvc)*** and rubber is now shown as ***Thermosetting (rubber)***.

(iv) New ***Chapter 44 Protection against Overvoltage***. This outlines the requirements for protecting electrical installations against overvoltages due to switching surges or from an atmospheric origin (lightning!!). Tables ***44A*** and ***44B*** give examples of equipment that withstand voltages and the categories of equipment. It is unlikely that this chapter will be of any real significance in the UK, as most equipment used is to a relevant British Standard, and the number of thunderstorm days anywhere are unlikely to exceed 25 per year.

(v) New Regulations ***473-01-06, 07 & 08*** and ***473-07-05*** incorporate and add to the old regulations regarding conductors in parallel.

(vi) New ***Chapter 48 Choice of protective measures as a function of External Influences***. This chapter deals with protection where there is a risk of fire due to the ***nature of processed or stored materials (482-02)***, and in locations with ***combustible constructional materials (482-03)***.

Part 5: Selection and erection

There are few significant changes in this part, most are editorial or re-written sentences.

514-10-01 Voltage warning notices should now read ***230 V*** *not* 250 V.

Part 6: Special installations or locations

The changes in this part are mainly editorial with a few additions.

Section 601: Bathrooms etc

The old AMD 3 has been incorporated with one or two minor amendments.

Section 604: Construction sites etc.

There are three new regulations ***604-01-02*** and ***03*** which give greater detail of the scope of this section and ***604-10-03*** which indicates the requirements for the selection of flexible cables i.e. ***Low temperature 300/500 V thermoplastic cable for reduced voltage systems*** and ***HO7 RN-F 400/750 V rated cables for 230/400 V systems.***

Section 607: High protective conductor current installations

Whilst this section has been completely re-written the content is generally unchanged. Where the protective conductor current is likely to exceed 10 mA, the requirement for two separate protective conductor terminals in BS EN 60309-2 plugs has been deleted but where high integrity protective conductors and connections are required ***accessories must have two earthing terminals.***

RCD's, should not operate at ***expected protective conductor currents.***

Section 611: Highway power supplies etc.

Once again this section is generally unchanged with only one new regulation ***611-05-02*** which requires a degree of protection for all electrical equipment of ***IP33***.

Regulation 611-02 has been added to with the requirements that ***access doors less than 2.5 m above the ground be locked or secured by the use of a key or tool.***

Regulation 611-02-02 also requires the use of a tool to remove barriers or enclosures to ***gain access to light sources of luminaires located less than 2.8 m above the ground.***

Regulation 611-04-03 has been added to, and includes the need for ***colour coded marker tape or cable tiles to be used with power supply cables.***

Part 7: Inspection and testing

Not a great deal of change here, just 2 new regulations and some modifications.

It is now required that for an initial verification, every installation be inspected and tested during ***and*** on completion.

New regulation ***713-12-01*** requires that the ***Prospective short circuit current and Prospective earth fault current at the origin and at other relevant points be ascertained by measurement, calculation or other method.***

New regulation ***732-01-02*** concerns Periodic Inspection and Testing and suggests that this may be replaced by ***an adequate regime of monitoring and maintenance provided this is carried out by skilled persons, and that the installation is under effective supervision.***

Both Electrical Installation Certificates and Periodic Test Reports must be accompanied by a schedule of test results ***and an inspection schedule.***

New regulation 742-01-02 requires every circuit to be identified on a schedule of test results.

Appendices

Appendix 1 and 2 have been updated with regards to new and amended standards and revised and new legislation.

Appendix 3, Time/Current graphs, have had all reference to BS 3871 mcb's deleted and RCBO's to BS EN61009 added.

Appendix 4 Current ratings etc. has Table 4A changed to 4A1 and another table, 4A2 added, which lists all the appropriate current rating tables.

Appendix 6 now includes samples of inspection and test schedules.

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16 EDITION IEE WIRING REGULATIONS

INSPECTION, TESTING & CERTIFICATION

Covers BS 7671 2001

IEE Wiring Regulations

Inspection, Testing and Certification

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INTRODUCTION

The IEE Wiring Regulations

Before we embark on the subject of inspection and testing, it is, perhaps, wise to refresh our memories with regards to one or two important topics from the 16th edition (BS7671 2001).

Clearly the protection of persons and livestock from shock and burns etc. and the prevention of damage to property, are priorities. In consequence, therefore, thorough inspection and testing of an installation and subsequent remedial work where necessary, will significantly reduce the risks.

So, let us start with electric shock, i.e. the passage of current through the body of such magnitude as to have significant harmful effects. Figure 1 illustrates the generally accepted effects of current passing through the human body.

How then are we at risk of electric shock, and how do we protect against it?

There are two ways in which we can be at risk:

1 Touching live parts of equipment or systems that are intended to be live, this is called *direct contact.*
2 Touching conductive parts which are not meant to be live, but have become live due to a fault, this is called *indirect contact.*

The conductive parts associated with indirect contact can either be metalwork of electrical equipment and accessories (Class 1) and that of electrical wiring systems such as conduit and trunking etc. called *exposed conductive parts*, or other metalwork such as pipes, radiators, girders etc. called *extraneous conductive parts.*

1 mA – 2 mA	Barely perceptible, no harmful effects
5 mA – 10 mA	Throw off, painful sensation
10 mA – 15 mA	Muscular contraction, can't let go!
20 mA – 30 mA	Impaired breathing
50 mA and above	Ventricular fibrillation and death

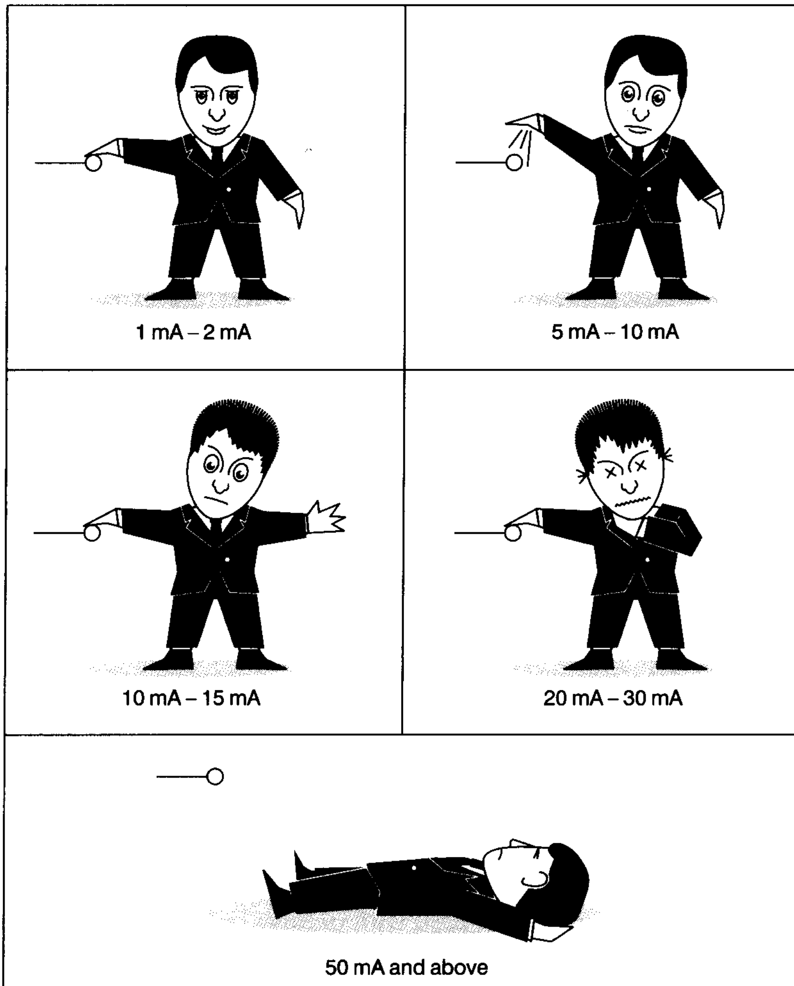

Figure 1 Electric shock

Let us now consider how we may protect against electric shock from whatever source.

Protection against both direct and indirect contact

One method of protecting against shock from both types of contact relies on the fact that the system voltage must not exceed extra low (50 V AC, 120 V ripple free DC), and that all associated wiring etc. is separated from all other circuits of a higher voltage. Such a system is known as a *separated extra low voltage (SELV)*. If a SELV system exceeds 25 VAC, 60 V ripple free DC, then extra protection from *direct contact* must be provided by barriers, enclosures and insulation.

Another method of protection is by the *limitation of discharge of energy* whereby any equipment is so arranged that the current that can flow through the human body or livestock is limited to a safe level. Typical of this method is electric fences.

Protection against direct contact

Apart from SELV, how can we prevent danger to persons and livestock from contact with intentionally live parts? Clearly we must minimize the risk of such contact, and this may be achieved in one or more of the following ways:

1 Insulate any live parts.
2 Ensure that that any uninsulated live parts are housed in suitable enclosures and/or are behind barriers.
3 Place obstacles in the way. (This method would only be used in areas where skilled and/or authorized persons were involved.)
4 Placing live parts out of reach. (Once again, only used in special circumstances, e.g. live rails of overhead travelling cranes.)

The use of a residual current device (RCD) cannot prevent direct contact, but it may be used to supplement any of the other measures taken, provided that it is rated at 30 mA or less and has a tripping time of not more than 40 ms at an operating current of five times its operating current.

It should be noted that RCDs are not the panacea for all electrical ills, they can malfunction, but they are a valid and effective back-up to the other methods. They must not be used as the sole means of protection.

Protection against indirect contact

How can we protect against shock from contact with live, exposed or extraneous conductive parts whilst touching earth, or from contact between live exposed and/or extraneous conductive parts? The most common method is by *earthed equipotential bonding and automatic disconnection of supply (EEBADS).*

All extraneous conductive parts are joined together with a main equipotential bonding conductor and connected to the main earthing terminal, and all exposed conductive parts are connected to the main earthing terminal by the circuit protective conductors. Add to this overcurrent protection that will operate fast enough when a fault occurs and the risk of severe electric shock is significantly reduced.

Other means of protecting against indirect contact may be used, but are less common and some require very strict supervision.

Use of class 2 equipment

Often referred to as double-insulated equipment, this is typical of modern appliances where there is no provision for the connection of a CPC. This does not mean that there should be no exposed conductive parts and that the casing of equipment should be of an insulating material; it simply indicates that live parts are so well insulated that faults from live to conductive parts cannot occur.

Non-conducting location

This is basically an area in which the floor, walls and ceiling are all insulated. Within such an area there must be no protective conductors, and socket outlets will have no earthing connections.

It must not be possible simultaneously to touch two exposed conductive parts, or an exposed conductive part and an extraneous conductive part. This requirement clearly prevents shock current passing through a person in the event of an earth fault, and the insulated construction prevents shock current passing to earth.

Earth-free local equipotential bonding

This is in essence a Faraday cage, where all metal is bonded together but *not* to earth. Obviously, great care must be taken when entering such a zone in order to avoid differences in potential between inside and outside.

The areas mentioned in this and the previous method are very uncommon. Where they do exist, they should be under constant supervision to ensure that no additions or alterations can lessen the protection intended.

Electrical separation

This method relies on a supply from a safety source such as an isolating transformer to BS 3535 which has no earth connection on the secondary side. In the event of a circuit that is supplied from a source developing a live fault to an exposed conductive part, there would be no path for shock current to flow (see Figure 2).

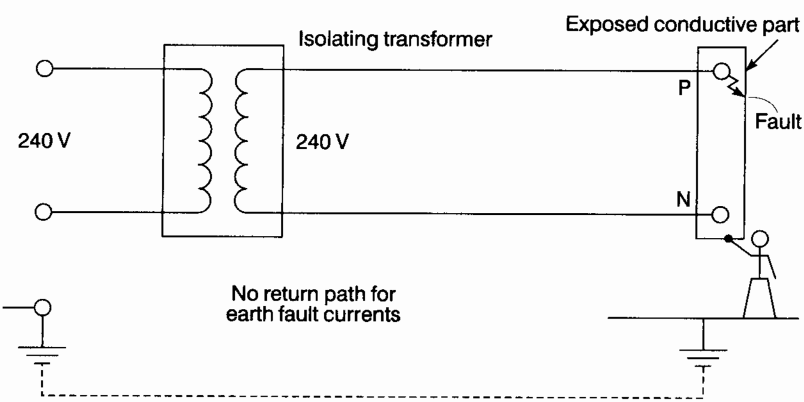

Figure 2

IP codes

First numeral: mechanical protection

0 No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.
1 Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example a hand, but not protection against deliberate access to such parts.
2 Protection against ingress of large solid foreign bodies. Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium-size solid foreign bodies.
3 Protection against contact with live or moving parts inside the enclosures by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small foreign bodies.
4 Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small solid foreign bodies.
5 Complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed.
6 Complete protection against contact with live or moving parts inside the enclosures. Protection against ingress of dust.

Second numeral: liquid protection

0 No protection.
1 Protection against drops of condensed water. Drops of condensed water falling on the enclosure shall have no harmful effect.
2 Protection against drops of liquid. Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical.
3 Protection against rain. Water falling in rain at an angle equal to or smaller than 60° with respect to the vertical shall have no harmful effect.
4 Protection against splashing. Liquid splashed from any direction shall have no harmful effect.
5 Protection against water jets. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect.
6 Protection against conditions on ships' decks (deck with watertight equipment). Water from heavy seas shall not enter the enclosures under prescribed conditions.
7 Protection against immersion in water. It must not be possible for water to enter the enclosure under stated conditions of pressure and time.
8 Protection against indefinite immersion in water under specified pressure. It must not be possible for water to enter the enclosure.
X Indicates no *specified* protection.

Figure 3

Once again, great care must be taken to maintain the integrity of this type of system, as an inadvertent connection to earth, or interconnection with other circuits, would render the protection useless.

As with direct contact, RCDs are a useful back-up to EEBADS, and their use is essential when hand-held equipment is used outside the main equipotential zone.

The use of enclosures is not limited to protection against direct contact they clearly provide protection against the ingress of foreign bodies and moisture. In order to establish to what degree an enclosure can resist such ingress, reference to the IP code (BSEN 60529) should be made. Figure 3 illustrates part of the IP code.

The most commonly quoted IP codes in the 16th edition are IP2X, IPXXB and IP4X. The X denotes that protection is not specified, not that there is no protection. For example, an enclosure that was to be immersed in water would be classified IPX8, there would be no point using the code IP68.

Note: IPXXB denotes protection against finger contact only.

1
AN OVERVIEW

So, here you are outside the premises, armed with lots of test instruments, a clipboard, a pad of test results sheets, the IEE Regulations, Guidance Notes 3, and an instruction to carry out an inspection and test of the electrical installation therein. Dead easy, you've been told, piece of cake, just poke about a bit, 'Megger' the wiring, write the results down, sign the test certificate and you should be on to the next job within the hour!

Oh! would that it were that simple! What if lethal defects were missed by just 'poking about'? What if other tests should have been carried out which may have revealed serious problems? What if things go wrong after you have signed to say all is in accordance with the Regulations? What if you were not actually competent to carry out the inspection and test in the first place? What if . . . and so on, the list is endless. Inspection, testing and certification is a serious and, in many instances, a complex matter, so let us wind the clock back to the point at which you were about to enter the premises to carry out your tests, and consider the implications of carrying out an inspection and test of an installation.

What are the legal requirements in all of this? Where do you stand if things go wrong? What do you need to do to ensure compliance with the law?

Statutory regulations

The IEE Wiring Regulations (BS 7671) and associated guidance notes are *not* statutory documents, they can however be used in a court of law to prove compliance with statutory requirements such as the Electricity at Work Regulations (EAWR) 1989, which cover all work activity associated with electrical systems in non-domestic situations. A list of other statutory Regulations are given in Appendix 2 of the IEE Regulations. However, it is the Electricity at Work Regulations that are most closely associated with BS7671, and as such it is worth giving some areas a closer look.

There are thirty-three Regulations in all, twelve of which deal with the special requirements of mines and quarries, and another four with exemptions and extensions outside the UK etc. We are only concerned with the first sixteen Regulations, and Regulation 29, the defence regulation, which we shall come back to later. Let us start then, with a comment on the meaning of *electrical systems and equipment*.

Electrical systems and equipment

According to the EAWR, electrical systems and equipment can encompass anything from power stations to torch or wrist-watch batteries. A battery may not create a shock risk, but may cause burns or injury as a result of attempting to destroy it by fire, whereby explosions may occur. A system can actually include the source of energy, so, a test instrument with its own supply e.g. a continuity tester is a system in itself, and a loop impedance tester, which requires an external supply source, becomes part of the system into which it is connected. From the preceding comments it will be obvious then, that in broad terms, if something is electrical, it is or is part of, an electrical system. So, where does responsibility lie for any involvement with such a system?

The EAWR requires that every employer, employee and self-employed person be responsible for compliance with the Regulations with regards to matters within their control, and as such are known *duty holders*. Where then do you stand as the person about to conduct an inspection and test of an installation? Most certainly, you are a duty holder in that you have control of the installation in so far as you will ultimately pass the installation as safe or make recommendations to ensure its safety. You also have control of the test instruments which, as already stated are systems in themselves, and control of the installation whilst testing is being carried out.

Any breach of the Regulations may result in prosecution, and unlike the other laws, under this Act you are presumed guilty and have to establish your innocence by invoking the Defence Regulation 29. Perhaps some explanation is needed here. Each of the sixteen Regulations has a status, in that it is either *absolute* or *reasonably practicable*.

Regulations that are *absolute* must be conformed to at all cost, whereas those that are *reasonably practicable* are conformed to, provided that all reasonable steps have been taken to ensure safety. For the contravention of an *absolute* requirement, Regulation 29 is available as a defence in the event of criminal prosecution, provided the accused can demonstrate that they took all reasonable and diligent steps to prevent danger or injury.

No one wants to end up in court accused of negligence, and so we need to be sure that we know what we are doing when we are inspecting and testing.

Apart from the knowledge required competently to carry out the verification process, the person conducting the inspection and test, must be in possession of test instruments appropriate to the duty required of them.

Instruments

In order to fulfil the basic requirements for testing to BS 7671, the following instruments are needed:

1 A low-resistance ohm-meter (continuity tester).
2 An insulation resistance tester.
3 A loop impedance tester.
4 An RCD tester.
5 A prospective short circuit current (PSCC) tester.
6 An approved test lamp or voltage indicator.
7 A proving unit.

Many instrument manufacturers have developed dual or multi-function instruments, hence it is quite common to have continuity and insulation resistance in one unit, loop impedance and PSCC in one unit, loop impedance, PSCC and RCD tests in one unit etc. However, regardless of the various combinations, let us take a closer look at the individual test instrument requirements.

Low resistance ohmmeters/continuity testers

Bells, buzzers, simple multimeters etc. will all indicate whether or not a circuit is continuous, but will not show the difference between the resistance of say, a 10 m length of 10 mm^2 conductor and a 10 m length of 1 mm^2 conductor. I use this example as an illustration, as it is based on a real experience of testing the continuity of a 10 mm^2 main bonding conductor between gas and water services. The services, some 10 m apart, were at either ends of a domestic premises. The 10 mm^2 conductor, connected to both services, disappeared under the floor, and a measurement between both ends indicated a resistance higher than expected. Further investigation revealed, that just under the floor at each end, the 10 mm^2 conductor had been terminated in a connector block and the join between the two, about 8 m, had been wired with a 1 mm^2 conductor. Only a milli-ohmmeter would have detected such a fault.

> A low resistance ohm-meter should have a no-load source voltage of between 4 V and 24 V, and be capable of delivering an AC or DC short circuit voltage of not less than 200 mA. It should have a resolution (i.e. a detectable difference in resistance) of at least 0.05 milli-ohms.

Insulation resistance testers

An *insulation resistance test* is the correct term for this form of testing, not a '*megger*' test as megger is a manufacturer's trade name, not the name of the test.

An insulation resistance tester must be capable of delivering 1 mA when the required test voltage is applied across the minimum acceptable value of insulation resistance.

Hence, an instrument selected for use on a low voltage (50 VAC–1000 VAC) system should be capable of delivering 1 mA at 500 V across a resistance of 0.5 megohms.

Loop impedance tester

This instrument functions by creating, in effect, an earth fault for a brief moment, and is connected to the circuit via a plug or by 'flying leads' connected separately to phase, neutral, and earth.

The instrument should only allow an earth fault to exist for a maximum of 40 ms, and a resolution of 0.01 ohms is adequate for circuits up to 50 A. Above this circuit rating, the ohmic values become too small to give such accuracy using a standard instrument, and more specialized equipment may be required.

RCD tester

Usually connected by the use of a plug, although 'flying leads' are needed for non-socket outlet circuits, this instrument allows a range of out of balance currents to flow through the RCD to cause its operation within specified time limits.

The test instrument should not be operated for longer than 2 seconds, and it should have a 10 per cent accuracy across the full range of test currents.

PSCC tester

Normally one half of a dual, loop impedance/PSCC tester, this instrument measures the prospective phase neutral fault current at the point of measurement using the same leads as for loop impedance.

Approved test lamp or voltage indicator

A flexible cord with a lamp attached is not an approved device, nor for that matter is the ubiquitous 'testascope' or 'neon screwdriver', which encourages the passage of current, at low voltage, through the body!

A typical approved test lamp is as shown in Figure 1.1.

The Health and Safety Executive, Guidance Note 38, recommend that the leads and probes associated with test lamps, voltage indicators, voltmeters etc. have the following characteristics:

1 The leads should be adequately insulated and, ideally, fused.
2 The leads should be easily distinguished from each other by colour.
3 The leads should be flexible and sufficiently long for their purpose.
4 The probes should incorporate finger barriers, to prevent accidental contact with live parts.
5 The probes should be insulated and have a maximum of 2 mm of exposed metal, but preferably have spring loaded enclosed tips.

Proving unit

This is an optional item of test equipment, in that test lamps should be proved on a known supply which could, of course, be an

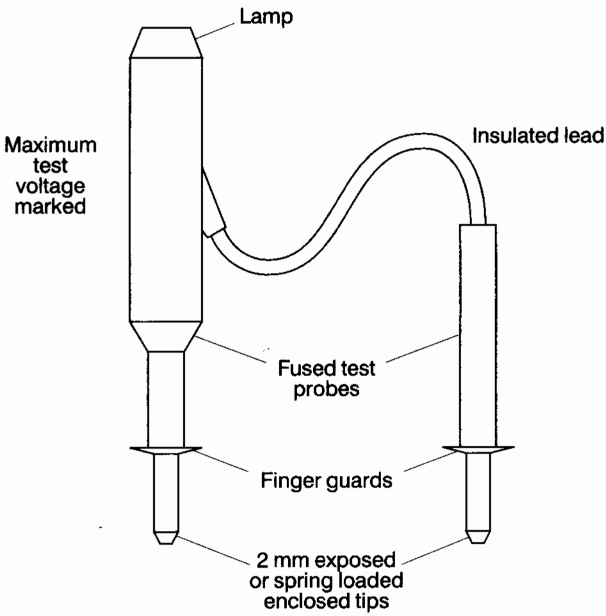

Figure 1.1

adjacent socket or lighting point etc. However, to prove a test lamp on such a known supply may involve entry into enclosures with the associated hazards that such entry could bring. A proving unit is a compact device not much larger than a cigarette packet, which is capable of electronically developing 240 V DC across which the test lamp may be proved. The exception to this are test lamps incorporating 240 V lamps which will not activate from the small power source of the proving unit.

> Test lamps must be proved against a voltage similar to that to be tested. Hence, proving test lamps that incorporate an internal check i.e. shorting out the probes to make a buzzer sound, is not acceptable if the voltage to be tested is higher than that delivered by the test lamp.

Care of test instruments

The Electricity at Work Regulations require that all electrical systems, this includes test instruments, be maintained to prevent danger. This does not restrict such maintenance to just a yearly calibration, but requires equipment to be kept in good condition in order that it is safe to use at all times.

Whilst test instruments and associated leads probes and clips etc., used in the electrical contracting industry are robust in design and manufacture, they still need treating with care and protecting from mechanical damage. Keep test gear in a separate box or case away from tools and sharp objects and always check the general condition of a tester and leads before they are used.

2
INITIAL INSPECTION

Inspection and testing

Circumstances which require an initial verification

New installations or Additions or Alterations

General reasons for initial verification

1 To ensure equipment and accessories are to a relevant standard.
2 To prove compliance with BS 7671
3 To ensure that the installation is not damaged so as to impair safety.

Information required

Assessment of general characteristics sections 311, 312 and 313 together with information such as drawings, charts etc. in accordance with Reg. 514–09–01.

Documentation required and to be completed

Electrical Installation Certificate signed or authenticated for the design and construction (could be the same person) and then for the inspection and test. A schedule of test results and an inspection schedule must accompany an Electrical Installation Certificate.

Sequence of tests

1 Continuity of all protective conductors
2 Continuity of ring final circuit conductors
3 Insulation resistance
4 Site applied insulation
5 Protection by separation of circuits
6 Protection against direct contact by barriers and enclosures provided during erection
7 Insulation of non-conducting floors and walls
8 Polarity
9 Earth electrode resistance
10 Earth fault loop impedance
11 Prospective fault current
12 Functional testing

Before any testing is carried out, a detailed physical inspection must be made to ensure that all equipment is to a relevant British or Harmonized European Standard, and that it is erected/installed in compliance with the IEE Regulations, and that it is not damaged such that it could cause danger. In order to comply with these requirements, the Regulations give a check list of some eighteen items that, where relevant, should be inspected.

However, before such an inspection, and test for that matter, is carried out, certain information *must* be available to the verifier. This information is the result of the Assessment of General Characteristics required by IEE Regulations Part 3, Sections 311, 312 and 313, and drawings, charts, and similar information relating to the installation. It is at this point that most readers who work in the real world of electrical installation will be lying on the floor laughing hysterically.

Let us assume that the designer and installer of the installation are competent professionals, and all of the required documentation is available.

Interestingly, one of the items on the check list *is* the presence of diagrams, instructions and similar information. If these are missing then there is a departure from the Regulations.

Another item on the list is the verification of conductors for current carrying capacity and voltage drop in accordance with the design. How on earth can this be verified without all the information? A 30 A Type B circuit breaker (CB) protecting a length of 4 mm^2 conductor may look reasonable, but is it correct, and are you prepared to sign to say that it is unless you are sure? Let us look then at the general content of the check list.

1 **Connection of conductors** Are terminations electrically and mechanically sound, is insulation and sheathing removed only to a minimum to allow satisfactory termination?
2 **Identification of conductors** Are conductors correctly identified in accordance with the Regulations?
3 **Routing of cables** Are cables installed such that account is taken of external influences such as mechanical damage, corrosion, heat etc?
4 **Conductor selection** Are conductors selected for current carrying capacity and voltage drop in accordance with the design?
5 **Connection of single pole devices** Are single pole protective and switching devices connected in the phase conductor only?
6 **Accessories and equipment** Are all accessories and items of equipment correctly connected?
7 **Thermal effects** Are fire barriers present where required and protection against thermal effects provided?
8 **Protection against shock** What methods have been used to provide protection against direct and indirect contact?
9 **Mutual detrimental influence** Are wiring systems installed such that they can have no harmful effect on non-electrical systems, or that systems of different currents or voltages are segregated where necessary?
10 **Isolation and switching** Are there appropriate devices for isolation and switching correctly located and installed?
11 **Undervoltage** Where undervoltage may give rise for concern, are there protective devices present?
12 **Protective devices** Are protective and monitoring devices correctly chosen and set to ensure protection against indirect contact and/or overcurrent?

13 **Labelling** Are all protective devices, switches (where necessary) and terminals correctly labelled?
14 **External influences** Have all items of equipment and protective measures been selected in accordance with the appropriate external influences?
15 **Access** Are all means of access to switchgear and equipment adequate?
16 **Notices and signs** Are danger notices and warning signs present?
17 **Diagrams** Are diagrams, instructions and similar information relating to the installation available?
18 **Erection methods** Have all wiring systems, accessories and equipment been selected and installed in accordance with the requirements of the Regulations, and are fixings for equipment adequate for the environment?

So, we have now inspected all relevant items, and provided that there are no defects that may lead to a dangerous situation when testing, we can now start the actual testing procedure.

3
TESTING CONTINUITY OF PROTECTIVE CONDUCTORS

All protective conductors, including main equipotential and supplementary bonding conductors must be tested for continuity using a low resistance ohmmeter.

For main equipotential bonding there is no single fixed value of resistance above which the conductor would be deemed unsuitable. Each measured value, if indeed it is measurable for very short lengths, should be compared with the relevant value for a particular conductor length and size. Such values are shown in Table 3.1.

Table 3.1 Resistance (Ω) of copper conductors at 20°C

CSA	*Length (m)*									
(mm²)	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.82	0.9
1.5	0.06	0.12	0.18	0.24	0.3	0.36	0.43	0.48	0.55	0.6
2.5	0.04	0.07	0.11	0.15	0.19	0.22	0.26	0.03	0.33	0.37
4	0.023	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.21	0.23
6	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.13	0.14	0.16
10	0.01	0.02	0.03	0.04	0.05	0.06	0.063	0.07	0.08	0.09
16	0.006	0.01	0.02	0.023	0.03	0.034	0.04	0.05	0.05	0.06
25	0.004	0.007	0.01	0.015	0.02	0.022	0.026	0.03	0.033	0.04
35	0.003	0.005	0.008	0.01	0.013	0.016	0.019	0.02	0.024	0.03

Where a supplementary equipotential bonding conductor has been installed between *simultaneously accessible* exposed and extraneous conductive parts, because circuit disconnection times cannot be met, then the resistance (R) of the conductor, must be equal to or less than 50/Ia. In the case of construction sites and agricultural or horticultural installations the 50 is replaced by 25.

So, $R \leqslant 50/\mathrm{Ia}$, or 25/Ia, where 50, and 25, are the voltages above which exposed metalwork should not rise, and Ia is the minimum current causing operation of the circuit protective device within 5 secs.

For example, suppose a 45 A BS 3036 fuse protects a cooker circuit, the disconnection time for the circuit cannot be met, and so a supplementary bonding conductor has been installed between the cooker case and an adjacent central heating radiator. The resistance (R) of that conductor should not be greater than 50/Ia, and Ia in this case is 145 A (see Figure 3.2B of the IEE Regulations)

i.e. $50/145 = 0.34\,\Omega$

How then, do we conduct a test to establish continuity of main or supplementary bonding conductors? Quite simple really, just connect the leads from a low resistance ohmmeter to the ends of the bonding conductor (Figure 3.1). One end should be disconnected from its bonding clamp, otherwise any measurement may include

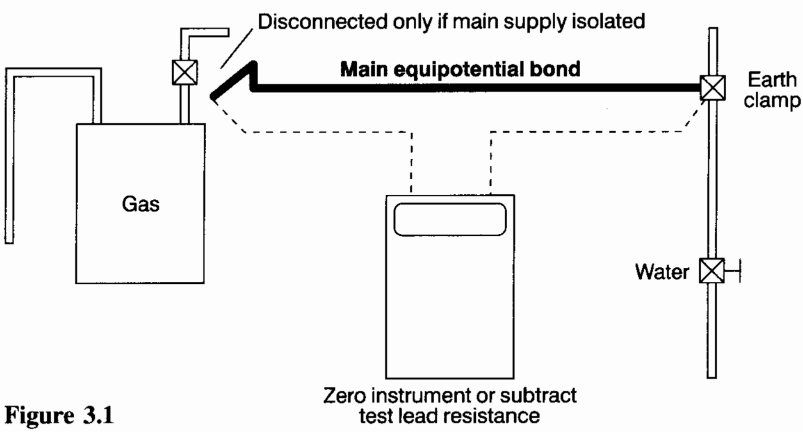

Figure 3.1

the resistance of parallel paths of other earthed metalwork. Remember to zero the instrument first or, if this facility is not available, record the resistance of the test leads so that this value can be subtracted from the test reading.

IMPORTANT NOTE: If the installation is in operation, then *never* disconnect main bonding conductors unless the supply can be isolated. Without isolation, persons and livestock are at risk of electric shock.

The continuity of circuit protective conductors may be established in the same way, but a second method is preferred, as the results of this second test indicate the value of $(R_1 + R_2)$ for the circuit in question.

The test is conducted in the following manner:

1 Temporarily link together the phase conductor and cpc of the circuit concerned in the distribution board or consumer unit.
2 Test between phase and cpc at EACH outlet in the circuit. A reading indicates continuity.
3 Record the test result obtained at the furthest point in the circuit. This value is $(R_1 + R_2)$ for the circuit.

Figure 3.2 illustrates the above method.

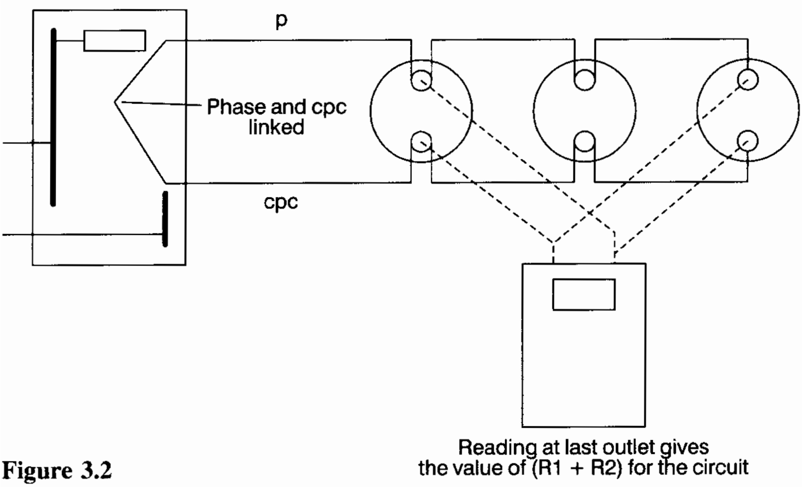

Figure 3.2

There may be some difficulty in determining the $(R_1 + R_2)$ values of circuits in installations that comprise steel conduit and trunking, and/or SWA and mims cables because of the parallel earth paths that are likely to exist. In these cases, continuity tests may have to be carried out at the installation stage before accessories are connected or terminations made off as well as after completion.

Although it is no longer considered good working practice to use steel conduit or trunking as a protective conductor, it is permitted, and hence its continuity must be proved. The enclosure must be inspected along its length to ensure that it is sound and then the standard low resistance test is performed. If the verifier has any doubt as to the soundness of the conductor, a further test is made using a high current test instrument which has a test voltage not exceeding 50 V and can deliver up to 1.5 times the design current of the circuit up to a maximum of 25 A. This test can cause arcing at faulty joints and hence should not be carried out if there is any chance of danger.

4
TESTING CONTINUITY OF RING FINAL CIRCUIT CONDUCTORS

There are two main reasons for conducting this test:

1 To establish that interconnections in the ring do not exist.
2 To ensure that the cpc is continuous, and indicate the value of ($R_1 + R_2$) for the ring.

What then are interconnections in a ring circuit, and why is it important to locate them? Figure 4.1 shows a ring final circuit with an interconnection.

The most likely cause of the situation shown in Figure 4.1 is where a DIY enthusiast has added sockets P, Q, R and S to an existing ring A, B, C, D, E and F.

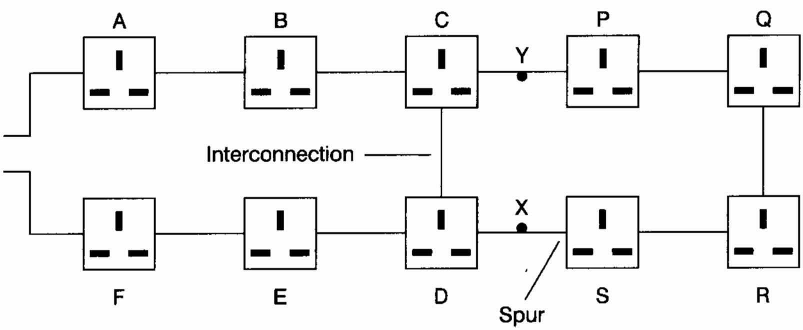

Figure 4.1

In itself there is nothing wrong with this. The problem arises if a break occurs at, say, point Y, or the terminations fail in socket C or P. Then there would be four sockets all fed from the point X which would then become a spur.

So, how do we identify such a situation with or without breaks at point 'Y'? A simple resistance test between the ends of the phase, neutral or circuit protective conductors will only indicate that a circuit exists, whether there are interconnections or not. The following test method is based on the philosophy that the resistance measured across any diameter of a perfect circle of conductor will always be the same value (Figure 4.2).

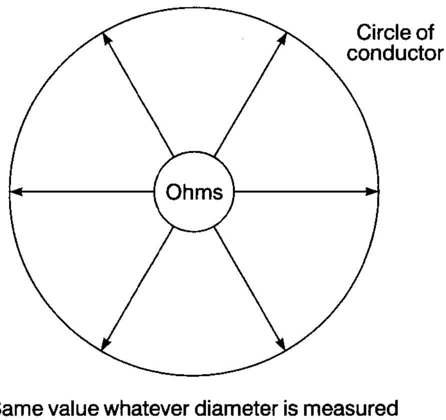

Figure 4.2

The perfect circle of conductor is achieved by cross connecting the phase and neutral legs of the ring (Figure 4.3).

The test procedure is as follows:

1 Identify the opposite legs of the ring. This is quite easy with sheathed cables, but with singles, each conductor will have to be identified, probably by taking resistance measurements between each one and the closest socket outlet. This will give three high readings and three low readings thus establishing the opposite legs.

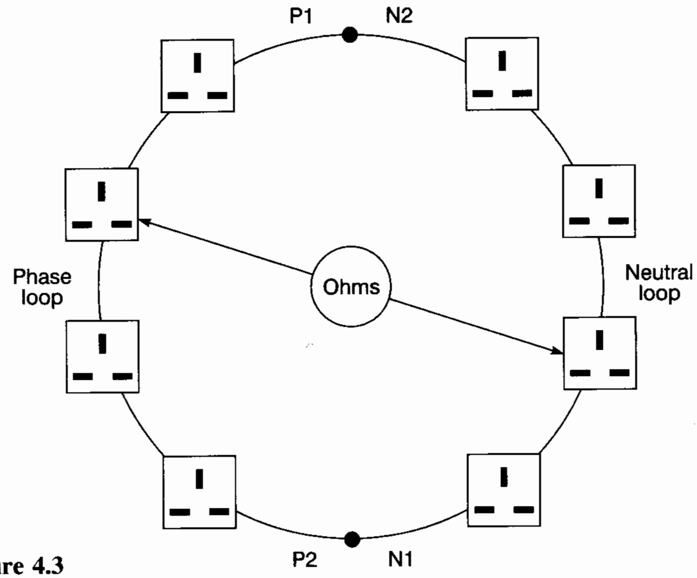

Figure 4.3

2 Take a resistance measurement between the ends of each conductor loop. Record this value.
3 Cross connect the opposite ends of the phase and neutral loops (Figure 4.4).
4 Measure between phase and neutral at each socket on the ring. The readings obtained should be, for a perfect ring, substantially the same. If an interconnection existed such as shown in Figure 4.1, then sockets A to F would all have similar readings, and those beyond the interconnection would have gradually increasing values to approximately the mid point of the ring, then decreasing

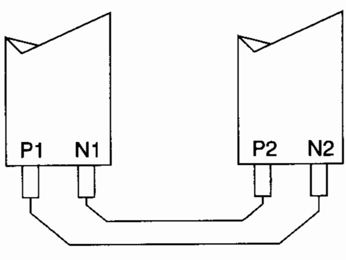

Figure 4.4

values back towards the interconnection. If a break had occurred at point Y then the readings from socket S would increase to a maximum at socket P. One or two high readings are likely to indicate either loose connections or spurs. A null reading, i.e. an open circuit indication, is probably a reverse polarity, either phase-cpc or neutral-cpc reversal. These faults would clearly be rectified and the test at the suspect socket(s) repeated.

5 Repeat the above procedure, but in this case cross connect the phase and cpc loops (Figure 4.5).

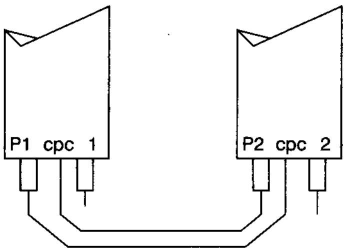

Figure 4.5

In this instance, if the cable is of the flat twin type, the readings at each socket will increase very slightly and then decrease around the ring. This difference, due to the phase and cpc being different sizes, will not be significant enough to cause any concern. The measured value is very important, it is $R_1 + R_2$ for the ring.

As before, loose connections, spurs and, in this case, P – N cross polarity, will be picked up.

Table 4.1

Initial measurements	P1–P2 0.52	N1–N2 0.52	cpc 1 – cpc2 0.86
Reading at each socket	0.26	0.26	0.32 – 0.34
For spurs, each metre in length will add the following resistance to the above values	0.015	0.015	0.02

Socket	P–N Reading	P–CPC Reading
A	OK	No Reading
B	No Reading	OK
C	No Reading	No Reading

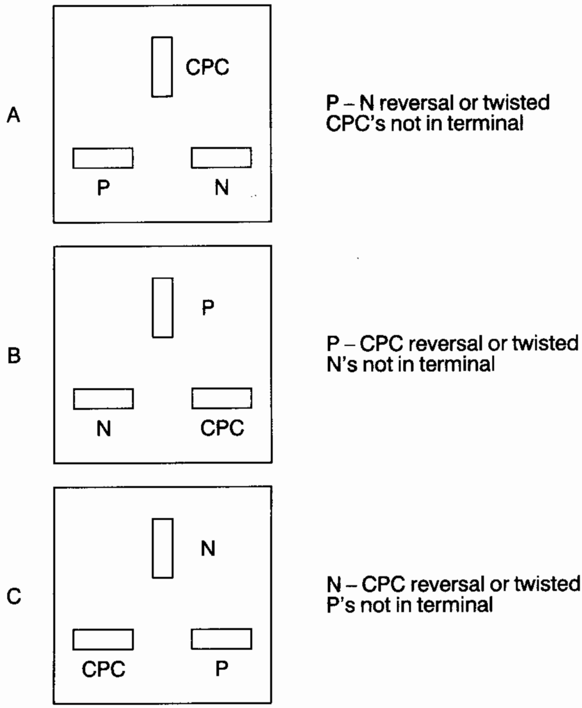

Figure 4.6

The details in Table 4.1 are typical approximate ohmic values for a healthy 70 m ring final circuit wired in 2.5/1.5 flat twin and cpc cable. (In this case the CPC will be approximately 1.67× the P or N resistance.)

As already mentioned null readings may indicate a reverse polarity. They could also indicate twisted conductors not in their terminal housing. The examples shown in Figure 4.6 may help to explain these situations.

5
TESTING INSULATION RESISTANCE

This is probably the most used and yet abused test of them all. Affectionately known as 'meggering', an *insulation resistance test* is performed in order to ensure that the insulation of conductors, accessories and equipment is in a healthy condition, and will prevent dangerous leakage currents between conductors and between conductors and earth. It also indicates whether any short circuits exist.

Insulation resistance, as just discussed, is the resistance measured between conductors and is made up of countless millions of resistances in parallel (Figure 5.1).

The more resistances there are in parallel, the *lower* the overall resistance, and in consequence, the longer a cable the lower the insulation resistance. Add to this the fact that almost all installation circuits are also wired in parallel, it becomes apparent that tests on large installations may give, if measured as a whole, pessimistically low values, even if there are no faults.

Under these circumstances, it is usual to break down such large installations into smaller sections, floor by floor, sub-main by sub-main etc. This also helps, in the case of periodic testing, to minimize disruption. The test procedure is as follows:

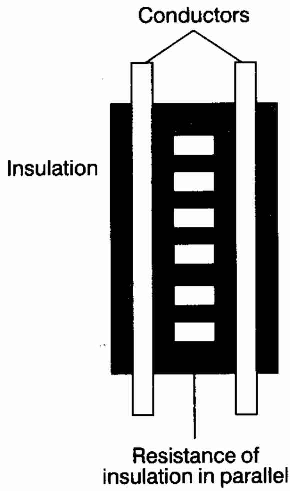

Figure 5.1

1 Disconnect all items of equipment such as capacitors and indicator lamps as these are likely to give misleading results. Remove any items of equipment likely to be damaged by the test, such as dimmer switches, electronic timers etc. Remove all lamps and accessories and disconnect fluorescent and discharge fittings. Ensure that the installation is disconnected from the supply, all fuses are in place, and MCBs and switches are in the on position. In some instances it may be impracticable to remove lamps etc. and in this case the local switch controlling such equipment may be left in the off position.
2 Join together all live conductors of the supply and test between this join and earth. Alternatively, test between each live conductor and earth in turn.
3 Test between phase and neutral. For three phase systems, join together all phases and test between this join and neutral. Then test between each of the phases. Alternatively, test between each of the live conductors in turn. Installations incorporating two-way lighting systems should be tested twice with the two-way switches in alternative positions.

Table 5.1

System	*Test voltage*	*Minimum insulation resistance*
SELV and PELV	250 V DC	0.25 MΩ
LV up to 500 V	500 V DC	0.5 MΩ
Over 500 V	1000 V DC	1.0 MΩ

Table 5.1 gives the test voltages and minimum values of insulation resistance for ELV and LV systems.

If a value of less than 2 MΩ is recorded it may indicate a situation where a fault is developing, but as yet still complies with the minimum permissible value. In this case each circuit should be tested separately and each should be above 2 MΩ.

Example

An installation comprising six circuits have individual insulation resistances of 2.5 MΩ, 8 MΩ, 200 MΩ, 200 MΩ, 200 MΩ and 200 MΩ, and so the total insulation resistance will be:

$$\frac{1}{R_t} = \frac{1}{2.5} + \frac{1}{8} + \frac{1}{200} + \frac{1}{200} + \frac{1}{200} + \frac{1}{200}$$

$$= 0.4 + 0.125 + 0.005 + 0.005 + 0.005 + 0.005$$

$$= 0.545$$

$$R_t = \frac{1}{0.545}$$

$$= 1.83\ \text{M}\Omega$$

This is clearly greater than the 0.5 MΩ minimum but less than 2 MΩ, but as all circuits are greater than 2 MΩ the system could be considered satisfactory.

6
SPECIAL TESTS

The next four tests are special in that they are not often required in the general type of installation. They also require special test equipment. In consequence, the requirements for these tests will only be briefly outlined in this chapter.

Site applied insulation

When insulation is applied to live parts during the erection process on site in order to provide protection against direct contact, then a test has to be performed to show that the insulation can withstand a high voltage equivalent to that specified in the BS for similar factory built equipment.

If supplementary insulation is applied to equipment on site, to provide protection against indirect contact, then the voltage withstand test must be applied, and the insulating enclosure must afford a degree of protection of not less than IP2X or IPXXB.

Protection by separation of circuits

When SELV or PELV is used as a protective measure, then the separation from circuits of a higher voltage has to be verified by an insulation resistance test at a test voltage of 250 V and result in a minimum insulation resistance of 0.25 MΩ. If the circuit is at low voltage and supplied from, say, a BS 3535 transformer the test is at 500 V with a minimum value of 0.555 MΩ.

Protection by barriers or enclosures

If, on site, protection against direct contact is provided by fabricating an enclosure or erecting a barrier, it must be shown that the enclosure can provide a degree of protection of at least IP2X or IPXXB. Readily accessible horizontal top surfaces should be to at least IP4X.

An enclosure having a degree of protection IP2X can withstand the ingress of fingers and solid objects exceeding 12 mm diameter. IPXXB is protection against finger contact only. IP4X gives protection against wires and solid objects exceeding 1 mm in diameter.

The test for IP2X or IPXXB is conducted with a 'standard test finger' which is supplied at a test voltage not less than 40 V and no more than 50 V. One end of the finger is connected in series with a lamp and live parts in the enclosure. When the end of the finger is introduced into the enclosure, provided the lamp does not light then the protection is satisfactory.

The test for IP4X is conducted with a rigid 1 mm diameter wire with its end bent at right angles. Protection is afforded if the wire does not enter the enclosure.

Protection by non-conducting location

This is a rare location and demands specialist equipment to measure the insulation resistance between insulated floors and walls at various points.

7
TESTING POLARITY

This simple test, often overlooked, is just as important as all the others, and many serious injuries and electrocutions could have been prevented if only polarity checks had been carried out.

The requirements are:

1 All fuses and single pole switches are in the phase conductor.
2 The centre contact of an Edison screw type lampholder is connected to the phase conductor.
3 All socket outlets and similar accessories are correctly wired.

Although polarity is towards the end of the recommended test sequence, it would seem sensible, on lighting circuits, for example, to conduct this test at the same time as that for continuity of CPCs (Figure 7.1).

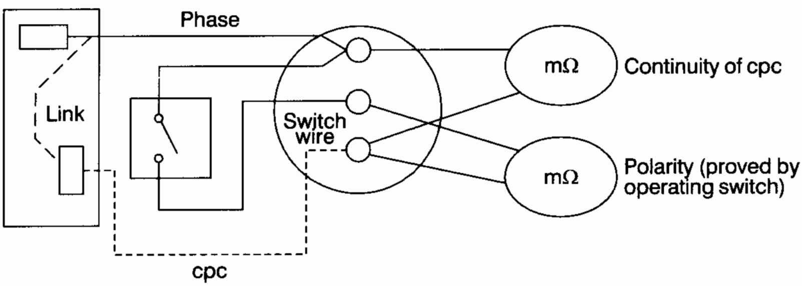

Figure 7.1

Testing polarity

As discussed earlier, polarity on ring final circuit conductors, is achieved simply by conducting the ring circuit test. For radial socket outlet circuits, however, this is a little more difficult. The continuity of the CPC will have already been proved by linking phase and CPC and measuring between the same terminals at each socket. Whilst a phase-CPC reversal would not have shown, a phase-neutral reversal would, as there would have been no reading at the socket in question. This would have been remedied, and so only phase-CPC reversals need to be checked. This can be done by linking together phase and neutral at the origin and testing between the same terminals at each socket. A phase-CPC reversal will result in no reading at the socket in question.

When the supply is connected, it is important to check that the incoming supply is correct. This is done using an approved voltage indicator at the intake position or close to it.

8
TESTING EARTH FAULT LOOP IMPEDANCE

This is very important but sadly, poorly understood. So let us remind ourselves of the component parts of the earth fault loop path (Figure 8.1). Starting at the point of fault:

1 The CPC.
2 The main earthing conductor and earthing terminal.
3 The return path via the earth for TT systems, and the metallic return path in the case of TN–S or TN–C–S systems. In the latter case the metallic return is the PEN conductor.
4 The earthed neutral of the supply transformer.
5 The transformer winding.
6 The phase conductor back to the point of fault.

Overcurrent protective devices must, under earth fault conditions, disconnect fast enough to reduce the risk of electric shock. This is achieved if the actual value of the earth fault loop impedance does not exceed the tabulated maximum values given in the IEE regulations.

The purpose of the test, therefore, is to determine the actual value of the loop impedance (Z_S), for comparison with those maximum values, and it is conducted as follows:

1 Ensure that all main equipotential bonding is in place.
2 Connect the test instrument either by its BS 4363 plug, or the 'flying leads', to the phase, neutral and earth terminals at

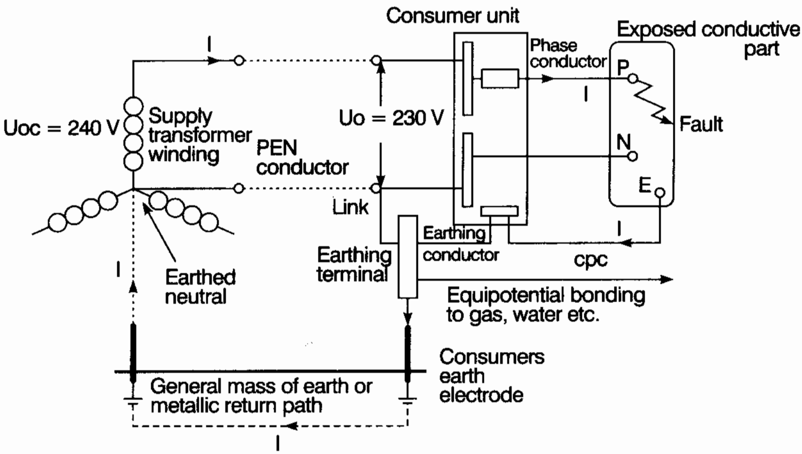

Figure 8.1

the remote end of the circuit under test. (If a neutral is not available, e.g. in the case of a three phase motor, connect the neutral probe to earth.)

3 Press to test and record the value indicated.

It must be understood, that this instrument reading is *not valid for direct comparison with the tabulated maximum values*, as account must be taken of the ambient temperature at the time of test, and the maximum conductor operating temperature, both of which will have an effect on conductor resistance. Hence, the $(R_1 + R_2)$ could be greater at the time of fault than at the time of test.

So, our measured value of Z_s must be corrected to allow for these possible increases in temperature occurring at a later date. This requires actually measuring the ambient temperature and applying factors in a formula.

Clearly this method of correcting Z_s is time consuming and unlikely to be commonly used. Hence, a rule of thumb method may be applied which simply requires that the measured value of Z_s does not exceed 3/4 of the appropriate tabulated value. Table 8.3 gives the 3/4 values of tabulated loop impedance for direct comparison with measured values.

Table 8.1 Values of loop impedance for comparison with test readings

Protection	*Disconnection time (s)*		*Rating of protection*																		
			5A	6A	10A	15A	16A	20A	25A	30A	32A	40A	45A	50A	60A	63A	80A	100A	125A	160A	200A
BS 3036 fuse	0.4	Z_s max	7.5	–	–	2	–	1.38	–	0.85	–	–	0.46								
	5	Z_s max	13.9	–	–	4.1	–	3	–	2.97	–	–	1.25	–	0.87	–	–	0.42			
BS 88 fuse	0.4	Z_s max	–	6.66	4	–	2.11	1.38	1.12	–	0.82	0.64	–	0.47							
	5	Z_s max	–	10.5	5.8	–	3.27	2.28	1.8	–	1.44	1.05	–	0.82	–	0.64	0.45	0.33	0.26	0.2	0.14
BS 1361 fuse	0.4	Z_s max	8.17	–	–	2.57	–	1.33	–	0.9	–	–	0.45								
	5	Z_s max	12.8	–	–	3.9	–	2.19	–	1.44	–	–	0.75	0.54	–	0.39	0.28				
BS 3871 MCB Type 1	0.4 & 5	Z_s max	9	7.5	4.5	3	2.81	2.25	1.8	1.5	1.41	1.12	1	0.9	–	0.71					
BS 3871 MCB Type 2	0.4 & 5	Z_s max	5.14	4.28	2.57	1.71	1.6	1.28	1.02	0.85	0.8	0.64	0.57	0.51	–	0.4					
BS 3871 MCB Type 3	0.4 & 5	Z_s max	3.6	3	1.8	1.2	1.12	0.9	0.72	0.6	0.56	0.45	0.4	0.36	–	0.28					
BS EN 60898 CB Type B	0.4 & 5	Z_s max	–	6	3.6	–	2.25	1.8	1.44	–	1.12	0.9	0.8	0.72	–	0.57					
BS EN 60898 CB Type C	0.4 & 5	Z_s max	3.6	3	1.8	1.2	1.12	0.9	0.72	0.6	0.56	0.45	0.4	0.36	–	0.28					
BS EN 60898 CB Type D	0.4 & 5	Z_s max	1.8	1.5	0.9	0.6	0.56	0.45	0.36	0.3	0.28	0.22	0.2	0.18	–	0.14					

In effect, a loop impedance test places a phase/earth fault on the installation, and if an RCD is present it may not be possible to conduct the test as the device will trip out each time the loop impedance tester button is pressed. Unless the instrument is of a type that has a built-in guard against such tripping, the value of Z_s will have to be determined from measured values of Z_e and $(R_1 + R_2)$, and the 3/4 rule applied.

IMPORTANT NOTE: Never short out an RCD in order to conduct this test.

As a loop impedance test creates a high earth fault current, albeit for a short space of time, some lower rated MCBs may operate resulting in the same situation as with an RCD, and Z_s will have to be calculated. It is not really good practice temporarily to replace the MCB with one of a higher rating.

External loop impedance Z_e

The value of Z_e is measured at the intake position on the supply side and with all main equipotential bonding disconnected. Unless the installation can be isolated from the supply, this test should not be carried out, as a potential shock risk will exist with the supply on and the main bonding disconnected.

Prospective fault current

This would normally be carried out at the same time as the measurement for Ze using a PFC or PSCC tester. If this value cannot be measured it must be ascertained by either enquiry or calculation.

9
TESTING EARTH ELECTRODE RESISTANCE

In many rural areas, the supply system is TT and hence reliance is placed on the general mass of earth for a return path under earth fault conditions. Connection to earth is made by an electrode, usually of the rod type, and preferably installed as shown in Figure 9.1.

In order to determine the resistance of the earth return path, it is necessary to measure the resistance that the electrode has with earth. If we were to make such measurements at increasingly longer distances from the electrode, we would notice an increase in

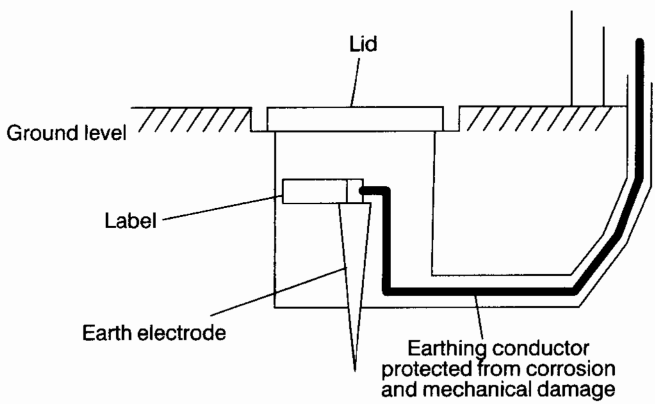

Figure 9.1

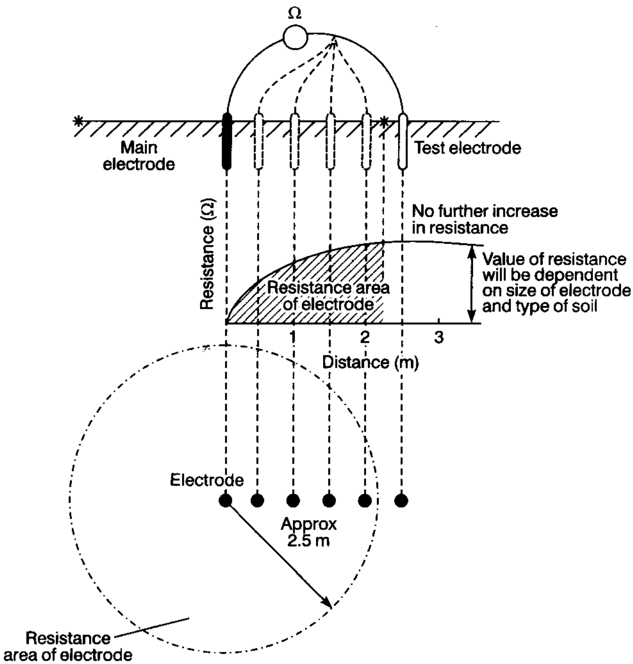

Figure 9.2

resistance up to about 2.5–3 m from the rod, after which no further increase in resistance would be noticed (Figure 9.2).

The maximum resistance recorded is the electrode resistance and the area that extends the 2.5–3 m beyond the electrode is known as the earth electrode resistance area.

There are two methods of making the measurement, one using a proprietary instrument, and the other using a loop impedance tester.

Method 1 – protection by overcurrent device

This method is based on the principle of the potential divider (Figure 9.3).

By varying the position of the slider the resistance at any point may be calculated from $R = V/I$.

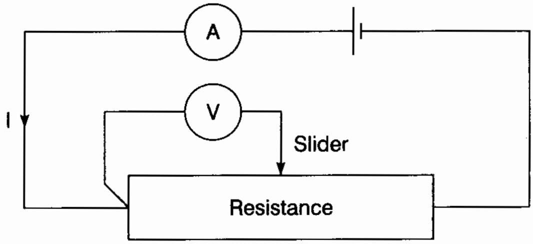

Figure 9.3

The earth electrode resistance test is conducted in a similar fashion, with the earth replacing the resistance and a potential electrode replacing the slider (Figure 9.4). In Figure 9.4 the earthing conductor to the electrode under test is temporarily disconnected.

The method of test is as follows:

1 Place the current electrode (C2) away from the electrode under test, approximately 10 times its length, i.e. 30 m for a 3 m rod.
2 Place the potential electrode mid way.
3 Connect test instrument as shown.
4 Record resistance value.

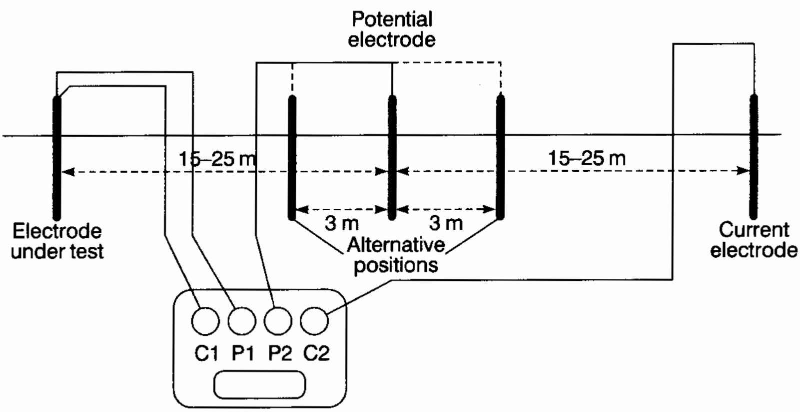

Figure 9.4

5 Move the potential electrode approximately 3 m either side of the mid position, and record these two readings.
6 Take an average of these three readings (this is the earth electrode resistance).
7 Determine the maximum deviation or difference of this average from the three readings.
8 Express this deviation as a percentage of the average reading.
9 Multiply this percentage deviation by 1.2.
10 Provided this value does not exceed a figure of 5% then the accuracy of the measurement is considered acceptable.

If three readings obtained from an earth electrode resistance test were 181 Ω, 185 Ω and 179 Ω. What is the value of the electrode resistance and is the accuracy of the measurement acceptable?

$$\text{Average value} = \frac{181 + 185 + 179}{3}$$

$$= 181.67\,\Omega$$

$$\text{Maximum deviation} = 185 - 181.67$$

$$= 3.33$$

$$\text{Expressed as a percentage of the average} = \frac{3.33 \times 100}{181.67}$$

$$= 1.83\%$$

$$\text{Measurement accuracy} = 1.83\% \times 1.2 = 2.2\%$$

(which is acceptable)

For TT systems the result of this test will indicate compliance if the product of the electrode resistance and the operating current of the overcurrent device does not exceed 50 V.

Method 2 – protection by a residual current device

In this case, an earth fault loop impedance test is carried out between the incoming phase terminal and the electrode (a standard test for Z_e).

The value obtained is added to the cpc resistance of the protected circuits and this value is multiplied by the operating current of the RCD. The resulting value should not exceed 50 V. If it does, then Method 1 should be used to check the actual value of the electrode resistance.

10
FUNCTIONAL TESTING

RCD RCBO operation

Where RCDs RCBOs are fitted, it is essential that they operate within set parameters. The RCD testers used are designed to do just this, and the basic tests required are as follows:

1 Set the test instrument to the rating of the RCD.
2 Set the test instrument to half rated trip.
3 Operate the instrument and the RCD should not trip.
4 Set the instrument to deliver the full rated tripping current of the RCD.
5 Operate the instrument and the RCD should trip out in the required time.

Table 10.1

RCD type	*½ rated*	*Full trip current*
BS 4239 and BS 7288 sockets	No trip	<200 ms
BS 4239 with time delay	No trip	½ time delay + 200 ms-time delay + 200 ms
BS EN 61009 or BS EN 61009 rcbo	No trip	300 ms
As above but Type S with time delay	No trip	130–500 ms

There seems to be a popular misconception regarding the ratings and uses of RCD's in that they are the panacea for all electrical ills and the only useful rating is 30 mA!!

Firstly, RCD's are not fail safe devices, they are electro-mechanical in operation and can malfunction. Secondly, general purpose RCD's are manufactured in ratings from 5 mA to 100 mA and have many uses. Let us first deal with RCD's rated at 30 mA or less. The accepted lethal level of shock current is 50 mA and hence RCD's rated at 30 mA or less would be appropriate for use where shock is an increased risk. BS7671 indicates that RCD's of 30 mA or less should be used in the following situations:

1 To protect circuits supplying hand held equipment outside the equipotential zone.
2 To protect all socket outlet circuits in a TT system installation.
3 To protect all socket outlets in a caravan park.
4 To provide supplementary protection against Direct contact.
5 For fixed current using equipment in bathrooms.

In all these cases and apart from conducting the tests already mentioned, it is required that the RCD be injected with a current five times its operating current and the tripping time should not exceed 40 ms.

Where loop impedence values cannot be met, RCD's of an appropriate rating can be installed. Their rating can be determined from

$$I\,n = 50/Zs$$

Where I n is the rated operating current of the device
50 is the touch voltage
Zs is the measured loop impedence

RCD's can also be used for:

1 Discrimination e.g. a 100 mA device to protect the whole installation and a 30 mA for the sockets.
2 Protection against fire use, say, a 500 mA device.

Functional testing

All RCDs have a built-in test facility in the form of a test button. Operating this test facility creates an artificial out of balance condition that causes the device to trip. This only checks the mechanics of the tripping operation, it is not a substitute for the tests just discussed.

All other items of equipment such as switchgear, controlgear interlocks etc. must be checked to ensure that they are correctly mounted and adjusted and that they function correctly.

11
PERIODIC INSPECTION

Periodic inspection and testing

Circumstance which require a periodic inspection and test

Test and inspection is due; insurance, mortgage, licensing reasons; change of use; change of ownership; after additions or alterations; after damage; change of loading; to assess compliance with current Regulations.

General reasons for a periodic inspection and test

1 To ensure the safety of persons and livestock.
2 To ensure protection of property from fire and heat.
3 To ensure that the installation is not damaged so as to impair safety.
4 To ensure that the installation is not defective and complies with the current Regulations.

General areas of investigation

Safety; wear and tear; corrosion; damage; overloading; age; external influences; suitability; effectiveness.

Documentation to be completed

Periodic test report, schedule of test results and an inspection schedule.

Sequence of tests

1 Continuity of all protective conductors.
2 Polarity.
3 Earth fault loop impedance.
4 Insulation resistance.
5 Operation of isolating and switching devices.
6 Operation of RCDs.
7 Prospective fault current.

and where appropriate

8 Continuity of ring final circuit conductors.
9 Earth electrode resistance.
10 Manual operation of RCDs.
11 Protection by separation of circuits.
12 Insulation of non-conducting floors and walls.

This could be so simple. As it is, periodic inspection and testing tends to be complicated and frustrating. On the domestic scene, I doubt if any house owner actually decides to have a regular inspection. They say, 'If it works it must be OK'. It is usually only when there is a change of ownership that the mortgage companies insist on an electrical survey. The worst cases are, however, industry and commerce. Periodic inspections are requested, reluctantly, to satisfy insurers or an impending visit by the HSE. Even then it is usually the case that 'you can't turn that off' or 'why can't you just test this bit and then issue a certificate for the whole lot'. Under the rare circumstances when an inspection and test is genuinely requested it is difficult to convince the client that, as there are no drawings, or information about the installation, and that no switchgear is labelled etc., you are going to be on site for a considerable time and at a considerable cost.

When there are no drawings or items of information, especially on a large installation, there may be a degree of exploratory work to be carried out in order to ensure safety whilst inspecting and testing. If it is felt that it may be unsafe to continue with the inspection and test, then drawings and information **must** be produced in order to avoid contravening the Health and Safety at Work Act Section 6.

However, let us assume, as with the initial inspection, that the original installation was erected in accordance with the 16th edition, and that any alterations and/or additions have been faithfully recorded on the original documentation which is, of course, readily available!

A periodic inspection and test under these circumstances should be relatively easy, as little dismantling of the installation will be necessary, and the bulk of the work will be inspection.

Inspection should be carried out with the supply disconnected as it may be necessary to gain access to wiring in enclosures etc. and hence, with large installations it will probably need considerable liaison with the client to arrange convenient times for interruption of supplies to various parts of the installation.

This is also the case when testing protective conductors, as these must *never* be disconnected unless the supply can be isolated. This is particularly important for main equipotential bonding conductors which need to be disconnected in order to measure Z_e.

In general an inspection should reveal:

1 Any aspects of the installation that may impair the safety of persons and livestock against the effects of electric shock and burns.
2 That there are no installation defects that could give rise to heat and fire and hence damage property.
3 That the installation is not damaged or deteriorated so as to impair safety.
4 That any defects or non-compliance with the Regulations, that may give rise to danger, are identified.

As was mentioned earlier, dismantling should be kept to a minimum and hence a certain amount of sampling will take place.

This sampling would need to be increased in the event of defects being found.

From the testing point of view, not all of the tests carried out on the initial inspection may need to be applied. This decision depends on the condition of the installation.

The continuity of protective conductors is clearly important as is insulation resistance and loop impedance, but one wonders if polarity tests are necessary if the installation has remained undisturbed since the last inspection. The same applies to ring circuit continuity as the P–N test is applied to detect inter-connections in the ring, which would not happen on their own.

It should be noted that if an installation is effectively supervised in normal use, then Periodic Inspection and Testing can be replaced by regular maintenance by skilled persons. This would only apply to, say, factory installations where there are permanent maintenance staff.

12
CERTIFICATION

Having completed all the inspection checks and carried out all the relevant tests, it remains to document all this information. This is done on electrical installation certificates, inspection schedules, test schedules, test result schedules, periodic inspection and test reports, minor works certificates and any other documentation you wish to append to the foregoing. Examples of such documentation are shown in the IEE Guidance Notes 3 on inspection and testing.

This documentation is vitally important. It has to be correct and signed or authenticated by a competent person. Electrical installation certificates and periodic reports must be accompanied by a schedule of test results and an inspection schedule for them to be valid. It should be noted that three signatures are required on an electrical installation certificate, one in respect of the design, one in respect of the construction and one in respect of the inspection and test. (For larger installations there may be more than one designer, hence the certificate has space for two signatures, i.e. designer 1 and designer 2.) It could be, of course, that for a very small company, one person signs all three parts. Whatever the case, the original must be given to the person ordering the work, and a duplicate retained by the contractor.

One important aspect of the electrical installation certificate is the recommended interval between inspections. This should be evaluated by the designer and will depend on the type of installation and its usage. In some cases the time interval is mandatory, especially where environments are subject to use by the public. Guidance Notes 3 give recommended maximum frequencies between inspections.

A periodic report form is very similar in part to an electrical installation certificate in respect of details of the installation, i.e. maximum demand, type of earthing system, Z_e, etc. The rest of the form deals with the extent and limitations of the inspection and test, recommendations, and a summary of the installation. The record of the extent and limitations of the inspection is very important. It must be agreed with the client or other third party exactly what parts of the installation will be covered by the report and those that will not. The interval until the next test is determined by the inspector.

With regard to the schedule of test results, test values should be recorded unadjusted, any compensation for temperature etc. being made after the testing is completed.

Any alterations or additions to an installation will be subject to the issue of an electrical installation certificate, except where the addition is, say, a single point added to an existing circuit, then the work is subject to the issue of a minor works certificate.

Summarising:

(i) The addition of points to existing circuits require a Minor Works Certificate.
(ii) A new installation or an addition or alteration that comprises new circuits requires an Electrical Installation Certificate.
(iii) An existing installation requires a Periodic Test Report

Note: (ii) and (iii) must be accompanied by a schedule of test results and an inspection schedule.

APPENDIX A
SAMPLE PAPER

Section A short answer

1 Indicate three main areas, about which you would require information, in order correctly to carry out an initial verification of a new installation.

2 There are various documents that are relevant to the inspection and testing of an installation, state:

(a) one statutory item of documentation
(b) two non-statutory items of documentation.

3 An Electrical Installation Certificate should be accompanied by signed documentation regarding three stages of an installation. What are these stages?

4 Apart from wear and tear state three areas of investigation that you would consider when carrying out a periodic inspection and test of an installation.

5 State three human senses that could be used during an inspection of an installation.

6 During a test on an installation, the following readings were obtained:

20 MΩ; 8 kA; 22 ms

List the instruments which gave these readings.

7 The following circuits are to be tested for insulation resistance. State the test voltages to be applied and the minimum acceptable value of insulation resistance in each case:

(a) SELV circuit
(b) LV circuit up to 500 V
(c) LV circuit over 500 V.

8 List the first three tests that should be carried out during an initial verification on a new domestic installation.

9 The test for the continuity of a cpc in a radial circuit feeding one socket outlet, uses a temporary link and a milli-ohmmeter, state:

(a) where the temporary link is connected
(b) where the milli-ohmmeter is connected
(c) what does the meter reading represent?

10 List three different protective conductors that would need to be connected to the main earthing terminal of an installation.

11 The following readings were obtained during the initial tests on a healthy ring final circuit:

P1–P2–0.8 Ω; N1–N2–0.8 Ω;
cpc1–cpc2–0.8 Ω

(a) what readings would you expect:
 (i) between P and N conductors at each socket outlet?
 (ii) between P and cpc at each socket outlet?
(b) what the P to cpc reading represents?

12 What happens to:

(a) conductor resistance when conductor length increases?
(b) insulation resistance when cable length increases?
(c) conductor resistance when conductor area increases?

13 List three precautions to be taken prior to commencing an insulation resistance test on an installation.

14 An enclosure has been fabricated on site to house electrical equipment. State the IP codes that the enclosure should at least

comply with.

15 What degree of protection is offered by enclosures offering the following:

(a) IP XXB
(b) IP4X
(c) IPX8.

16 List three reasons for conducting a dead polarity test on an installation.

17 What earthing systems are attributed to the following:

(a) an overhead line supply with no earth?
(b) a multicore supply cable with a separate neutral and earth?
(c) a supply cable in which the functions of earth and neutral are performed by one conductor?

18 State three locations where special considerations should be made with regards to electrical installations.

19 From the formula

$$Z_s = Z_e + \frac{(R_1 + R_2) \times 1.2 \times L}{1000}$$

what is represented by:

(a) Z_e?
(b) R_2?
(c) 1.2?

20 State any three functional tests that may be carried out on a domestic installation.

Section B

Figure A1 shows the layout of the electrical installation in a new detached garage. You are to carry out an initial verification of that installation.

1 (a) What documentation/information will you require in order to carry out the verification?
  (b) Where should it be located?
  (c) What particularly important details regarding this installation should have been included on such documentation?
  (d) What consideration should be given to the existing installation from which this new installation is fed?

2 List five areas of inspection for this installation that should be carried out prior to testing.

3 The following test results were obtained from a ring final circuit continuity test. State if the readings for each socket are

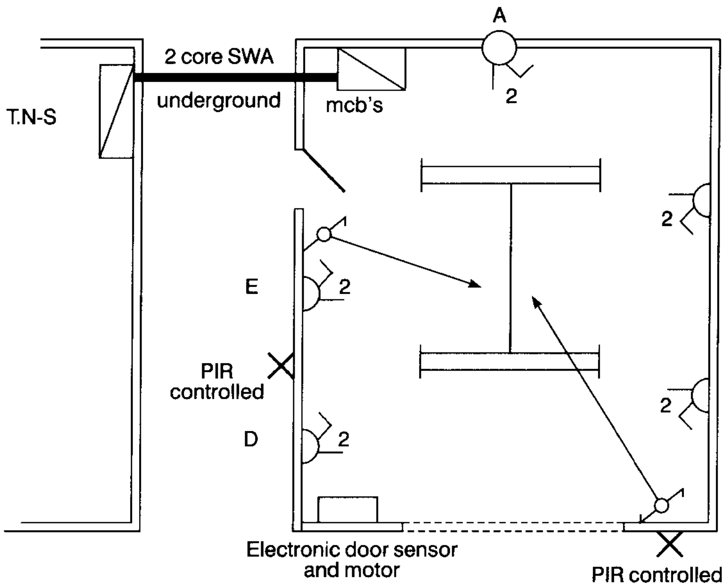

Figure A1

satisfactory and give reasons for those readings you feel are unsatisfactory.

Phase, neutral and cpc loops = 0.5 Ω

Socket	*P–N*	*P-cpc*
A	0.25	0.26
B	No reading	0.25
C	0.35	0.24
D	0.24	No reading
E	0.26	0.26

4 (a) Describe in detail how you would carry out an insulation resistance test on this installation.
(b) The test result indicates an overall value of 1.75 MΩ, what actions, if any, should be taken. Explain your reasons.

5 A loop impedance test on the lighting circuit cannot be conducted, as the 6A Type B MCB keeps tripping out. Explain why this is, and how the problem may be overcome in order to conduct the test.

6 (a) The electronic door sensor/motor is wired on its own radial circuit, list all the component parts of the earth fault loop path associated with this circuit in the event of a fault to earth.
(b) If the maximum value of loop impedance for this circuit is 2.4 Ω and an earth fault causes a current of 120 A, show by calculation if this value will disconnect the circuit in the required time.

APPENDIX B SUGGESTED SOLUTIONS TO SAMPLE PAPER

Section A

1 Any three of:
- to ensure accessories etc. to relevant standard
- to ensure compliance with BS7671
- to ensure no damage that may cause danger

(3 marks)

2 (a) *The Electricity at Work Regulations* **(1 mark)**
(b) any two of:
- BS 7671
- *Guidance Note 3*
- *The On-Site Guide.*

(2 marks)

3
- design
- construction
- inspection and testing.

(3 marks)

4 Any three of:
- to ensure safety of persons and livestock
- to ensure protection from fire and heat
- to ensure that the installation is not damaged so as to impair safety
- to ensure that the installation is not defective and complies with current regulations.

(3 marks)

5 • visual
• touch
• smell.

(3 marks)

6 • insulation resistance tester
• prospective short circuit current tester
• RCD tester.

(3 marks)

7 • 250 V and 0.25 MΩ
• 500 V and 0.5 MΩ
• 1000 V and 1.0 MΩ

(3 marks)

8 • continuity of protective conductors
• continuity of ring final circuit conductors
• insulation resistance.

(3 marks)

9 • between P and E at the consumer unit
• between P and E at the socket outlet
• this value is $(R_1 + R_2)$ for the circuit.

(3 marks)

10 Any three of:
• circuit protective conductor
• main equipotential bonding conductor
• earthing conductor
• lightning conductor.

(3 marks)

11 • 0.4 Ω
• 0.4 Ω
• $(R_1 + R_2)$ for the ring.

(3 marks)

12 • increases
• decreases
• decreases.

(3 marks)

13 Any three of:
• check on existence of electronic equipment
• check there are no neons, capacitors etc. in circuit

- all switches closed and accessories equipment removed
- no danger to persons or livestock by conducting the test.

(3 marks)

14
- IP 2X
- IP XXB
- IP 4X

(3 marks)

15
- finger contact only
- small foreign solid bodies or 1 mm diameter wires
- total submersion.

(3 marks)

16
- all single pole devices in phase conductor only
- centre contact of Edison screw lampholders in phase conductor
- all accessories correctly connected.

(3 marks)

17
- TT
- T–N–S
- TN–C–S

(3 marks)

18 Any three of:
- bathrooms and shower basins
- hot air saunas
- swimming pools
- construction sites
- agricultural and horticultural situations
- restrictive conductive locations
- high earth leakage locations
- caravans
- caravan parks
- highway power supplies and street furniture.

(3 marks)

19
- external loop impedance
- resistance of cpc
- multiplier for conductor operating temperature.

(3 marks)

20 Any three of:
- test button operation of an RCD
- operation of dimmer switch
- operation of main isolating switch
- operation of MCBs
- operation of two-way switching.

(3 marks)

Section B

1 (a) The results of the assessment of general characteristics section 311, 312 and 313, and diagrams charts and similar information regarding the installation **(5 marks)**

(b) In or adjacent to the distribution board **(3 marks)**

(c) Reference to the electronic door sensor and the PIR controlled external luminaires as these could be vulnerable to a typical test **(3 marks)**

(d) Maximum demand, rating of consumer unit, earthing and bonding arrangements, capacity of main protective device etc. **(4 marks)**

2 Any five relevant areas from the check list. **(3 marks each)**

Items inspected

☐ 1 Connection of conductors

☐ 2 Identification of conductors

☐ 3 Routing of cables in safe zones or protected against mechanical damage

☐ 4 Selection of conductors for current and voltage drop

☐ 5 Connection of single-pole devices for protection or switching in phase conductors only

☐ 6 Correct connection of socket-outlets and lampholders

☐ 7 Presence of fire barriers and protection against thermal effects

8 Method of protection against electric shock

(a) Protection against both direct and indirect contact

☐ SELV

☐ Limitation of discharge of energy

(b) Protection against direct contact

☐ Insulation of live parts

☐ Barrier or enclosure

☐ Obstacles

☐ Placing out of reach

☐ PELV

(c) Protection against indirect contact

(i) Earthed equipotential bonding and automatic disconnection of supply

☐ Presence of earthing conductors

☐ Presence of protective conductors

☐ Presence of main equipotential bonding conductors

☐ Presence of supplementary equipotential bonding conductors

(ii) Use of Class II equipment or equivalent insulation

(iii) Non-conducting location

☐ Absence of protective conductors

(iv) Earth-free local equipotential bonding

☐ Presence of earth-free equipotential bonding conductors

(v) Electrical separation (413–06)

☐ 9 Prevention of mutual detrimental influence

☐ 10 Presence of appropriate devices for isolating and switching correctly located

☐ 11 Presence of undervoltage protective devices where appropriate

12 Choice and setting of protective and monitoring devices (for protection against indirect contact and/or overcurrent)

- ☐ Residual current devices
- ☐ Overcurrent devices

☐ 13 Labelling of protective devices, switches and terminals

☐ 14 Selection of equipment and protective measures appropriate to external influences

☐ 15 Adequacy of access to switchgear and equipment

☐ 16 Presence of danger notices and other warnings

☐ 17 Presence of diagrams, instructions and necessary information

☐ 18 Erection methods

☐ 19 Requirements of special locations

Tick to indicate item has been inspected
Delete if item not applicable

3 • Socket A OK as readings are approximately $\frac{1}{2}$ of 0.5 Ω **(3 marks)**

- Socket B cross polarity P-cpc, or twisted N conductors not in N terminal **(3 marks)**
- Socket C loose neutral connection **(3 marks)**
- Socket D cross polarity P–N, or twisted CPCs not in terminal **(3 marks)**
- Socket E OK. **(3 marks)**

4 (a) Conduct the test from the house as this will then include the SWA cable. Disconnect the supply to the PIR controlled lights and the electronic door sensor. Disconnect the capacitor and ballast at each fluorescent luminaire. With the garage main switch and the MCBs ON and any accessories

unplugged, test at 500 V between live conductors connected together and earth and then between each live conductor. Operate the two-way switches during each test. The test readings should not be less than 0.5 MΩ.

(8 marks)

(b) If any reading is below 2 MΩ, then there may be a latent defect and then each circuit should be tested separately and the insulation resistance in each case should be greater than 2 MΩ.

(7 marks)

5 As a loop impedance tester delivers a high current for a short time, it is not unusual for sensitive MCBs with low ratings to trip out on overload. The loop impedance in such cases will have to be determined by a combination of measurement and calculation as follows:

Measure Z_e and measure $(R_1 + R_2)$ for the circuit, then $Z_s = Z_c + (R_1 + R_2)$

(7 marks)

6 (a)
- The point of fault
- The cpc
- The steel wire armour of the garage supply
- The earthing conductor
- The metallic earth return path of the supply cable
- The earthed neutral of the transformer
- The transformer winding
- Phase conductors.

(8 marks)

(b) $Z_s = U_{oc}/I$
$= 240/120$
$= 2\,\Omega$

so circuit protection will operate fast enough.

(7 marks)

BS 7671 2001 THE CHANGES

The new BS 7671 2001 contains many small editorial and Regulation number alterations; some substantial revisions and amendments; two new chapters and associated regulations; three new sections and the inclusion of the revised section 601 for bathrooms.

The bulk of the original BS 7671 1992 remains unaffected and the changes will not significantly effect the work of the electrical operative. The feel and look (apart from the colour) of the new edition is unchanged and the extent of additions, amendments and re-written regulations etc., are indicated by vertical lines in the margins of each page.

So, as the story teller says, let us begin at the beginning!

Part 1: Scope, object and fundamental principals

The whole of the original Part 1 has been re-written, rearranged etc. and three new sections ***131, 132*** and ***133*** added. These outline the general requirements for ***Design (131), Selection of electrical equipment (132) and Erection and Inspection and Testing of installations (133).***

Part 2: Definitions

There are only six significant changes to the list of definitions, two are deletions (earth leakage and hazardous live part), one (residual

current) is re-written and three are new (***mobile & offshore installations, leakage current and protective conductor current***).

Protective conductor current replaces Earth leakage current and is defined as ***Electric current which flows in a protective conductor under normal operating conditions.*** This is clearly not a fault current and is typical of the current flowing in the cpc's of IT equipment installations.

Leakage current on the other hand flows, ***under normal operating conditions, in an unwanted conductive path*** e.g. pipework which is not intended as cpc.

Part 3: Assessment of general characteristics

This part remains unchanged with the exception of Regulation 331-01-01 Compatibility, where there are some small editorial changes and the addition of ***Power factor, Undervoltage*** and ***Unbalanced loads*** to the list of harmful effects.

Part 4: Protection for safety

This part contains by far the most amendments and additions and include:

- (i) A change in test current requirements for residual current devices.
- (ii) Changes to Loop impedance tables.
- (iii) Change of pvc to ***Thermoplastic*** and the addition of ***Thermosetting*** to rubber cables.
- (iv) A new chapter on ***Overvoltage***.
- (v) New regulations regarding conductors in parallel.
- (vi) A new chapter regarding ***Protective measures as a function of external influences***.

(i) 412-06-02 (ii): When a residual current device is used as supplementary protection against Direct Contact it should have a rating $I\Delta n$ not exceeding 30 mA and should operate in

40 ms at a residual current of *5* × ***IΔn*** *not* 150 mA (except for 30 mA devices).

(ii) In tables 41B2, 41C and 471 (also 604B2 and 605B2) all reference to miniature circuit breakers to ***BS 3871 types 1, 2 and 3*** has been removed and ***RCBO's to BS EN 61009*** included.

(iii) In table 43A and elsewhere in BS7671, pvc has been replaced by ***Thermoplastic (pvc)*** and rubber is now shown as ***Thermosetting (rubber)***.

(iv) New ***Chapter 44 Protection against Overvoltage***. This outlines the requirements for protecting electrical installations against overvoltages due to switching surges or from an atmospheric origin (lightning!!). Tables ***44A*** and ***44B*** give examples of equipment that withstand voltages and the categories of equipment. It is unlikely that this chapter will be of any real significance in the UK, as most equipment used is to a relevant British Standard, and the number of thunderstorm days anywhere are unlikely to exceed 25 per year.

(v) New Regulations ***473-01-06, 07 & 08*** and ***473-07-05*** incorporate and add to the old regulations regarding conductors in parallel.

(vi) New ***Chapter 48 Choice of protective measures as a function of External Influences***. This chapter deals with protection where there is a risk of fire due to the ***nature of processed or stored materials (482-02)***, and in locations with ***combustible constructional materials (482-03)***.

Part 5: Selection and erection

There are few significant changes in this part, most are editorial or re-written sentences.

514-10-01 Voltage warning notices should now read ***230 V*** *not* 250 V.

Part 6: Special installations or locations

The changes in this part are mainly editorial with a few additions.

Section 601: Bathrooms etc

The old AMD 3 has been incorporated with one or two minor amendments.

Section 604: Construction sites etc.

There are three new regulations ***604-01-02*** and ***03*** which give greater detail of the scope of this section and ***604-10-03*** which indicates the requirements for the selection of flexible cables i.e. ***Low temperature 300/500 V thermoplastic cable for reduced voltage systems*** and ***HO7 RN-F 400/750 V rated cables for 230/400 V systems.***

Section 607: High protective conductor current installations

Whilst this section has been completely re-written the content is generally unchanged. Where the protective conductor current is likely to exceed 10 mA, the requirement for two separate protective conductor terminals in BS EN 60309-2 plugs has been deleted but where high integrity protective conductors and connections are required ***accessories must have two earthing terminals.***

RCD's, should not operate at ***expected protective conductor currents.***

Section 611: Highway power supplies etc.

Once again this section is generally unchanged with only one new regulation ***611-05-02*** which requires a degree of protection for all electrical equipment of ***IP33***.

Regulation 611-02 has been added to with the requirements that ***access doors less than 2.5 m above the ground be locked or secured by the use of a key or tool.***

Regulation 611-02-02 also requires the use of a tool to remove barriers or enclosures to ***gain access to light sources of luminaires located less than 2.8 m above the ground.***

Regulation 611-04-03 has been added to, and includes the need for ***colour coded marker tape or cable tiles to be used with power supply cables.***

Part 7: Inspection and testing

Not a great deal of change here, just 2 new regulations and some modifications.

It is now required that for an initial verification, every installation be inspected and tested during ***and*** on completion.

New regulation ***713-12-01*** requires that the ***Prospective short circuit current and Prospective earth fault current at the origin and at other relevant points be ascertained by measurement, calculation or other method.***

New regulation ***732-01-02*** concerns Periodic Inspection and Testing and suggests that this may be replaced by ***an adequate regime of monitoring and maintenance provided this is carried out by skilled persons, and that the installation is under effective supervision.***

Both Electrical Installation Certificates and Periodic Test Reports must be accompanied by a schedule of test results ***and an inspection schedule.***

New regulation 742-01-02 requires every circuit to be identified on a schedule of test results.

Appendices

Appendix 1 and 2 have been updated with regards to new and amended standards and revised and new legislation.

Appendix 3, Time/Current graphs, have had all reference to BS 3871 mcb's deleted and RCBO's to BS EN61009 added.

Appendix 4 Current ratings etc. has Table 4A changed to 4A1 and another table, 4A2 added, which lists all the appropriate current rating tables.

Appendix 6 now includes samples of inspection and test schedules.

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