CHAPTER 1

Design

Important terms/topics covered in this chapter:

- Assessment of general characteristics
- Basic protection
- Fault protection
- IP and IK codes
- The earth fault loop path
- Supplementary equipotential bonding
- Overcurrent
- Let-through-energy
- Discrimination
- Undervoltage
- Overvoltage
- Isolation and switching
- Design current
- Diversity
- Nominal rating of protection
- Rating factors
- Current carrying capacity of conductors
- Voltage drop
- Shock risk and thermal constraints.

At the end of this chapter the reader should,

- understand the need to assess all relevant characteristics of the installation,
- have reinforced their knowledge of Basic and Fault protection and how such protection is achieved,
- understand how 'let-through-energy' can cause damage to cables,
- be able to distinguish between 'Isolation' and 'Switching',
- be able to determine suitable wiring systems for particular applications,

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- be able to carry out basic design calculations to determine cable sizes,
- recognize various types of installation diagram.

Any design to the 17th 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 17th Edition, 'Assessment of General Characteristics', indicates six main headings under which these considerations should be addressed. These are:

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

4. Maintainability
5. Recognized safety services
6. Assessment of continuity of service.

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. Table 1.1 gives examples of the classification.

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

Table 1.1 Examples of Classifications of External Influences

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

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 residual current devices (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

The Electricity at Work Regulations 1989 require every system to be maintained such as to prevent danger; consequently, 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 hence, 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 regard to a change of usage.

Example 1.1

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 which comprises 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 existing 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 701, IEE Regulations. Ideally all metal conduit and trunking should be removed together with any socket outlets within 3 m of the boundary of zone 1. The trunking could be replaced with PVC; alternatively it could be boxed in using insulating material and screw-on lids to enable access. It could be argued that no action is necessary as it is above 2.25 m and therefore outside of all the zones. 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 as BA2 (children), it is probably wise to provide additional protection against shock by installing 30 mA RCDs on all 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. A maintenance programme should be in place and all safety and protective measures should be effective throughout the intended life of the installation.

1(b) New shower area (BS 7671 Section 701)

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 prospective fault current (PFC) 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, the installation of a completely separate system. Whichever the method adopted, a distribution circuit 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 shock would be by basic protection (insulation and barriers and enclosures) and fault protection (protective earthing, protective equipotential bonding and automatic disconnection); additional protection would be provided by RCDs/RCBOs.

External influences. These have already been addressed in above.

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

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

2 Total assumed current demand

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 for Chapter 3 of this book illustrate such shortened answers.

PROTECTION FOR SAFETY

Part 4 of the 17th 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, overload, fault current, undervoltage, overvoltage, and the requirements for isolation and switching. Let us now deal, in broad terms, with each of these areas.

PROTECTION AGAINST ELECTRIC 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, or (b) by touching exposed-conductive parts of electrical equipment or systems, which have been made live by a fault. Table 1.2 indicates the common methods of protecting against either of these situations.

Insulation or barriers and enclosures (Basic protection)

One method used to protect against contact with live parts is to insulate or house them in enclosures and/or place them behind barriers. In order to ensure that such protection will be satisfactory, the enclosures/barriers must conform to BS EN 60529, commonly referred to as the Index of Protection (IP) code. This details the amount of protection an enclosure can offer to the ingress of mechanical objects, foreign solid bodies and moisture. Table 1.3 (see page 10) 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. Also, protection for wiring systems against external mechanical impact needs to be considered. Reference should be made to BS EN 62262, the IK code (Table 1.4, see page 11).

Protective earthing, protective equipotential bonding and automatic disconnection in case of a fault (Fault protection)

As Table 1.2 indicates, this method is the most common method of providing Fault protection, and hence it is important to expand on this topic.

There are two basic ways of receiving an electric shock by contact with conductive parts made live due to a fault:

1. Via parts of the body and the general mass of earth (typically hands and feet) or
2. Via parts of the body and simultaneously accessible *exposed and extraneous conductive parts* (typically hand to hand) – see Figure 1.1.

Clearly, the conditions shown in Figure 1.1 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 protective bonding is carried out, then the magnitude and duration of earth faults will be reduced to such a level as not to cause danger.

Table 1.2 Common Methods of Protection Against Shock

Protection by	Protective Method	Applications and Comments
SELV (separated extra low voltage)	Basic and fault protection	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	Basic protection	This is simply 'basic insulation'.
Barriers and enclosures	Basic protection	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, for example 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.
Obstacles	Basic protection	Restricted to areas only accessible to skilled persons, for example sub-stations with open fronted busbar chambers, etc.
Placing out of reach	Basic protection	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)	Basic protection	These may only be used as additional protection, 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 $5 \times I_{\Delta n}$.
	Fault protection	Used where the loop impedance requirements cannot be met or for protecting socket outlet circuits supplying portable equipment used outdoors.
		Preferred method of earth fault protection for TT systems.

(Continued)

Table 1.2 Common Methods of Protection Against Shock—Cont'd

Protection by	Protective Method	Applications and Comments
Earthing, equipotential bonding and automatic disconnection of supply	Fault protection	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.
Class II equipment	Fault protection	Sometimes referred to as double insulated equipment and marked with the BS symbol ⧈.
Non-conducting location	Fault protection	Rarely used – only for very special installations under strict supervision.
Earth-free local equipotential bonding	Fault protection	Rarely used – only for very special installations under strict supervision.
Electrical separation	Fault protection	Rarely used – only for very special installations under strict supervision. However, a domestic shaver point is an example of this method for one item of equipment.

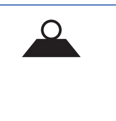
Table 1.3 IP Codes

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, 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.

Table 1.3 IP Codes—Cont'd

First Numeral:	***Mechanical Protection***
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.
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.

Table 1.4 IK Codes Protection Against Mechanical Impact

Code		
00		No protection
01 to 05		Impact 1 joule

(Continued)

Table 1.4 IK Codes Protection Against Mechanical Impact—Cont'd

Code		
06	500 g 20 cm	Impact 1 joule
07	500 g 40 cm	Impact 2 joules
08	1.7 kg 29.5 cm	Impact 5 joules
09	5 kg 20 cm	Impact 10 joules
10	5 kg 40 cm	Impact 20 joules

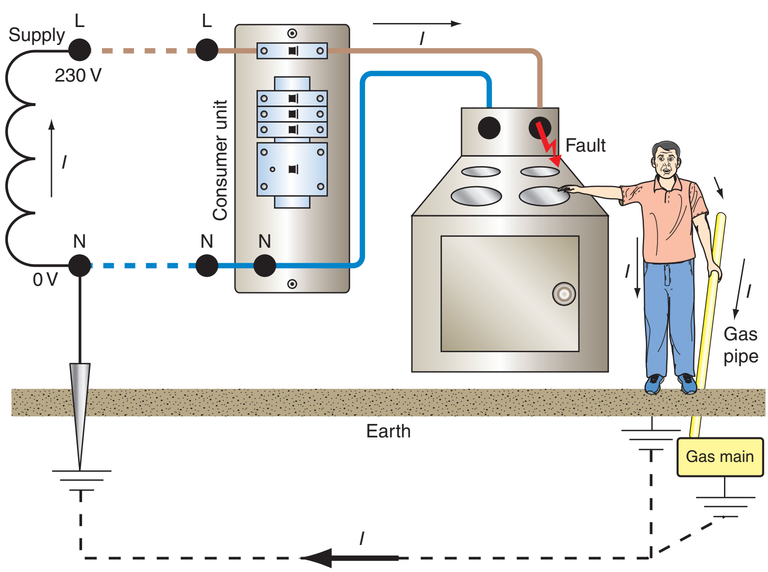


FIGURE 1.1 Shock path.

The disconnection times for final circuits not exceeding 32 A is 0.4 s and for distribution circuits and final circuits over 32 A is 5 s. For TT systems these times are 0.2 s and 1 s.

The connection of protective 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 are correct, the level of shock voltage will not be harmful.

Figure 1.2 shows the earth fault system which provides Fault protection.

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 service cables Z_e, and the resistance of the line conductor R_1 and circuit protective conductor (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 41.2, 41.3 or 41.4 of the Regulations, the protection will operate within the prescribed time limits.

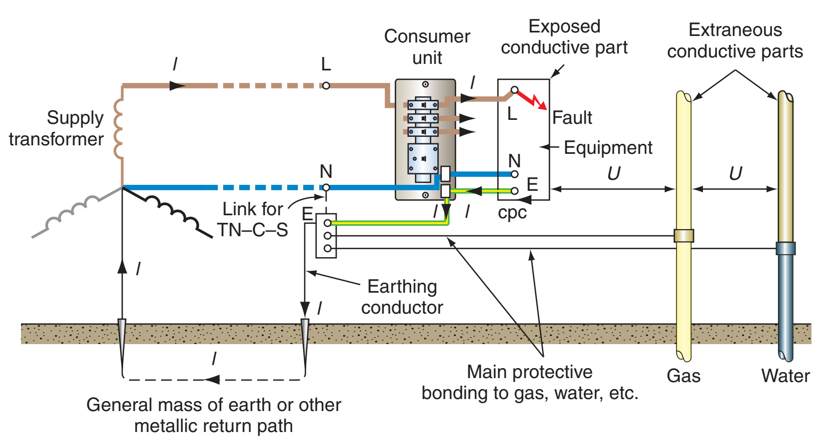


FIGURE 1.2 Earth fault loop path.

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

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

Note

The multiplier corrects the resistance at 20c 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 Distribution Network Operator (DNO) and calculate the value of Z_e, or use the maximum likely values quoted by the DNOs, which are:

TT system	21 Ω
TN-S system	0.8 Ω
TN-C-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 distribution circuit cable protected by a 160 A, BS 88 fuse and supplied via a TNC-S system, would present great difficulties, as the maximum value of Z_s (Table 41.4(a)) for such a fuse is 0.25 Ω and the quoted likely value of Z_e is 0.35 Ω. In this case the DNO 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 used as Additional protection to Fault protection and 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 location is an area of increased risk such as detailed in Part 7 of the Regulations, e.g. bathrooms, etc. and swimming pools (see also Chapter 3).

PROTECTION AGAINST THERMAL EFFECTS (IEE REGULATIONS CHAPTER 42)

The provision of such protection requires, in the main, a commonsense 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 Harmonized Document limiting temperature, the designer should conform to the requirements of Table 42.1, IEE Regulations.

Section 422 of this chapter deals with 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 chapter 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 is further sub-divided into:

(a) Short-circuit current (between live conductors) and
(b) Earth fault current (between line 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.

Table 1.5 indicates some of the common types of protective device used to protect electrical equipment during the presence of overcurrents and fault currents.

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:

   $I_n \geq I_b$

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

   $I_z \geq I_n$

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:

   $I_2 \leq 1.45 \times I_z$

For fuses to BS 88 and BS 1361, and MCBs or CBs, compliance with (2) above automatically gives compliance with (3). For fuses to BS 3036

Table 1.5 Commonly Used Protective Devices

Device	Application	Comments
Semi-enclosed re-wireable fuse BS 3036	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.
HBC fuse links BS 88-6 and BS EN 60269-2	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.
HBC fuse links BS 1361	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 and CBs (miniature circuit breakers) BS 3871, now superseded by BS EN 60898 CBs	Domestic consumer units and 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 60947-2	Industrial situations where high current and breaking capacities are required	Breaking capacity, 22–50 kA in ranges 16–1200 A. 2, 3 and 4 pole types available.

(re-wireable) compliance with (3) is achieved if the nominal setting of the device I_n is less than or equal to $0.725 \times I_z$:

$$I_n \le 0.725 \times I_z$$

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 and in the case of a circuit breaker, make 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 1.3 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’.

The total amount of energy let-through into the conductors is given by $(I_f)^2 t_2$ in Figure 1.4.

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).

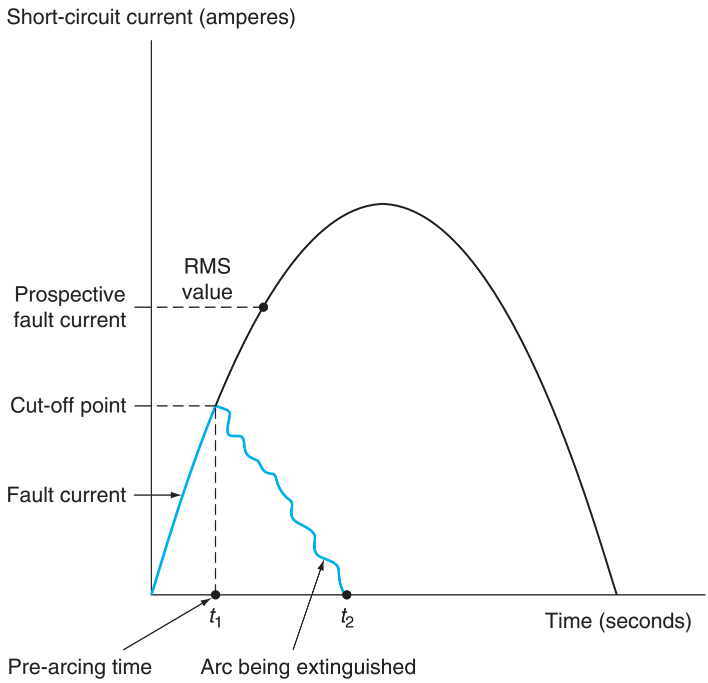


FIGURE 1.3 Pre-arcing let-through.

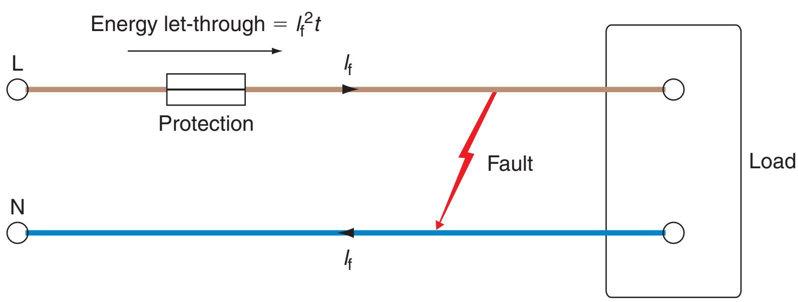


FIGURE 1.4 Pre-arcing let-through.

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 regard 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 54.7 (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 $I^2t = k^2s^2$.

For flat, twin and three-core cables the formula method of verification will be necessary, as the cpc incorporated in such cables is always smaller than the associated line 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'.

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. Table 1.6 shows the 'let-through' values for a range of BS 88 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.

Table 1.6 $(I_f)^2{}_t$ 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)	$I_t^2 t$ Pre-arcing	$I_t^2 t$ Total at 415 V
2	0.9	17
4	4	12
6	16	59
10	56	170
16	190	580
20	310	810
25	630	1700
32	1200	2800
40	2000	6000
50	3600	11 000
63	6500	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

PROTECTION AGAINST UNDERVOLTAGE (IEE REGULATIONS SECTION 445)

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). Switching on of very large loads can have the effect of causing such undervoltages.

PROTECTION AGAINST OVERVOLTAGE (IEE REGULATIONS SECTIONS 442 AND 443)

This chapter deals with the requirements of an electrical installation to withstand overvoltages caused by: (1) transient overvoltages of atmospheric origin, and (2) switching surges within the installation. It is unlikely that installations in the UK will be affected by the requirements of item (1) as the number of thunderstorm days per year is not likely to exceed 25. In the case of item (2), when highly inductive loads are switched, the sudden movement of associated magnetic fields can cause transient overvoltages.

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. 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, an isolator may be used for functional switching, but not usually 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.

The IEE Regulations (Section 537) deal with this topic and in particular Isolation, Switching off for mechanical maintenance, Emergency switching, and Functional switching.

Tables 1.7–1.9 indicate some of the common devices and their uses.

Table 1.7 Common Types of Isolators and Switches

Device	Application	Comments
Isolator or discon-nector	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 discon-nector	Main switch on consumer units and distribution fuse boards	These are ON LOAD devices but can still perform the function of isolation.

Table 1.8 Common devices

Device	Isolation	Emergency	Function
Circuit breakers	Yes	Yes	Yes
RCDs	Yes	Yes	Yes
Isolating switches	Yes	Yes	Yes
Plugs and socket outlets	Yes	No	Yes
Ditto but over 32 A	Yes	No	No
Switched fused connection unit	Yes	Yes	Yes
Unswitched fused connection unit	Yes	No	No
Plug fuses	Yes	No	No
Cooker units	Yes	Yes	Yes

Table 1.9 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 Fault protection 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 Fault protection on the system. Some forms come prewired 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.
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 unsegregated trunking. Cable reference system as follows:

Table 1.9 Common Wiring Systems and Cable Types—Cont'd

System/Cable Type	Applications	Comments
		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.
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.

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 rating 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. Table 1.9 gives details of commonly installed 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:

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

Three phase:

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

where:

P = power in watts

V = line to neutral voltage in volts

V_L = line to line voltage in volts

Eff% = efficiency

PF = power factor.

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 distribution circuit 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 41.2, 41.3 or 41.4. For types and sizes outside the scope of these tables, details from the manufacturer will need to be sought.

Rating factors

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

C_a	Factor for ambient air and ground temperature	(From IEE Regulations Tables 4B1, 4B2 or 4B3)
C_g	Factor for groups of cables	(From IEE Regulations Table 4C1 to 4C5)
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 52.2)

Application of rating 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. A blanket application of correction factors can result in unrealistically large conductor sizes, so consider the following:

1. If the cable in Figure 1.5 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 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 1.6(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 worst one will automatically compensate for the others. The relevant

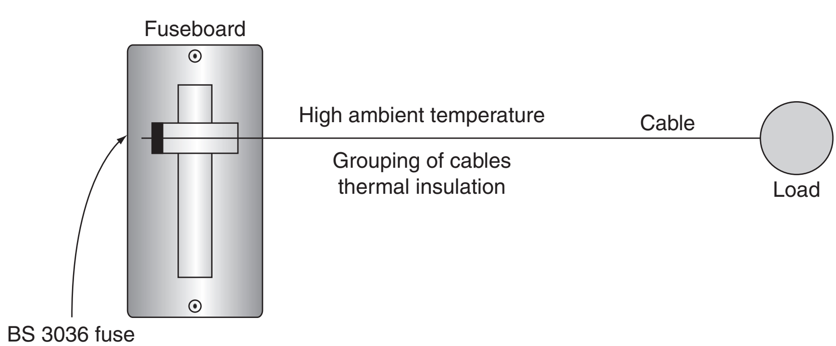


FIGURE 1.5 Conditions along cable route.

factors are shown in Figure 1.6(b) and apply only if $C_f = 0.725$ and $C_i = 0.5$. If protection was *not* by BS 3036 fuse, then apply only $C_i = 0.5$.

3. In Figure 1.7 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

$$I_n \geq \frac{I_n}{C_a \times C_g \times C_f \times C_i}$$

Remember, only the relevant factors are to be used!

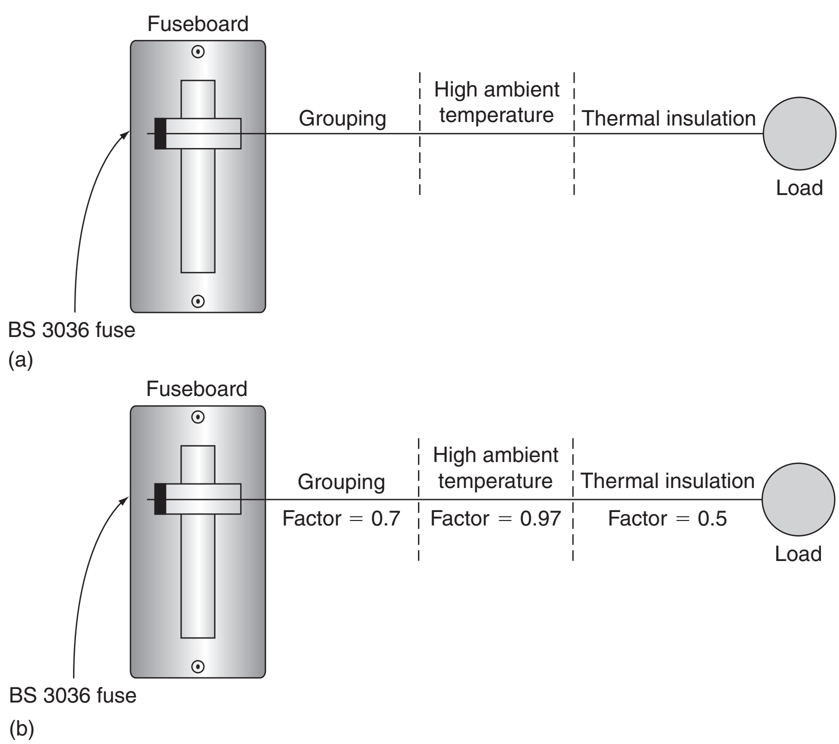


FIGURE 1.6 Conditions along cable route.

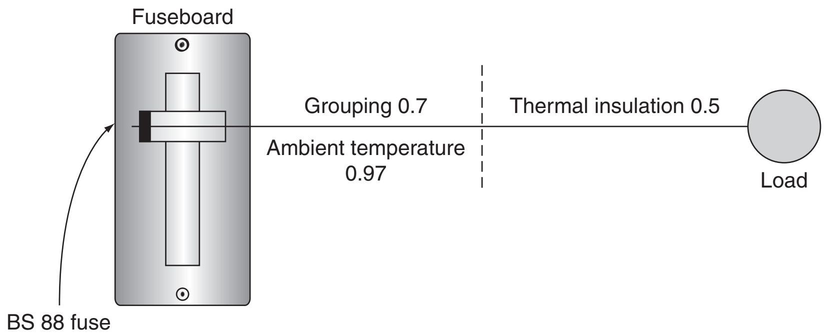


FIGURE 1.7 Conditions along cable route.

As we have seen when discussing overload protection, the IEE Regulations permit the omission of such protection in certain circumstances (433.3.1); in these circumstances, I_n is replaced by I_b and the formula becomes:

$$I_n \geq \frac{I_b}{C_a \times C_g \times C_f \times C_i}$$

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 4A2 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 B are less than those for method C. Having selected the correct cable rating table and relevant reference method, the conductor size is determined to correspond with I_t.

Voltage drop

In many instances this may well be the most onerous condition to affect cable 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.

Table 1.10 Voltage Drop Values

	Lighting	Power
	3%	5%
230 V single phase	6.9 V	11.5 V
400 V three phase	12 V	20 V

These requirements are fulfilled if the voltage drop between the origin of the installation and any load point does not exceed the following values (IEE Regulations, Appendix 12) (Table 1.10).

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):

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

For conductor sizes in excess of 16 mm^2 the impedance values of volt drop in the IEE Regulations tables, Appendix 4 (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 54.7 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 54.2 to 54.6.

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

Example 1.2

A consumer has asked to have a new 9 kW/230 V shower unit installed in a domestic premises. The existing eight-way consumer unit houses BS 3871 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 Ω, and the length of the run from consumer unit to shower is approximately 28 m. The installation reference method is method C, and the ambient temperature will not exceed 30°C. If flat twin cable with cpc is to be used, calculate the minimum cable size.

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.

Design current I_b (based on rated values)

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

Choice and setting of protection

The type of MCB most commonly found in domestic installations over 10 years old is a BS 3871 Type 2, and the nearest European standard to this is a BS EN 60898 Type B. So from IEE Regulations Table 41.3, the protection would be a 40 A Type B CB with a corresponding maximum value of loop impedance Z_s of 1.15 Ω.

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:

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

but as there are no rating factors,

$$I_t \geq I_b \quad \text{so} \quad I_t \geq 39\,\text{A}$$

Selection of conductor size

As the cable is to be PVC Twin with cpc, the conductor size will be selected from IEE Regulations Table 4D5 column 6. Hence I_t will be 47 A and the conductor size 6.0 mm^2.

Voltage drop

From IEE Regulations Table 4D5 column 7, the mV drop is 7.3, so:

$$\text{Volt drop} = \frac{\text{mV} \times I_b \times L}{1000} = \frac{7.3 \times 39 \times 28}{1000} = 7.97\,\text{V}\,(\text{acceptable})$$

Whilst this may satisfy BS 7671, such a high value could cause inefficiency and the manufacturer should be consulted.

Evaluation for shock risk

The line 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 the On-Site Guide, 28 m of cable would have a resistance under operating conditions of:

$$\frac{28\times(3.08+7.41)\times1.2}{1000}=0.35\,\Omega$$

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

$$Z_s = Z_e + R_1 + R_2 = 0.18+0.35 = 0.53\,\Omega$$

which is clearly less than the maximum value of 1.15.

Evaluation of thermal constraints

Fault current I is found from:

$$I=\frac{U_0}{Z_s}$$

where

U_0 = nominal line voltage to earth

Z_s = calculated value of loop impedance

$$I=\frac{230}{0.53}=434\text{ A}$$

t for 434 A from IEE Regulations curves, Figure 3.4 for a 40 A CB is less than 0.1 s. k from IEE Regulations Table 54.3 is 115.

$$s=\frac{\sqrt{I^2t}}{k}=\frac{\sqrt{434^2\times0.1}}{115}=1.2\,\text{mm}^2$$

which means that the 2.5 mm² cpc is perfectly adequate. It does not mean that a 1.2 mm² cpc could be used.

Hence, provided the extra demand can be accommodated, the new shower can be wired in 6.0 mm² flat twin cable with a 2.5 mm² cpc and protected by a 40 A BS EN 60898 Type B CB.

Example 1.3

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 BS 88 fuses, located at the intake position. It has been decided to supply the heaters with PVC singles in steel trunking (reference method B), 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 needs to be used (IEE Regulation 543.1.2).

Design current I_b

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

Type and setting of protection I_n

$I_n \geq I_b$ so, from IEE Regulations Table 41.4, a BS 88 50 A fuse would be used, with a corresponding maximum value of Z_s of 1.04 Ω (Figure 1.8).

Rating factors

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

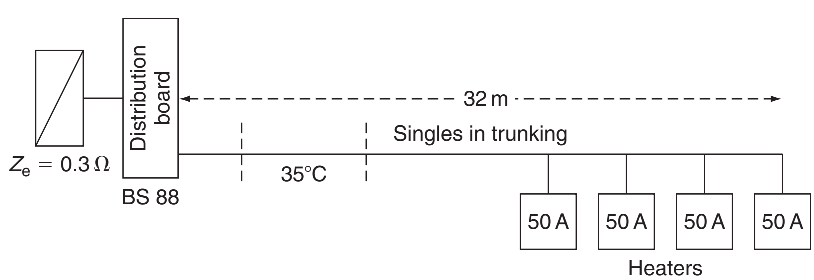


FIGURE 1.8 Diagram for example 1.3

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

Tabulated current-carrying capacity I_t

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

$$I_t \geq \frac{I_n}{C_a \times C_g} \geq \frac{50}{0.94 \times 0.65} \geq 82\ \text{A}$$

Selection of conductor size

From IEE Regulations Table 4D1A column 4, $I_t = 101$ A, and the conductor size is 25.0 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 54.7, or by calculation. The former

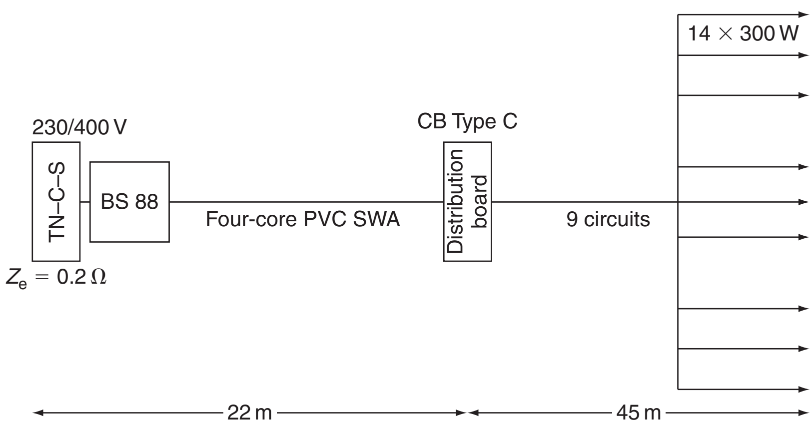


FIGURE 1.9 Diagram for example 1.4

method will produce a size of 16 mm², whereas calculation tends to produce considerably smaller sizes. The calculation involves the rearrangement of the formula:

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

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 1.04. The rearranged formula is:

$$R_2 = \frac{[(Z_s - Z_e) \times 1000]}{L \times 1.2} - R_1 = \frac{[(1.04 - 0.3) \times 1000]}{32 \times 1.2}$$
$$- 0.727 \,(\text{from } R_1 + R_2 \text{ tables}) = 18.54\,\text{m'}$$

The nearest value to this maximum is 18.1 mΩ (from $R_1 + R_2$ tables) giving a cpc size of 1.0 mm². 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

$$\text{Fault current } I = \frac{U_o}{Z_s} = \frac{230}{1} = 230\,\text{A}$$

t from 50 A BS 88 curve = 3 s

$k = 115$ (IEE Regulations Table 54.3)

$$s = \frac{\sqrt{I^2 t}}{k} = \frac{\sqrt{230^2 \times 3}}{115} = 3.46\,\text{mm}^2$$

Hence, our 1.0 mm² cpc is too small to satisfy the thermal constraints, and hence a 4.0 mm² cpc would have to be used. So the heaters would be supplied using 25.0 mm² live conductors, a 4.0 mm² cpc and 50 A BS 88 protection.

Example 1.4

Part of the lighting installation in a new warehouse is to comprise a distribution circuit to a three-phase lighting distribution board from which nine single-phase final circuits are to be fed. The distribution circuit, protected by BS 88 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_s calculated to be 0.2 Ω. The ambient temperature will not exceed 30°C (see Fig. 1.9).

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:

$$I_b = \frac{14 \times 300 \times 1.8}{230} = 32.8 \text{ A}$$

(the 1.8 is the multiplier for discharge lamps)

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

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

Distribution circuit design current I_b

Distribution circuit I_b per phase = 98.4 A.

Nominal rating of protection I_n

$I_n \geq I_b$ so, from IEE Regulations Table 41.4, the protection will be 100 A with a maximum loop impedance Z_s of 0.42 Ω.

Rating 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:

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

Cable selection

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

Voltage drop

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

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

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 $25\,\text{mm}^2$ four-core cable is 2.1 mΩ/m. Hence,

$$R_1 = 0.727\ \text{m}\Omega/\text{m and } R_2 = 2.1\ \text{m}\Omega/\text{m}$$

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

Clearly ok, as Z_s maximum is 0.42 Ω.

Thermal constraints

$$I = \frac{U_o}{Z_s} = \frac{230}{0.274} = 839\,\text{A}$$

$t = 0.7$ from BS 88 (curve for 100 A)

$k = 51$ (IEE Regulations Table 54.4)

$$s = \frac{\sqrt{839^2 \times 0.7}}{51} = 13.76\,\text{mm}^2$$

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 54.7 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 41.3, $I_n \geq I_b = 40$ A with a corresponding maximum value for Z_s of 0.57 Ω.

Rating factors

Only grouping needs to be considered:

C_g for nine circuits = 0.5 (IEE Regulations Table 4C1).

Tabulated current-carrying capacity I_t

$$I_t \geq \frac{I_n}{C_g} \geq \frac{40}{0.5} \geq 80\,\text{A}$$

Cable selection

From IEE Regulations Table 4D1A, $I_t \geq 80\,\text{A} = 101$ A and conductor size will be 25 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 mm^2 conductor is 1.8 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:

$$1.87 + 2.6 = 4.47\,\text{V}\,(\text{acceptable})$$

Shock risk constraints

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

In this case, Z_e will be the Z_s value for the distribution circuit.

Rearranging as before, to establish a minimum cpc size, we get:

$$R_2 = \frac{[(Z_s - Z_e) \times 1000]}{L \times 1.2} - R_1\,(\text{for } 25\,\text{mm}^2)$$

$$= \frac{(0.57 - 0.274) \times 1000}{45 \times 1.2} - 0.727 = 4.75\,\text{m}\Omega$$

Therefore, the nearest value below this gives a size of 4.0 mm^2:

$$\text{Total } Z_s = 0.274 + \frac{(0.727 + 4.61)}{1000} \times 45 \times 12 = 0.56\,\Omega$$

(less than the maximum of 0.57 Ω)

Thermal constraints

$$I = \frac{U_o}{Z_s} = \frac{230}{0.56} = 410\,\text{A}$$

t from Type C CB curve for 32 A is less than 0.1 s. $k = 115$ (IEE Regulations Table 54.3)

$$s = \frac{\sqrt{410^2 \times 0.1}}{115} = 1.12\,\text{mm}^2$$

Hence our 4.0 mm^2 cpc is adequate. So, the calculated cable design details are as follows:

- Distribution circuit protection. 100 A BS 88 fuses, distribution circuit 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 trunking, the requirement is that the space occupied by conductors should not exceed 45% of the internal trunking area. 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 1.5

What size of straight conduit 2.5 m long would be needed to accommodate ten 2.5 mm^2 and five 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

$31 \times 5 \quad = 155$

$43 \times 10 = 430$

$\text{Total} \quad = 585$

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.

Example 1.6

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 = 800

Tabulated cable term for 4.0 mm^2 = 58

$$\text{Number of cables} = \frac{800}{58} = 13.79$$

Hence thirteen 4.0 mm^2 conductors may be installed.

Example 1.7

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 conduit.

Example 1.8

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 1.9

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

Hence $8.1 \times 20 = 162$

$11.4 \times 35 \quad = 399$

$15.2 \times 28 \quad = 425.6$

Total = 986.6

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 (Figure 1.10).

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 (see Figures 1.11 and 1.12).

Note the details of the design calculations shown in Figure 1.12, all of which is essential information for the testing and inspection procedure.

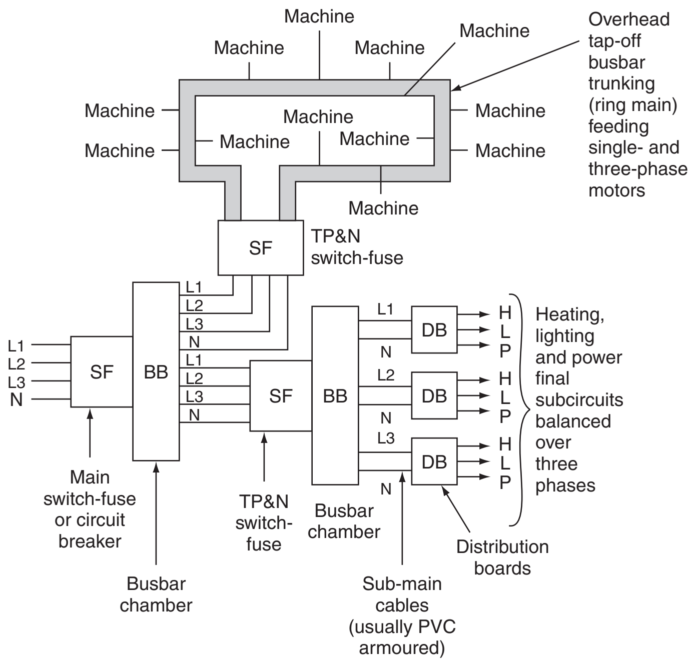


FIGURE 1.10 Layout of industrial installation.

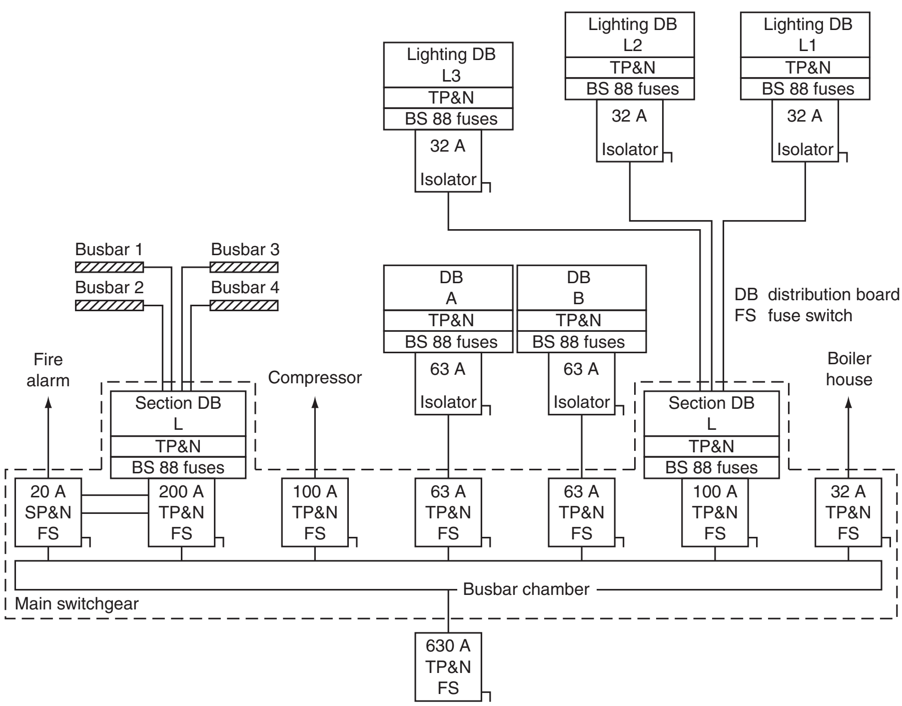


FIGURE 1.11 Distribution system, block type.

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 1.13 shows such a system.

Distribution board 3 (DB3) under the stairs would have appeared on a diagram such as Figure 1.13, with its final circuits indicated. The floor

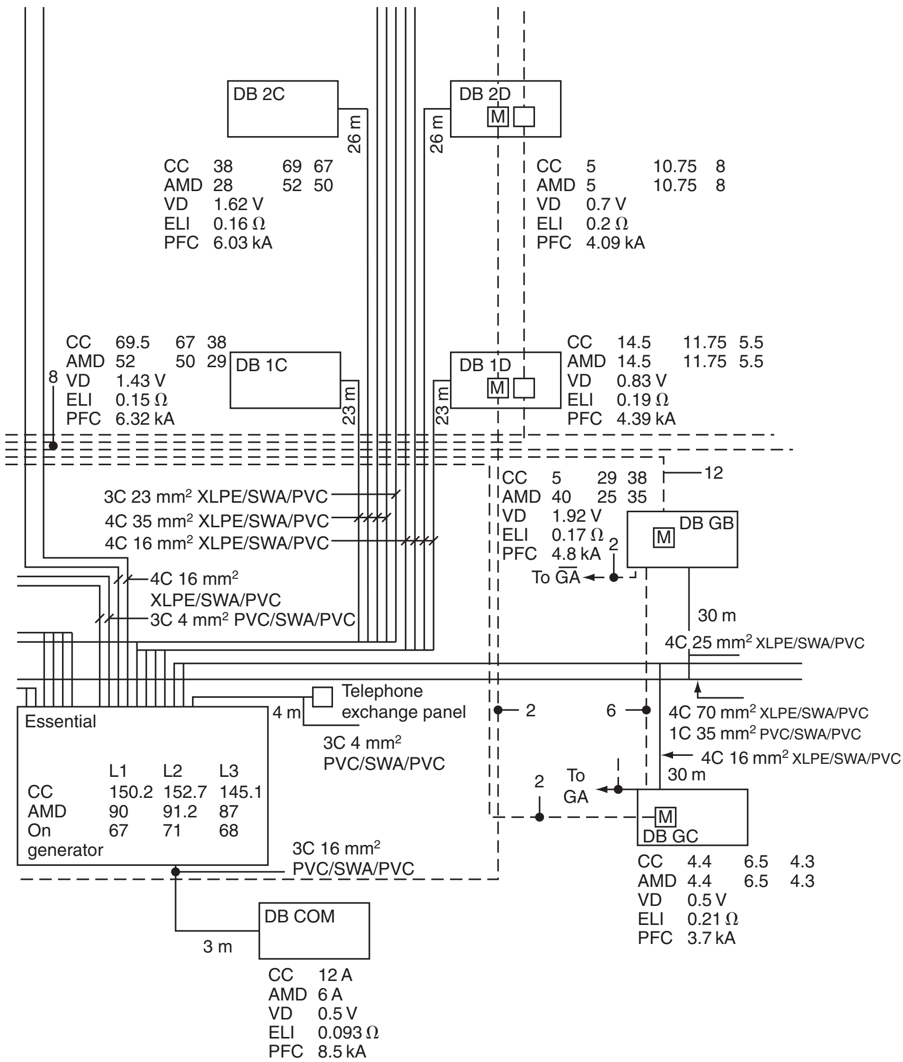


FIGURE 1.12 Distribution system, interconnection type. CC: circuit current; AMD: assumed maximum demand; VD: volt drop; ELI: earth loop impedance; PFC: prospective fault or short-circuit current.

plan shows which circuits are fed from DB3, and the number and phase colour of the protection. For example, the fluorescent lighting in the main entrance hall is fed from fuse or MCB 1 on the brown phase of DB3, and is therefore marked DB3/Br1. Similarly, the water heater circuit in the female toilets is fed from fuse or MCB 2 on the black phase, i.e. DB3/Bk2.

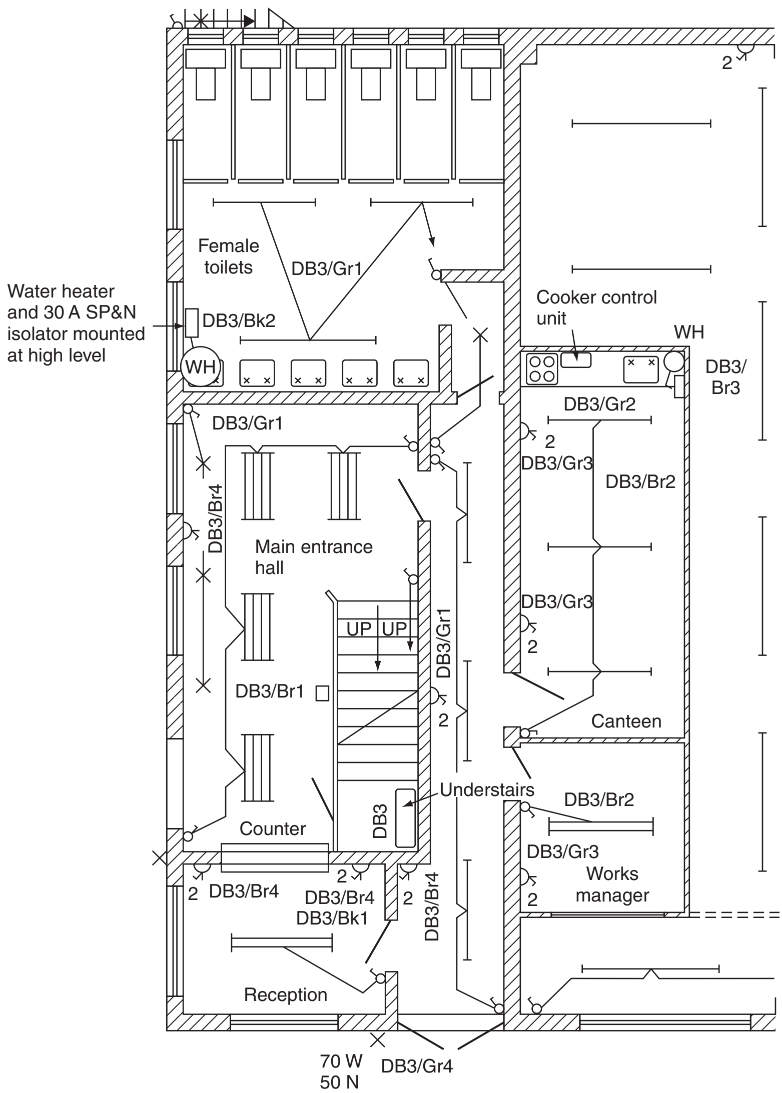


FIGURE 1.13 Example floor plan.

Figures 1.14–1.16 illustrate a simple but complete scheme for a small garage/workshop. Figure 1.14 is an isometric drawing of the garage and the installation, from which direct measurements for materials may be taken. Figure 1.15 is the associated floor plan, which cross-references with the DB schedule and interconnection details shown in Figure 1.16.

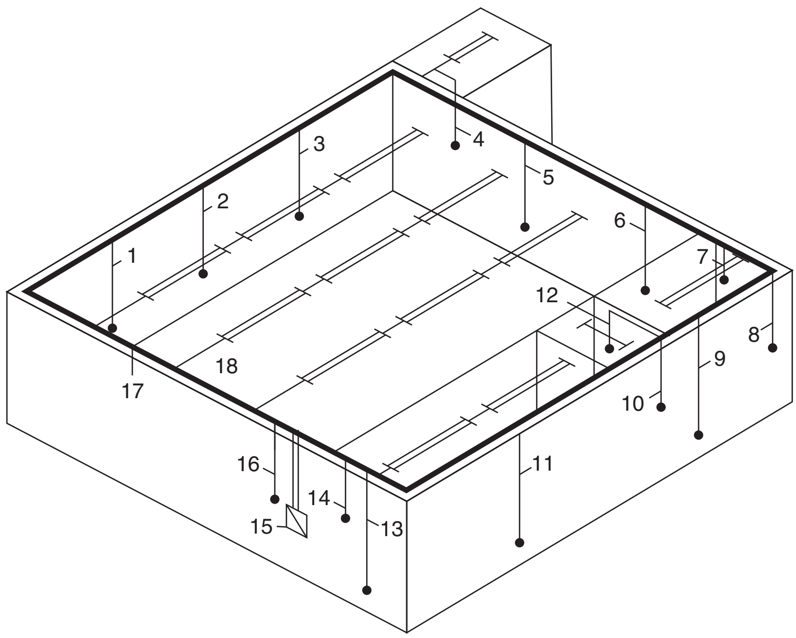


FIGURE 1.14 Isometric drawing for garage/workshop. 1 – Three-phase supply to ramp: 20 mm conduit, 2 – single-phase supply to double sockets: 20 mm conduit. Also 3, 4, 5, 6, 9, 11, 13 – single-phase supply to light switch in store: 20 mm conduit, 7 – single-phase supply to light switch in compressor: 20 mm conduit, 8 – three-phase supply to compressor: 20 mm conduit, 10 – single-phase supply to heater in WC: 20 mm conduit, 12 – single-phase supply to light switch in WC: 20 mm conduit, 14 – single-phase supply to light switch in office: 20 mm conduit, 15 – main intake position, 16 – single-phase supplies to switches for workshop lights: 20 mm conduit, 17 – 50 mm × 50 mm steel trunking, 18 – supplies to fluorescent fittings: 20 mm conduit.

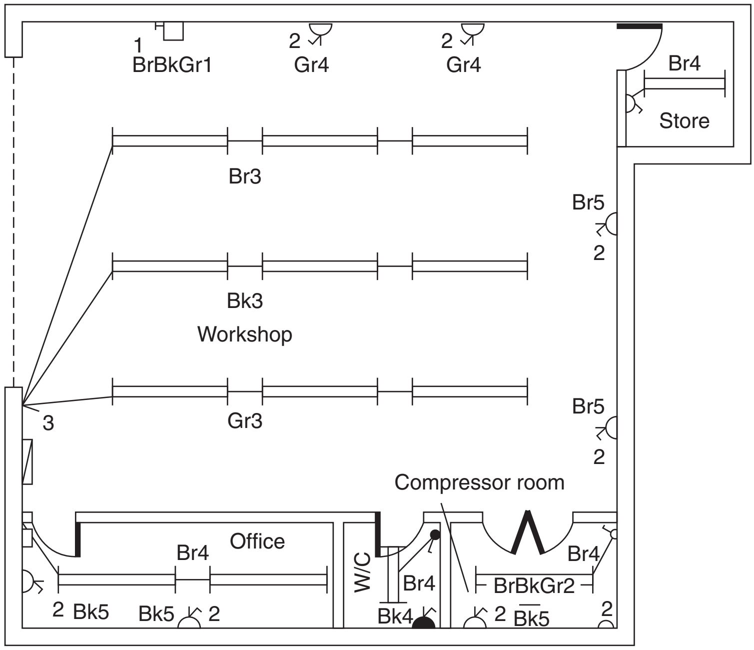


FIGURE 1.15 Floor plan for garage/workshop.

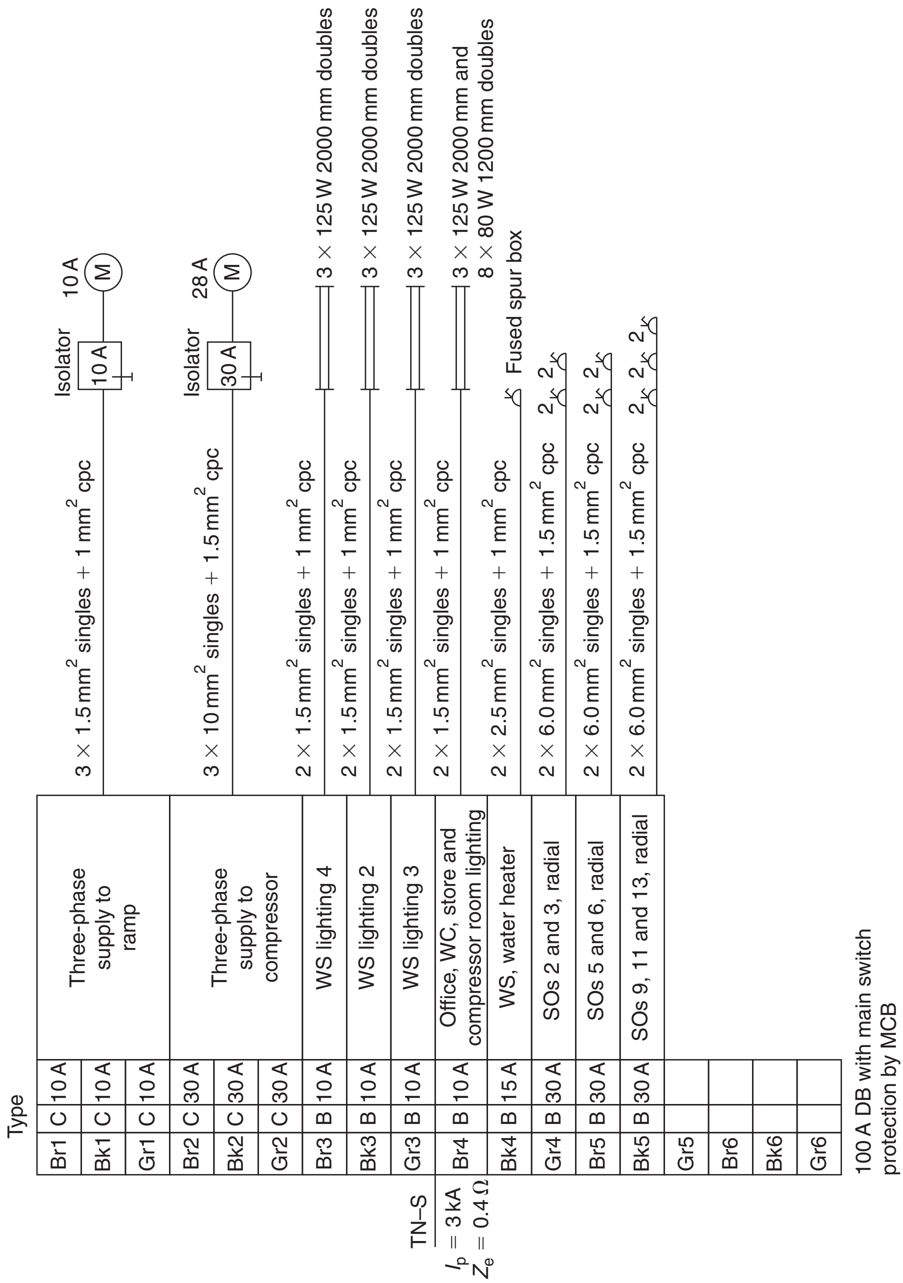


FIGURE 1.16 Details of connection diagram for garage/workshop.

Questions

1. State the three categories of external influence.
2. Which of the main chapter headings in Part 3 of BS 7671 is relevant to starting currents?
3. State the most common method of providing Basic protection.
4. State the most common method of providing Fault protection.
5. What would be the IP code for an item of equipment that is subject to splashes and the ingress of small foreign bodies?
6. What is the impact code for an impact resistance of 5 joules?
7. What is the maximum disconnection time for a distribution circuit supplied by a TT system?
8. State the simple formula for calculation of the earth fault loop impedance of a circuit.
9. Excluding RCDs state the other method of providing 'additional protection'.
10. What type of overcurrent would flow if a motor became jammed?
11. What is pre-arcing let-through energy?
12. What is achieved in a circuit when the total let-through energy of a minor protective device is less the pre-arcing let-through energy of the major device?
13. What installation voltage condition would be likely to arise if several large motors were energized at the same time?
14. What installation voltage condition would be likely to arise if heavily inductive loads were switched off?
15. What switching device has fuses as part of the switching mechanism?
16. State the full formula for determining three-phase design current.
17. What is the term used to indicate the assumption that not all of an installation would be energized at any one time?
18. What would be the de-rating factor for a cable totally surrounded by thermal insulation for a length of 2 m?
19. State the formula used to determine whether a cpc is acceptable to withstand let-through energy.
20. What type of diagram would be used to display the simple sequential arrangement of equipment in an installation?

Answers

1. Environment, utilization and building.
2. Compatibility.
3. Insulation of live parts, barriers or enclosures.
4. Automatic disconnection of supply.
5. IP44.
6. IK08.
7. 1 s.

8. $Z_s = Z_e + (R_1 + R_2)$.
9. Supplementary equipotential bonding.
10. Overload current.
11. The electrical energy that a protective device lets through, under fault conditions, up to its cut off point.
12. Discrimination.
13. Undervoltage.
14. Overvoltage.
15. Fuse switch.
16. $I_b = \dfrac{P(\text{watts})}{\sqrt{3} \times V_L \times \text{Eff\%} \times \text{PF}}$
17. Diversity.
18. 0.5.
19. $S = \dfrac{\sqrt{I^2 t}}{k}$
20. Block diagram.