FIGURE 4.53
LED used in seven-segment display.

FIGURE 4.54
Symbol and appearance of an LDR.

LIGHT-DEPENDENT RESISTOR

Almost all materials change their resistance with a change in temperature. Light energy falling on a suitable semiconductor material also causes a change in resistance. The semiconductor material of a light-dependent resistor (LDR) is encapsulated as shown in Fig. 4.54 together with the circuit symbol. The resistance of an LDR in total darkness is about $10\,\mathrm{M\Omega}$, in normal room lighting about $5\,\mathrm{k\Omega}$ and in bright sunlight about $100\,\Omega$. They can carry tens of milliamperes, an amount which is sufficient to operate a relay. The LDR uses this characteristic to switch on automatically street lighting and security alarms.

PHOTODIODE

The photodiode is a normal junction diode with a transparent window through which light can enter. The circuit symbol and general appearance are shown in Fig. 4.55. It is operated in reverse bias mode and the leakage current increases in proportion to the amount of light falling on the junction. This is due to the light energy breaking bonds in the crystal lattice of the semiconductor material to produce holes and electrons.

Photodiodes will only carry microamperes of current but can operate much more quickly than LDRs and are used as 'fast' counters when the light intensity is changing rapidly.

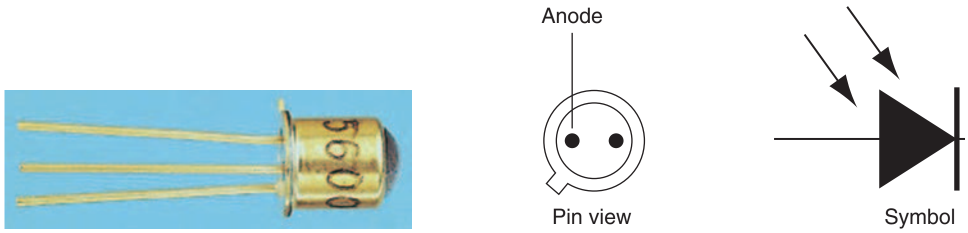


FIGURE 4.55
Symbol for, pin connections of and appearance of a photodiode.

FIGURE 4.56
Symbol for and appearance of a thermistor.

THERMISTOR

The thermistor is a thermal resistor, a semiconductor device whose resistance varies with temperature. Its circuit symbol and general appearance are shown in Fig. 4.56. They can be supplied in many shapes and are used for the measurement and control of temperature up to their maximum useful temperature limit of about 300°C. They are very sensitive and because the bead of semiconductor material can be made very small, they can measure temperature in the most inaccessible places with very fast response times. Thermistors are embedded in high-voltage underground transmission cables in order to monitor the temperature of the cable. Information about the temperature of a cable allows engineers to load the cables more efficiently. A particular cable can carry a larger load in winter for example, when heat from the cable is being dissipated more efficiently. A thermistor is also used to monitor the water temperature of a motor car.

TRANSISTORS

The transistor has become the most important building block in electronics. It is the modern, miniature, semiconductor equivalent of the thermionic valve and was invented in 1947 by Bardeen, Shockley and Brattain at the Bell Telephone Laboratories in the United States. Transistors are packaged as separate or *discrete* components, as shown in Fig. 4.57.

There are two basic types of transistor, the *bipolar* or junction transistor and the *field-effect transistor* (FET).

The FET has some characteristics which make it a better choice in electronic switches and amplifiers. It uses less power and has a higher resistance and frequency response. It takes up less space than a bipolar transistor and, therefore, more of them can be packed together on a given area of

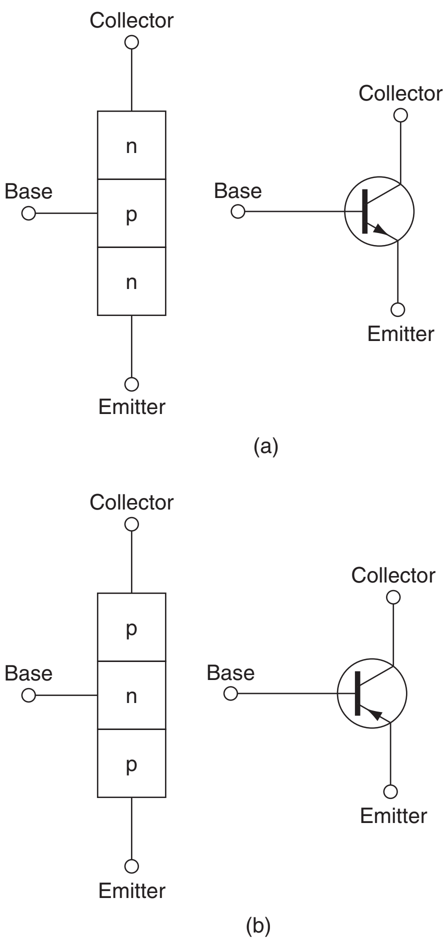


FIGURE 4.58
Structure of and symbol for (a) n-p-n and (b) p-n-p transistors.

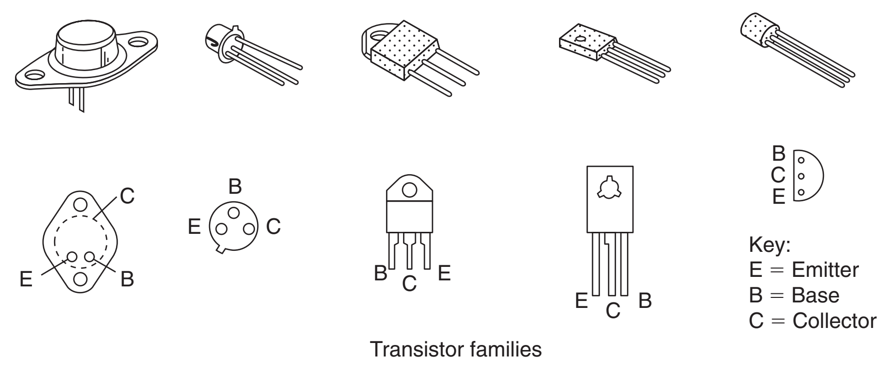


FIGURE 4.57
The appearance and pin connections of the transistor family.

silicon chip. It is, therefore, the FET which is used when many transistors are integrated on to a small area of silicon chip as in the IC that will be discussed later.

When packaged as a discrete component the FET looks much the same as the bipolar transistor. Its circuit symbol and connections are given in the Appendix. However, it is the bipolar transistor which is much more widely used in electronic circuits as a discrete component.

The bipolar transistor

The bipolar transistor consists of three pieces of semiconductor material sandwiched together as shown in Fig. 4.58. The structure of this transistor makes it a three-terminal device having a base, collector and emitter terminal. By varying the current flowing into the base connection a much larger current flowing between collector and emitter can be controlled. Apart from the supply connections, the n-p-n and p-n-p types are essentially the same but the n-p-n type is more common.

A transistor is generally considered a current-operated device. There are two possible current paths through the transistor circuit, shown in Fig. 4.59: the base–emitter path when the switch is closed; and the collector–emitter path. Initially, the positive battery supply is connected to the n-type material of the collector, the junction is reverse biased and, therefore, no current will flow. Closing the switch will forward bias the base–emitter junction and current flowing through this junction causes current to flow across the collector–emitter junction and the signal lamp will light.

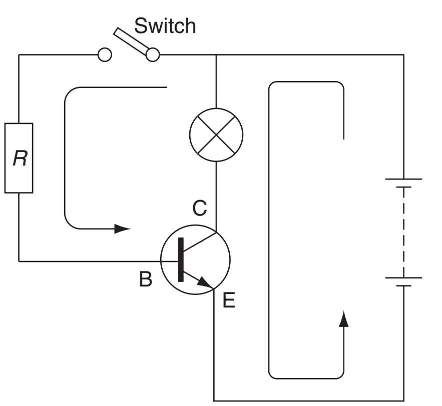


FIGURE 4.59
Operation of the transistor.

A small base current can cause a much larger collector current to flow. This is called the *current gain* of the transistor, and is typically about 100. When I say a much larger collector current, I mean a large current in electronic terms, up to about half an ampere.

We can, therefore, regard the transistor as operating in two ways: as a switch because the base current turns on and controls the collector current; and as a current amplifier because the collector current is greater than the base current.

We could also consider the transistor to be operating in a similar way to a relay. However, transistors have many advantages over electrically operated switches such as relays. They are very small, reliable, have no moving parts and, in particular, they can switch millions of times a second without arcing occurring at the contacts.

Table 4.6 Transistor Testing Using an Ohmmeter

A 'good' n-p-n transistor will give the following readings:
Red to base and black to collector = low resistance Red to base and black to emitter = low resistance Reversed connections on the above terminals will result in a high resistance reading, as will connections of either polarity between the collector and emitter terminals.
A 'good' p-n-p transistor will give the following readings:
Black to base and red to collector = low resistance Black to base and red to emitter = low resistance Reversed connections on the above terminals will result in a high resistance reading, as will connections of either polarity between the collector and emitter terminals.

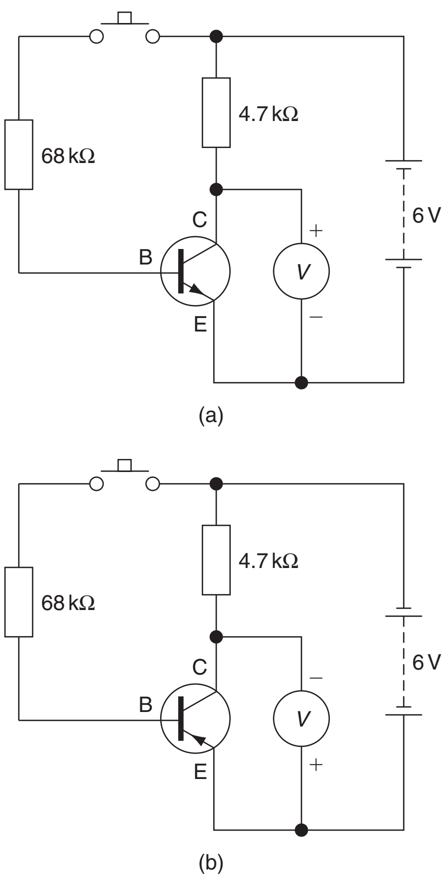


FIGURE 4.60
Transistor test circuits (a) n-p-n transistor test; (b) p-n-p transistor test.

Transistor testing

A transistor can be thought of as two diodes connected together and, therefore, a transistor can be tested using an ohmmeter in the same way as was described for the diode.

Assuming that the red lead of the ohmmeter is positive, the transistor can be tested in accordance with Table 4.6.

When many transistors are to be tested, a simple test circuit can be assembled as shown in Fig. 4.60.

With the circuit connected, as shown in Fig. 4.60 a 'good' transistor will give readings on the voltmeter of 6V with the switch open and about 0.5 V when the switch is made. The voltmeter used for the test should have a high internal resistance, about ten times greater than the value of the resistor being tested – in this case 4.7 kΩ – and this is usually indicated on the back of a multi-range meter or in the manufacturers' information supplied with a new meter.

INTEGRATED CIRCUITS

ICs were first developed in the 1960s. They are densely populated miniature electronic circuits made up of hundreds and sometimes thousands of microscopically small transistors, resistors, diodes and capacitors, all connected together on a single chip of silicon no bigger than a baby's fingernail. When assembled in a single package, as shown in Fig. 4.61, we call the device an IC.

There are two broad groups of IC: digital ICs and linear ICs. Digital ICs contain simple switching-type circuits used for logic control and calculators,

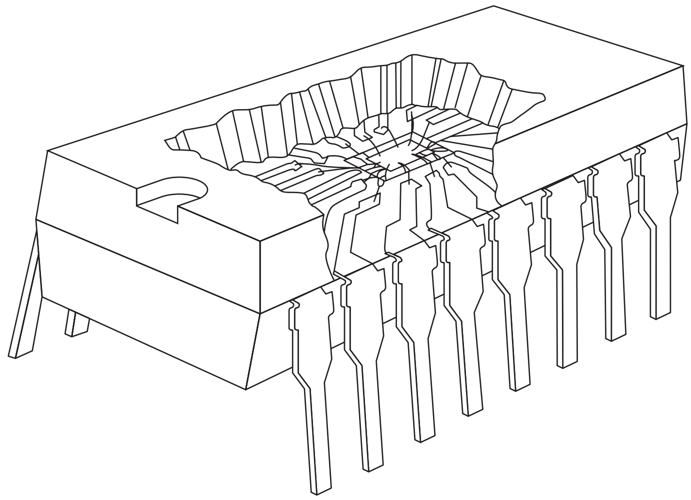


FIGURE 4.61
Exploded view of an IC.

linear ICs incorporate amplifier-type circuits which can respond to audio and radio frequency signals. The most versatile linear IC is the operational amplifier which has applications in electronics, instrumentation and control.

The IC is an electronic revolution. ICs are more reliable, cheaper and smaller than the same circuit made from discrete or separate transistors, and electronically superior. One IC behaves differently than another because of the arrangement of the transistors within the IC.

Manufacturers' data sheets describe the characteristics of the different ICs, which have a reference number stamped on the top.

When building circuits, it is necessary to be able to identify the IC pin connection by number. The number 1 pin of any IC is indicated by a dot pressed into the encapsulation; it is also the pin to the left of the cutout (Fig. 4.62). Since the packaging of ICs has two rows of pins they are called DIL (dual in line) packaged ICs and their appearance is shown in Fig. 4.63.

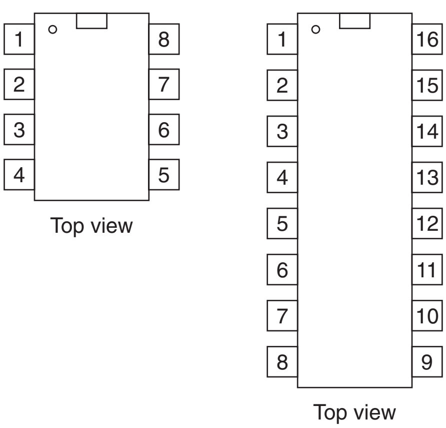


FIGURE 4.62
IC pin identification.

ICs are sometimes connected into DIL sockets and at other times are soldered directly into the circuit. The testing of ICs is beyond the scope of a practising electrician, and when they are suspected of being faulty an identical or equivalent replacement should be connected into the circuit, ensuring that it is inserted the correct way round, which is indicated by the position of pin number 1 as described earlier.

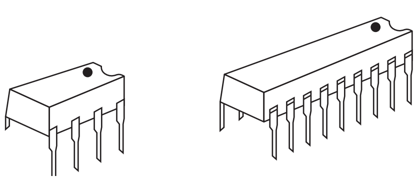


FIGURE 4.63
DIL packaged ICs.

THE THYRISTOR

The *thyristor* was previously known as a 'silicon controlled rectifier' since it is a rectifier which controls the power to a load. It consists of four pieces of semiconductor material sandwiched together and connected to three terminals, as shown in Fig. 4.64.

The word thyristor is derived from the Greek word *thyra* meaning door, because the thyristor behaves like a door. It can be open or shut, allowing

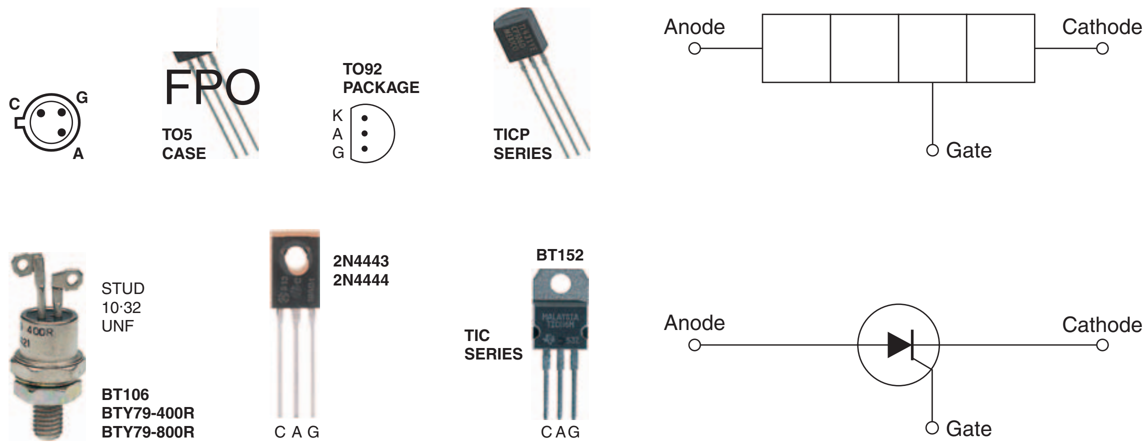


FIGURE 4.64
Symbol for and structure and appearance of a thyristor.

Table 4.7 Thyristor Testing Using an Ohmmeter

A 'good' thyristor will give the following readings:
Black to cathode and red on gate = low resistance Red to cathode and black on gate = a higher resistance value The value of the second reading will depend upon the thyristor, and may vary from only slightly greater to very much greater. Connecting the test instrument leads from cathode to anode will result in a very high resistance reading, whatever polarity is used.

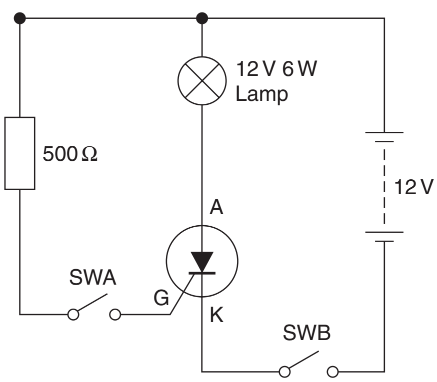


FIGURE 4.65
Thyristor test circuit.

or preventing current flow through the device. The door is opened – we say the thyristor is triggered – to a conducting state by applying a pulse voltage to the gate connection. Once the thyristor is in the conducting state, the gate loses all control over the devices. The only way to bring the thyristor back to a non-conducting state is to reduce the voltage across the anode and cathode to zero or apply reverse voltage across the anode and cathode.

We can understand the operation of a thyristor by considering the circuit shown in Fig. 4.65. This circuit can also be used to test suspected faulty components.

When SWB only is closed the lamp will not light, but when SWA is also closed, the lamp lights to full brilliance. The lamp will remain illuminated even when SWA is opened. This shows that the thyristor is operating correctly. Once a voltage has been applied to the gate the thyristor becomes forward conducting, like a diode, and the gate loses control.

A thyristor may also be tested using an ohmmeter as described in Table 4.7, assuming that the red lead of the ohmmeter is positive.

The thyristor has no moving parts and operates without arcing. It can operate at extremely high speeds, and the currents used to operate the gate are very small. The most common application for the thyristor is to control the power supply to a load, for example, lighting dimmers and motor speed control.

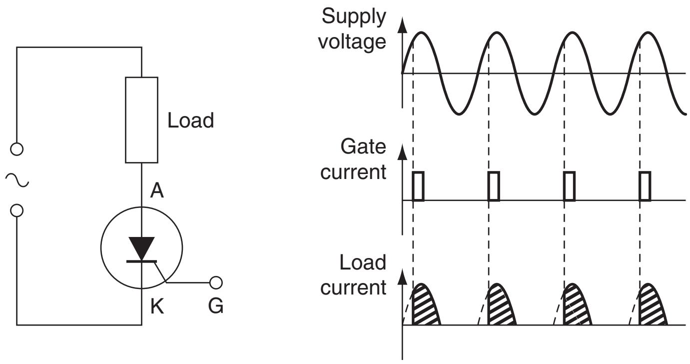


FIGURE 4.66
Waveforms to show the control effect of a thyristor.

The power available to an a.c. load can be controlled by allowing current to be supplied to the load during only a part of each cycle. This can be achieved by supplying a gate pulse automatically at a chosen point in each cycle, as shown by Fig. 4.66. Power is reduced by triggering the gate later in the cycle.

The thyristor is only a half-wave device (like a diode) allowing control of only half the available power in an a.c. circuit. This is very uneconomical, and a further development of this device has been the triac which is considered next.

THE TRIAC

The triac was developed following the practical problems experienced in connecting two thyristors in parallel, to obtain full-wave control, and in providing two separate gate pulses to trigger the two devices.

The triac is a single device containing a back-to-back, two-directional thyristor which is triggered on both halves of each cycle of the a.c. supply by the same gate signal. The power available to the load can, therefore, be varied between zero and full load.

Its symbol and general appearance are shown in Fig. 4.67. Power to the load is reduced by triggering the gate later in the cycle, as shown by the waveforms of Fig. 4.68.

The triac is a three-terminal device, just like the thyristor, but the terms anode and cathode have no meaning for a triac. Instead, they are called main terminal one (MT_1) and main terminal two (MT_2). The device is triggered by applying a small pulse to the gate (G). A gate current of 50 mA is sufficient to trigger a triac switching up to 100 A. They are used for many commercial applications where control of a.c. power is required, for example, motor speed control and lamp dimming.

THE DIAC

The diac is a two-terminal device containing a two-directional Zener diode. It is used mainly as a trigger device for the thyristor and triac. The symbol is shown in Fig. 4.69.

FIGURE 4.67
Appearance of a triac.

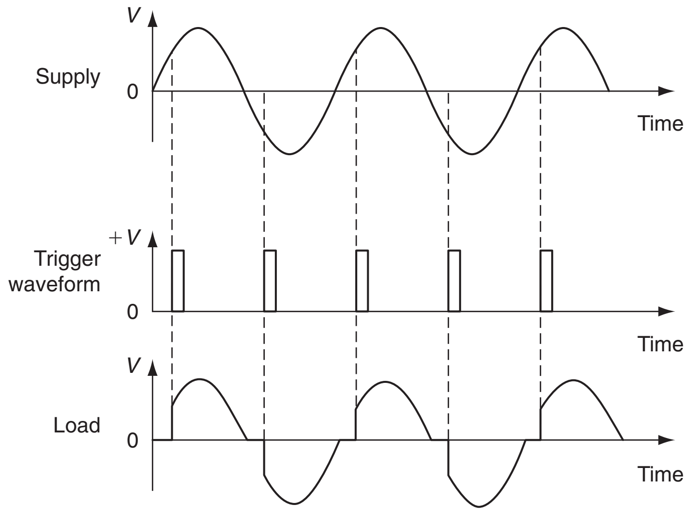


FIGURE 4.68
Waveforms to show the control effect of a triac.

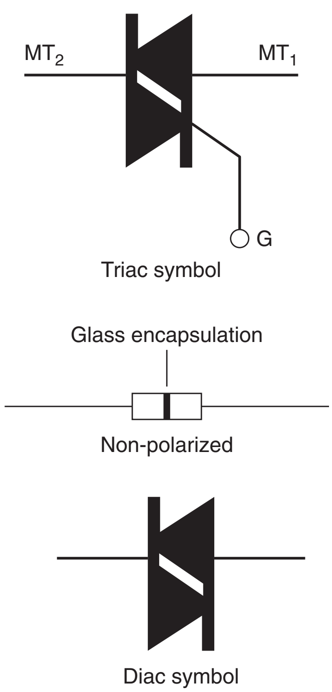


FIGURE 4.69
Symbol for and appearance of a diac used in triac firing circuits.

The device turns on when some predetermined voltage level is reached, say 30V, and, therefore, it can be used to trigger the gate of a triac or thyristor each time the input waveform reaches this predetermined value. Since the device contains back-to-back Zener diodes it triggers on both the positive and negative half-cycles.

Voltage divider

At the beginning of this chapter we considered the distribution of voltage across resistors connected in series. We found that the supply voltage was divided between the series resistors in proportion to the size of the resistor. If two identical resistors were connected in series across a 12 V supply, as shown in Fig. 4.70(a), both common sense and a simple calculation would confirm that 6V would be measured across the output. In the circuit shown in Fig. 4.70(b), the 1 and 2 kΩ resistors divide the input voltage into three equal parts. One part, 4 V, will appear across the 1 kΩ resistor and two parts, 8 V, will appear across the 2 kΩ resistor. In Fig. 4.70(c) the situation is reversed and, therefore, the voltmeter will read 4 V. The division of the voltage is proportional to the ratio of the two resistors and, therefore, we call this simple circuit a *voltage divider* or *potential divider*. The values of the resistors R_1 and R_2 determine the output voltage as follows:

$$V_{OUT} = V_{IN} \times \frac{R_2}{R_1 + R_2} \text{ (V)}$$

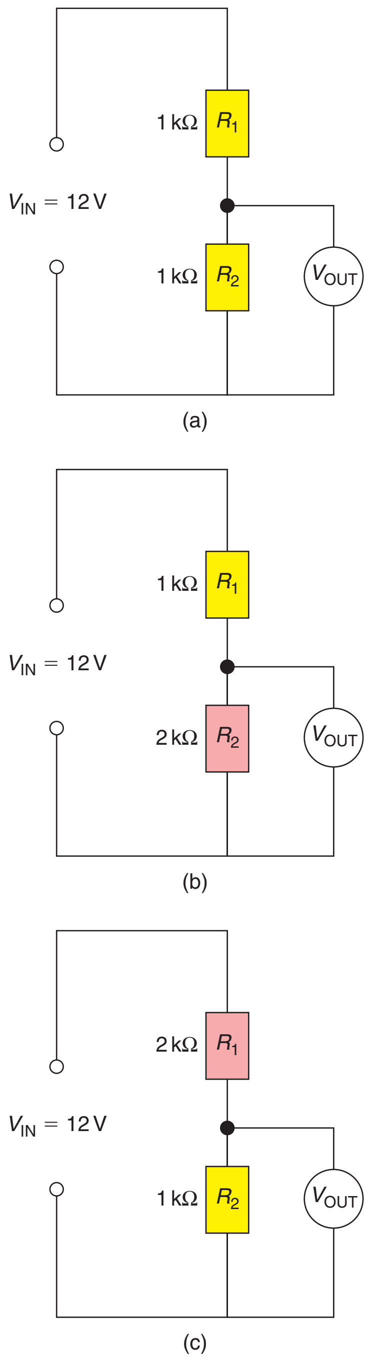


FIGURE 4.70
Voltage divider circuit.

For the circuit shown in Fig. 4.70(b),

$$V_{OUT} = 12\ \text{V} \times \frac{2\ \text{k}\Omega}{1\ \text{k}\Omega + 2\ \text{k}\Omega} = 8\ \text{V}$$

For the circuit shown in Fig. 4.70(c),

$$V_{OUT} = 12\text{V} \times \frac{1\ \text{k}\Omega}{2\ \text{k}\Omega + 1\ \text{k}\Omega} = 4\text{V}$$

Example 1

For the circuit shown in Fig. 4.71, calculate the output voltage.

$$V_{OUT} = 6\ \text{V} \times \frac{2.2\ \text{k}\Omega}{10\ \text{k}\Omega + 2.2\ \text{k}\Omega} = 1.08\ \text{V}$$

Example 2

For the circuit shown in Fig. 4.72(a), calculate the output voltage.

We must first calculate the equivalent resistance of the parallel branch:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_T} = \frac{1}{10\ \text{k}\Omega} + \frac{1}{10\ \text{k}\Omega} = \frac{1+1}{10\ \text{k}\Omega} = \frac{2}{10\ \text{k}\Omega}$$

$$R_T = \frac{10\ \text{k}\Omega}{2} = 5\ \text{k}\Omega$$

The circuit may now be considered as shown in Fig. 4.72(b):

$$V_{OUT} = 6\ \text{V} \times \frac{10\ \text{k}\Omega}{5\ \text{k}\Omega + 10\ \text{k}\Omega} = 4\ \text{V}$$

Voltage dividers are used in electronic circuits to produce a reference voltage which is suitable for operating transistors and ICs. The volume control in a radio or the brightness control of a cathode-ray oscilloscope requires a continuously variable voltage divider and this can be achieved by connecting a variable resistor or potentiometer, as shown in Fig. 4.73. With the wiper arm making a connection at the bottom of the resistor, the output would be zero. When connection is made at the centre, the voltage would be 6 V, and at the top of the resistor the voltage would be 12 V. The voltage is continuously variable between 0 and 12 V simply by moving the wiper arm of a suitable variable resistor such as those shown in Fig. 4.37.

When a load is connected to a voltage divider it 'loads' the circuit, causing the output voltage to fall below the calculated value. To avoid this, the resistance of the load should be at least ten times as great as the value of the resistor across which it is connected. For example, the load connected across the voltage divider shown in Fig. 4.70(b) must be greater than 20 kΩ

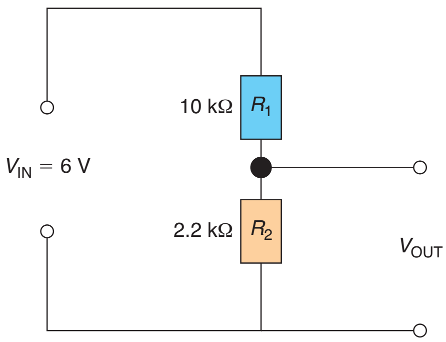


FIGURE 4.71
Voltage divider circuit for Example 1.

Definition

Rectification is the conversion of an a.c. supply into a unidirectional or d.c. supply.

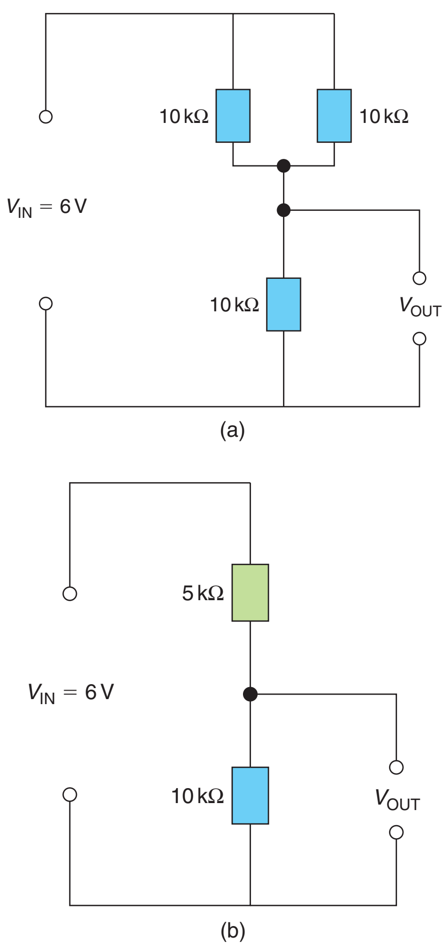


FIGURE 4.72
(a) Voltage divider circuit for Example 2; (b) Equivalent circuit for Example 2.

and across 4.70(c) greater than 10 kΩ. This problem of loading the circuit also occurs when taking voltage readings, as discussed later in this chapter under the subheading Instrument Errors.

Rectification of a.c.

When a d.c. supply is required, batteries or a rectified a.c. supply can be provided. Batteries have the advantage of portability, but a battery supply is more expensive than using the a.c. mains supply suitably rectified. **Rectification** is the conversion of an a.c. supply into a unidirectional or d.c. supply. This is one of the many applications for a diode which will conduct in one direction only, that is when the anode is positive with respect to the cathode.

HALF-WAVE RECTIFICATION

The circuit is connected as shown in Fig. 4.74. During the first half-cycle the anode is positive with respect to the cathode and, therefore, the diode will conduct. When the supply goes negative during the second half-cycle, the anode is negative with respect to the cathode and, therefore, the diode will not allow current to flow. Only the positive half of the waveform will be available at the load and the lamp will light at reduced brightness.

FULL-WAVE RECTIFICATION

Figure 4.75 shows an improved rectifier circuit which makes use of the whole a.c. waveform and is, therefore, known as a full-wave rectifier. When the four diodes are assembled in this diamond-shaped configuration, the circuit is also known as a *bridge rectifier*. During the first half-cycle diodes D_1 and D_3 conduct, and diodes D_2 and D_4 conduct during the second half-cycle. The lamp will light to full brightness.

Full-wave and half-wave rectification can be displayed on the screen of a CRO and will appear as shown in Figs. 4.74 and 4.75.

Smoothing

The circuits of Figs. 4.74 and 4.75 convert an alternating waveform into a waveform which never goes negative, but they cannot be called continuous d.c. because they contain a large alternating component. Such a waveform is too bumpy to be used to supply electronic equipment but may be used for battery charging. To be useful in electronic circuits the output must be smoothed. The simplest way to smooth an output is to connect a large-value capacitor across the output terminals as shown in Fig. 4.76.

When the output from the rectifier is increasing, as shown by the dotted lines of Fig. 4.77, the capacitor charges up. During the second quarter of the cycle, when the output from the rectifier is falling to zero, the capacitor discharges into the load. The output voltage falls until the output from the rectifier once again charges the capacitor. The capacitor connected to the full-wave rectifier circuit is charged up twice as often as the

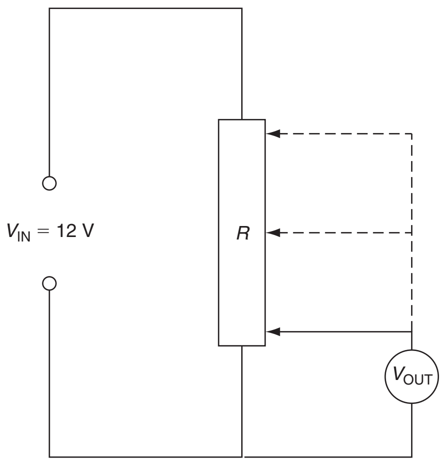


FIGURE 4.73
Constantly variable voltage divider circuit.

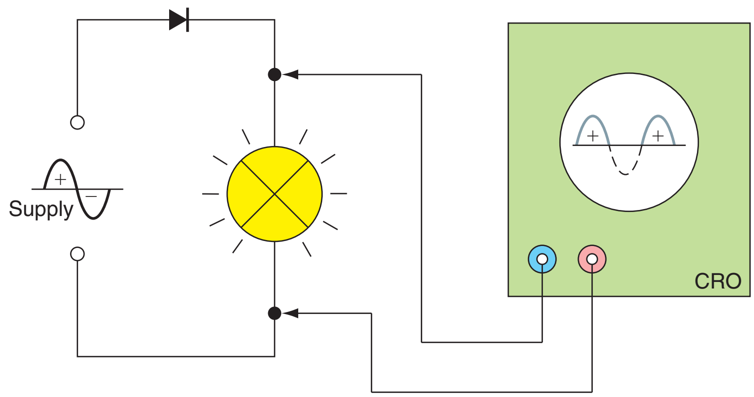


FIGURE 4.74
Half-wave rectification.

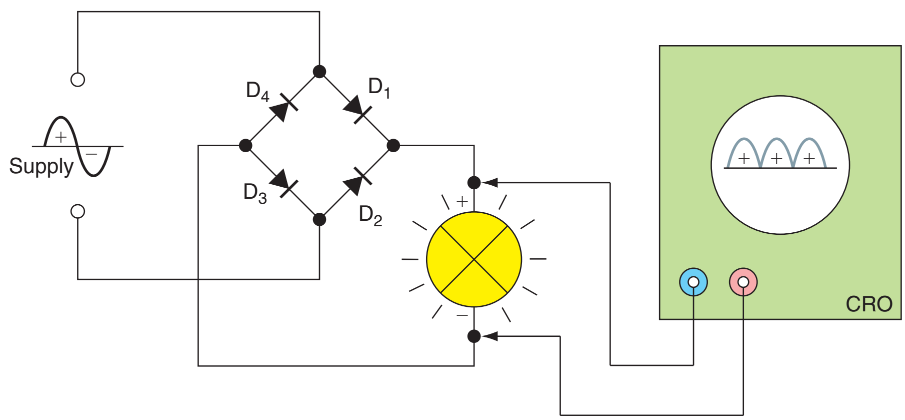


FIGURE 4.75
Full-wave rectification using a bridge circuit.

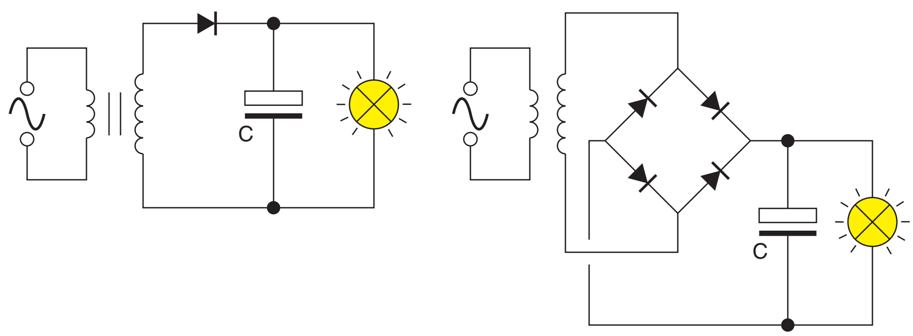


FIGURE 4.76
Rectified a.c. with smoothing capacitor connected.

capacitor connected to the half-wave circuit and, therefore, the output ripple on the full-wave circuit is smaller, giving better smoothing. Increasing the current drawn from the supply increases the size of the ripple. Increasing the size of the capacitor reduces the amount of ripple.

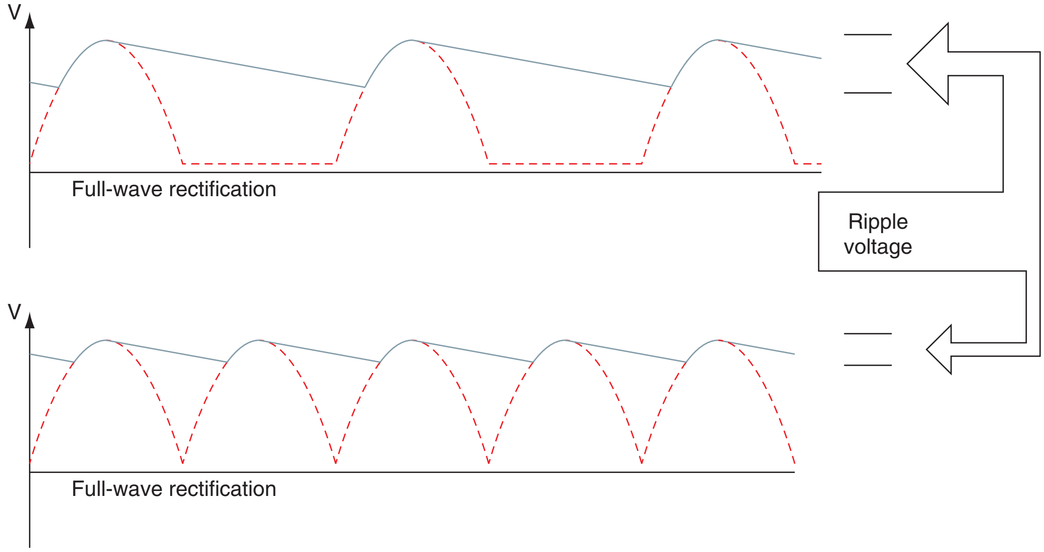


FIGURE 4.77
Output waveforms with smoothing showing reduced ripple with full wave.

Try This

Battery Charger

- Do you have a battery charger for your car battery?
- What type of circuit do you think is inside?
- Carefully look inside and identify the components.

LOW-PASS FILTER

The ripple voltage of the rectified and smoothed circuit shown in Fig. 4.76 can be further reduced by adding a low-pass filter, as shown in Fig. 4.78. A low-pass filter allows low frequencies to pass while blocking higher frequencies. Direct current has a frequency of zero hertz, while the ripple voltage of a full-wave rectifier has a frequency of 100 Hz. Connecting the low-pass filter will allow the d.c. to pass while blocking the ripple voltage, resulting in a smoother output voltage.

The low-pass filter shown in Fig. 4.78 does, however, increase the output resistance, which encourages the voltage to fall as the load current increases. This can be reduced if the resistor is replaced by a choke, which has a high-impedance to the ripple voltage but a low resistance, which reduces the output ripple without increasing the output resistance.

Stabilized power supplies

The power supplies required for electronic circuits must be ripple-free, stabilized and have good regulation, that is the voltage must not change in value over the whole load range. A number of stabilizing circuits are available which, when connected across the output of the circuit shown in Fig. 4.76, give a constant or stabilized voltage output. These circuits use the

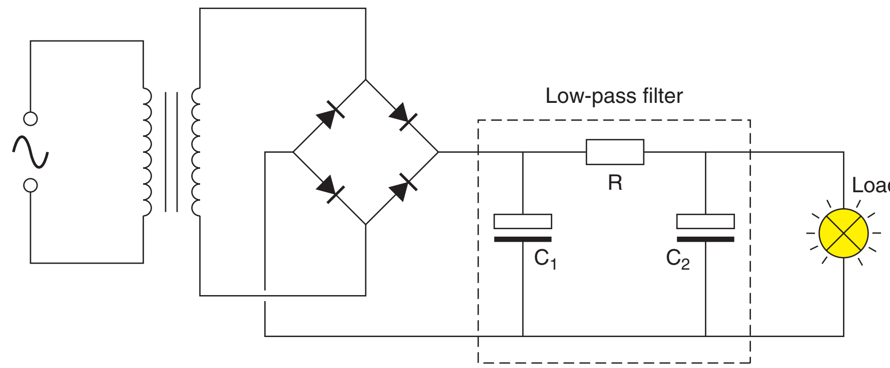


FIGURE 4.78
Rectified a.c. with low-pass filter connected.

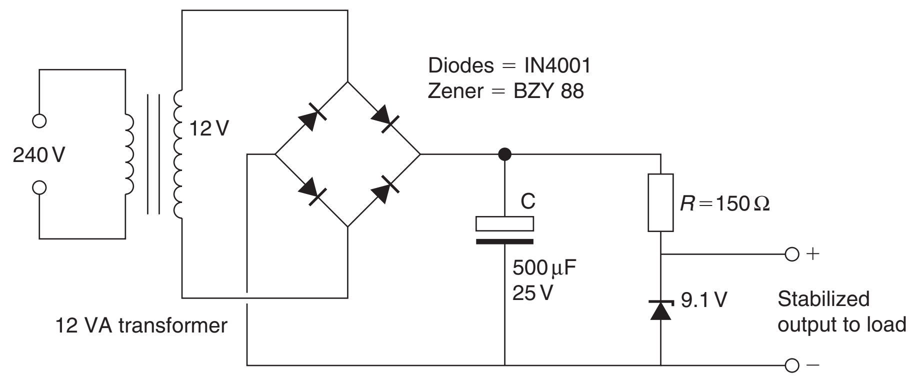


FIGURE 4.79
Stabilized d.c. supply.

characteristics of the Zener diode which was described by the experiment in Fig. 4.50.

Figure 4.79 shows an a.c. supply which has been rectified, smoothed and stabilized. You could build and test this circuit at college if your lecturers agree.

Lighting and luminares

In ancient times, much of the indoor work done by humans depended upon daylight being available to light the interior. Today almost all buildings have electric lighting installed and we automatically assume that we can work indoors or out of doors at any time of the day or night, and that light will always be available.

Good lighting is important in all building interiors, helping work to be done efficiently and safely and also playing an important part in creating pleasant and comfortable surroundings.

Lighting schemes are designed using many different types of light fitting or luminaire. 'Luminaire' is the modern term given to the equipment which supports and surrounds the lamp and may control the distribution of the light. Modern lamps use the very latest technology to provide illumination cheaply and efficiently. To begin to understand the lamps and lighting technology used today, we must first define some of the terms we will be using.

LUMINOUS INTENSITY – SYMBOL *I*

This is the illuminating power of the light source to radiate luminous flux in a particular direction. The earliest term used for the unit of luminous intensity was the candle power because the early standard was the wax candle. The SI unit is the candela (pronounced candeela and abbreviated as cd).

LUMINOUS FLUX – SYMBOL *F*

This is the flow of light which is radiated from a source. The SI unit is the lumen, one lumen being the light flux which is emitted within a unit solid angle (volume of a cone) from a point source of 1 candela.

ILLUMINANCE – SYMBOL *E*

This is a measure of the light falling on a surface, which is also called the incident radiation. The SI unit is the lux (lx) and is the illumination produced by 1 lumen over an area of 1 m^2.

LUMINANCE – SYMBOL *L*

Since this is a measure of the brightness of a surface it is also a measure of the light which is reflected from a surface. The objects we see vary in appearance according to the light which they emit or reflect towards the eye.

The SI units of luminance vary with the type of surface being considered. For a diffusing surface such as blotting paper or a matt white painted surface the unit of luminance is the lumen per square metre. With polished surfaces such as a silvered glass reflector, the brightness is specified in terms of the light intensity and the unit is the candela per square metre.

Illumination laws

Rays of light falling upon a surface from some distance d will illuminate that surface with an illuminance of say 1 lx. If the distance d is doubled as shown in Fig. 4.80, the illuminance of 1 lx will fall over four square units of area. Thus the illumination of a surface follows the **inverse square law**, where

$$E = \frac{I}{d^2}\,(\mathrm{lx})$$

Definition

Thus the illumination of a surface follows the *inverse square law*, where

$$E = \frac{I}{d^2}\,(\mathrm{lx})$$

Example 1

A lamp of luminous intensity 1000 cd is suspended 2 m above a laboratory bench. Calculate the illuminance directly below the lamp:

$$E = \frac{I}{d^2}\,(\mathrm{lx})$$

$$\therefore E = \frac{1000\ \mathrm{cd}}{(2\ \mathrm{m})^2} = 250\ \mathrm{lx}$$

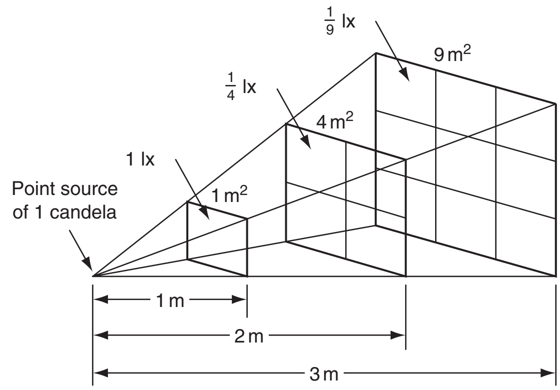


FIGURE 4.80
The inverse square law.

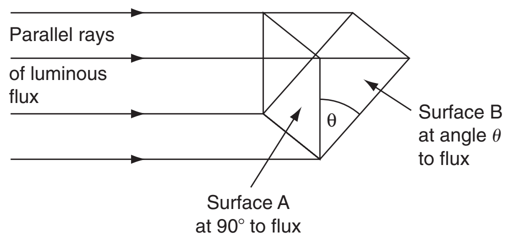


FIGURE 4.81
The cosine law.

Definition

$$E = \frac{I \cos \theta}{d^2} \text{(lx)}$$

Since the two surfaces are joined together by the trigonometry of the cosine rules this equation is known as the *cosine law*.

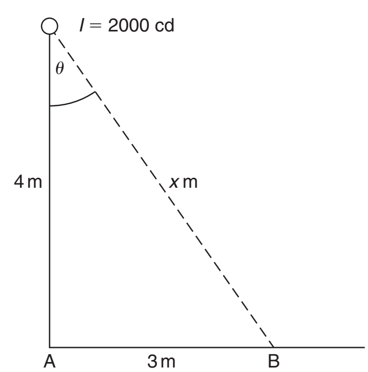
The illumination of surface A in Fig. 4.81 will follow the inverse square law described above. If this surface were removed, the same luminous flux would then fall on surface B. Since the parallel rays of light falling on the inclined surface B are spread over a larger surface area, the illuminance will be reduced by a factor θ, and therefore:

$$E = \frac{I \cos \theta}{d^2} \text{(lx)}$$

Since the two surfaces are joined together by the trigonometry of the cosine rules this equation is known as the **cosine law**.

Example 2

A street lantern suspends a 2000 cd light source 4 m above the ground. Determine the illuminance directly below the lamp and 3 m to one side of the lamp base.



The illuminance below the lamp, E_A, is:

$$E_A = \frac{I}{d^2}(\text{lx})$$

$$\therefore E_A = \frac{2000\ \text{cd}}{(4\ \text{m})^2} = 125\ \text{lx}$$

To work out the illuminance at 3 m to one side of the lantern, E_B, we need the distance between the light source and the position on the ground at B; this can be found by Pythagoras' theorem:

$$x\ (\text{m}) = \sqrt{(4\ \text{m})^2 + (3\ \text{m})^2} = \sqrt{25\ \text{m}}$$

$$x = 5\ \text{m}$$

$$\therefore E_B = \frac{I \cos\theta}{d^2}(\text{lx}) \text{ and } \cos\theta = \frac{4}{5}$$

$$\therefore E_B = \frac{2000\ \text{cd} \times 4}{(5\ \text{m})^2 \times 5} = 64\ \text{lx}$$

Example 3

A discharge lamp is suspended from a ceiling 4 m above a bench. The illuminance on the bench below the lamp was 300 lx. Find:

(a) the luminous intensity of the lamp
(b) the distance along the bench where the illuminance falls to 153.6 lx.

For (a),

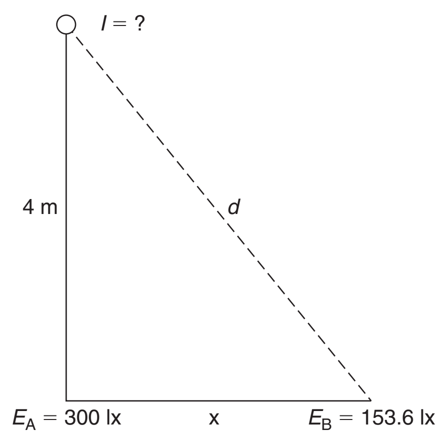
$$E_A = \frac{I}{d^2}(\text{lx})$$

$$\therefore I = E_A\ d^2(\text{cd})$$

$$I = 300\ \text{lx} \times 16\ \text{m} = 4800\ \text{cd}$$

For (b),

$$E_B = \frac{I}{d^2}\cos\theta\,(\text{lx})$$



$$\therefore d^2 = \frac{I \cos\theta}{E_B}(\mathrm{m}^2)$$

$$d^2 = \frac{4800\ \mathrm{cd}}{153.6\ \mathrm{lx}} \times \frac{4\ \mathrm{m}}{d\ \mathrm{m}}$$

$$d^3 = 125$$

$$\therefore \mathrm{d} = \sqrt[3]{125} = 5\ \mathrm{m}$$

By Pythagoras,

$$x = \sqrt{5^2 - 4^2} = 3\mathrm{m}$$

The recommended levels of illuminance for various types of installation are given by the IES (Illumination Engineers Society). Some examples are given in Table 4.8.

Table 4.8 Illuminance Values

Task	Working situation	Illuminance (lx)
Casual vision	Storage rooms, stairs and washrooms	100
Rough assembly	Workshops and garages	300
Reading, writing and drawing	Classrooms and offices	500
Fine assembly	Electronic component assembly	1000
Minute assembly	Watchmaking	3000

The activities being carried out in a room will determine the levels of illuminance required since different levels of illumination are required for the successful operation or completion of different tasks. The assembly of electronic components in a factory will require a higher level of illumination than, say, the assembly of engine components in a garage because the electronic components are much smaller and finer detail is required for their successful assembly.

The inverse square law calculations considered earlier are only suitable for designing lighting schemes where there are no reflecting surfaces producing secondary additional illumination. This method could be used to design an outdoor lighting scheme for a cathedral, bridge or public building.

Interior luminaires produce light directly on to the working surface but additionally there is a secondary source of illumination from light reflected from the walls and ceilings. When designing interior lighting schemes the method most frequently used depends upon a determination of the total flux required to provide a given value of illuminance at the working place. This method is generally known as the **lumen method**.

Definition

When designing interior lighting schemes the method most frequently used depends upon a determination of the total flux required to provide a given value of illuminance at the working place. This method is generally known as the *lumen method*.

THE LUMEN METHOD

To determine the total number of luminaires required to produce a given illuminance by the lumen method we apply the following formula:

$$\text{Total number of luminaires required to provide a chosen level of illumination at a surface} = \frac{\text{Illuminance level (lx)} \times \text{Area (m}^2)}{\text{Lumen output of each luminaire (lm)} \times \text{UF} \times \text{LLF}}$$

where

- the illuminance level is chosen after consideration of the IES code,
- the area is the working area to be illuminated,
- the lumen output of each luminaire is that given in the manufacturer's specification and may be found by reference to tables such as Table 4.9,
- UF is the utilization factor,
- LLF is the light loss factor.

Utilization factor

The light flux reaching the working plane is always less than the lumen output of the lamp since some of the light is absorbed by the various surface textures. The method of calculating the utilization factor (UF) is detailed in Chartered Institution of Building Services Engineers (CIBSE) Technical Memorandum No 5, although lighting manufacturers' catalogues give factors for standard conditions. The UF is expressed as a number which is always less than unity; a typical value might be 0.9 for a modern office building.

Light Loss Factor

The light output of a luminaire is reduced during its life because of an accumulation of dust and dirt on the lamp and fitting. Decorations also

Table 4.9 Characteristics of a Thorn Lighting 1500 mm 65 W Bi-Pin Tube

Tube colour	Initial lamp lumens*	Lighting design lumens†	Colour rendering quality	Colour appearance
Artifical daylight	2600	2100	Excellent	Cool
De Luxe Natural	2900	2500	Very Good	Intermediate
De Luxe Warm white	3500	3200	Good	Warm
Natural	3700	3400	Good	Intermediate
Daylight	4800	4450	Fair	Cool
Warm white	4950	4600	Fair	Warm
White	5100	4750	Fair	Warm
Red	250*	250	Poor	Deep red

Coloured tubes are intended for decorative purposes only.
*The initial lumens are the measured lumens after 100 hours of life.
†The lighting design lumens are the output lumens after 2000 hours.

Burning position	Lamp may be operated in any position
Rated life	7500 hours
Efficacy	30–70 lm/W depending upon the tube colour

deteriorate with time, and this results in more light flux being absorbed by the walls and ceiling.

You can see from Table 4.9 that the output lumens of the lamp decrease with time – for example, a warm white tube gives out 4950 lumens after the first 100 hours of its life but this falls to 4600 lumens after 2000 hours.

The total light loss can be considered under four headings:

1. light loss due to luminaire dirt depreciation (LDD),
2. light loss due to room dirt depreciation (RDD),
3. light loss due to lamp failure factor (LFF),
4. light loss due to lamp lumen depreciation (LLD).

The LLF is the total loss due to these four separate factors and typically has a value between 0.8 and 0.9.

When using the LLF in lumen method calculations we always use the manufacturer's initial lamp lumens for the particular lamp because the LLF takes account of the depreciation in lumen output with time. Let us now consider a calculation using the lumen method.

Example

It is proposed to illuminate an electronic workshop of dimensions 9 × 8 × 3 m to an illuminance of 550 lx at the bench level. The specification calls for luminaires having one 1500 mm 65 W natural tube with an initial output of 3700 lumens (see Table 4.9). Determine the number of luminaires required for this installation when the UF and LLF are 0.9 and 0.8, respectively.

$$\text{The number of luminaires required} = \frac{E\ (\text{lx}) \times \text{area}\ (\text{m}^2)}{\text{lumens from each luminaire} \times \text{UF} \times \text{LLF}}$$

$$\text{The number of luminaires} = \frac{550\ \text{lx} \times 9\ \text{m} \times 8\text{m}}{3700 \times 0.9 \times 0.8} = 14.86$$

Therefore 15 luminaires will be required to illuminate this workshop to a level of 550 lx.

Comparison of light sources

When comparing one light source with another we are interested in the colour reproducing qualities of the lamp and the efficiency with which the lamp converts electricity into illumination. These qualities are expressed by the lamp's efficacy and colour rendering qualities.

Definition

The performance of a lamp is quoted as a ratio of the number of lumens of light flux which it emits to the electrical energy input which it consumes. Thus *efficacy* is measured in lumens per watt; the greater the efficacy the better is the lamp's performance in converting electrical energy into light energy.

Lamp efficacy

The performance of a lamp is quoted as a ratio of the number of lumens of light flux which it emits to the electrical energy input which it consumes. Thus **efficacy** is measured in lumens per watt; the greater the efficacy the better is the lamp's performance in converting electrical energy into light energy.

A general lighting service (GLS) lamp, for example, has an efficacy of 14 lumens per watt, while a fluorescent tube, which is much more efficient at converting electricity into light, has an efficacy of about 50 lumens per watt.

Colour rendering

We recognize various materials and surfaces as having a particular colour because luminous flux of a frequency corresponding to that colour is reflected from the surface to our eye which is then processed by our brain. White light is made up of the combined frequencies of the colours red, orange, yellow, green, blue, indigo and violet. Colours can only be seen if the lamp supplying the illuminance is emitting light of that particular frequency. The ability to show colours faithfully as they would appear in daylight is a measure of the colour rendering property of the light source.

Definition

GLS lamps produce light as a result of the heating effect of an electrical current. Most of the electricity goes to producing heat and a little to producing light. A fine tungsten wire is first coiled and coiled again to form the incandescent filament of the GLS lamp.

GLS LAMPS

GLS lamps produce light as a result of the heating effect of an electrical current. Most of the electricity goes to producing heat and a little to producing light. A fine tungsten wire is first coiled and coiled again to form the incandescent filament of the GLS lamp. The coiled coil arrangement reduces filament cooling and increases the light output by allowing the filament to operate at a higher temperature. The light output covers the visible spectrum, giving a warm white to yellow light with a colour rendering quality classified as fairly good. The efficacy of the GLS lamp is 14 lumens per watt over its intended lifespan of 1000 hours.

Key Fact

Energy efficiency

- Over the next few years the government will phase out GLS lamps.
- So that we will have to use more energy efficient lamps such as Compact Fluorescent Lamps (CFLs).

The filament lamp in its simplest form is a purely functional light source which is unchallenged on the domestic market despite the manufacture of more efficient lamps. One factor which may have contributed to its popularity is that lamp designers have been able to modify the glass envelope of the lamp to give a very pleasing decorative appearance, as shown in Fig. 4.82.

TUNGSTEN HALOGEN DICHROIC REFLECTOR MINIATURE SPOT LAMPS

Tungsten Halogen Dichroic Reflector Miniature Spot Lamps such as the one shown in Fig. 4.83 are extremely popular in the lighting schemes of the new millennium. Their small size and bright white illumination makes them very popular in both commercial and domestic installations. They are available as a 12 volt bi-pin package in 20, 35 and 50 watts and as a 230 volt bayonet type cap (called a GU10 or GZ10 cap) in 20, 35 and 50 watts. However, their efficacy is only 20 lumens per watt over a 2000-hour lifespan.

Definition

Discharge lamps do not produce light by means of an incandescent filament but by the excitation of a gas or metallic vapour contained within a glass envelope.

DISCHARGE LAMPS

Discharge lamps do not produce light by means of an incandescent filament but by the excitation of a gas or metallic vapour contained within a glass envelope. A voltage applied to two terminals or electrodes sealed into the end of a glass tube containing a gas or metallic vapour will excite the contents and produce light directly. Fluorescent tubes and CFLs operate on this principle.

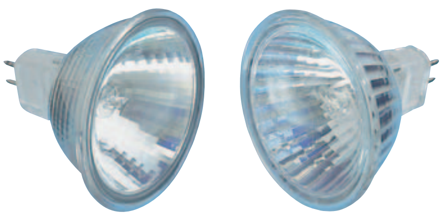


FIGURE 4.83
Tungsten Halogen Dichroic Reflector Lamp.

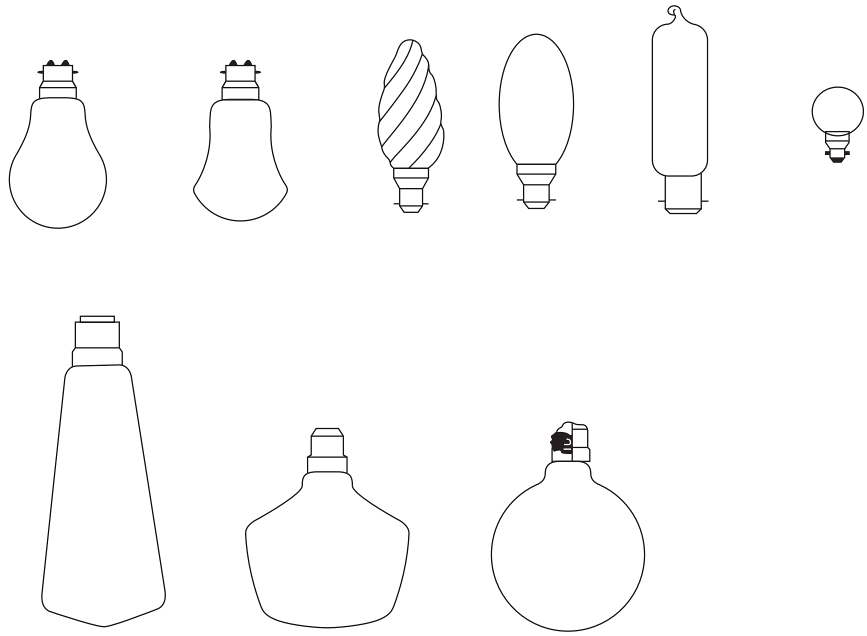


FIGURE 4.82
Some decorative GLS lamp shapes.

Fluorescent tube

A **fluorescent lamp** is a linear arc tube, internally coated with a fluorescent powder, containing a low-pressure mercury vapour discharge. The lamp construction is shown in Fig. 4.84 and the characteristics of the variously coloured tubes are given in Table 4.9.

Definition

A *fluorescent lamp* is a linear arc tube, internally coated with a fluorescent powder, containing a low-pressure mercury vapour discharge.

Passing a current through the cathodes of the tube causes them to become hot and produce a cloud of electrons which ionize the gas in the immediate vicinity of the cathodes. This ionization then spreads to the whole length of the tube, producing invisible ultraviolet rays and some blue light. The fluorescent powder on the inside of the tube is sensitive to ultraviolet rays and converts this radiation into visible light. The fluorescent powder on the inside of the tube can be mixed to give light of almost any desired colour or grade of white light. Some mixes have their maximum light output in the yellow–green region of the spectrum giving maximum efficacy but poor colour rendering. Other mixes give better colour rendering at the cost of reduced lumen output as can be seen from Table 4.9. The lamp has many domestic, industrial and commercial applications. Its efficacy varies between 30 and 70 lumens per watt depending upon the colour rendering qualities of the tube.

Definition

CFLs are miniature fluorescent lamps designed to replace ordinary GLS lamps.

Energy-efficient lamps

CFLs are miniature or compact fluorescent lamps designed to replace ordinary GLS lamps. They are available in a variety of shapes and sizes so that they can be fitted into existing light fittings. Fig. 4.85 shows three typical

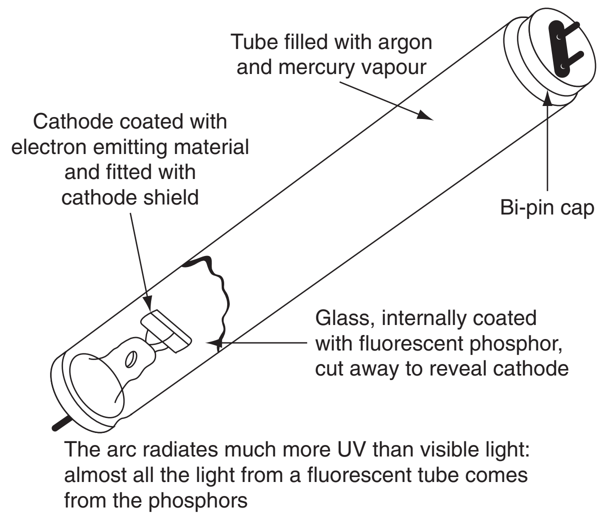


FIGURE 4.84
Fluorescent lamp construction.

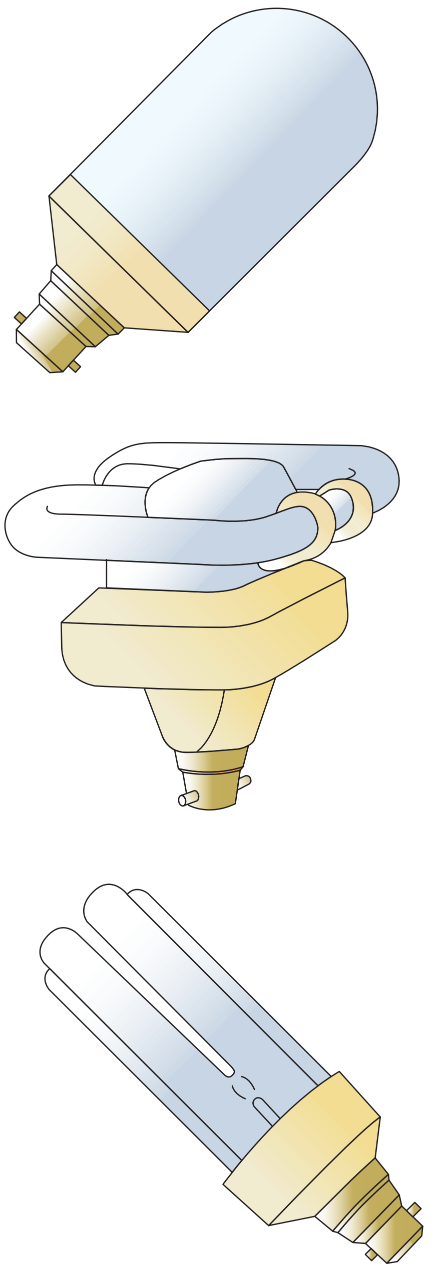


FIGURE 4.85
Energy-efficient lamps. (CFLs)

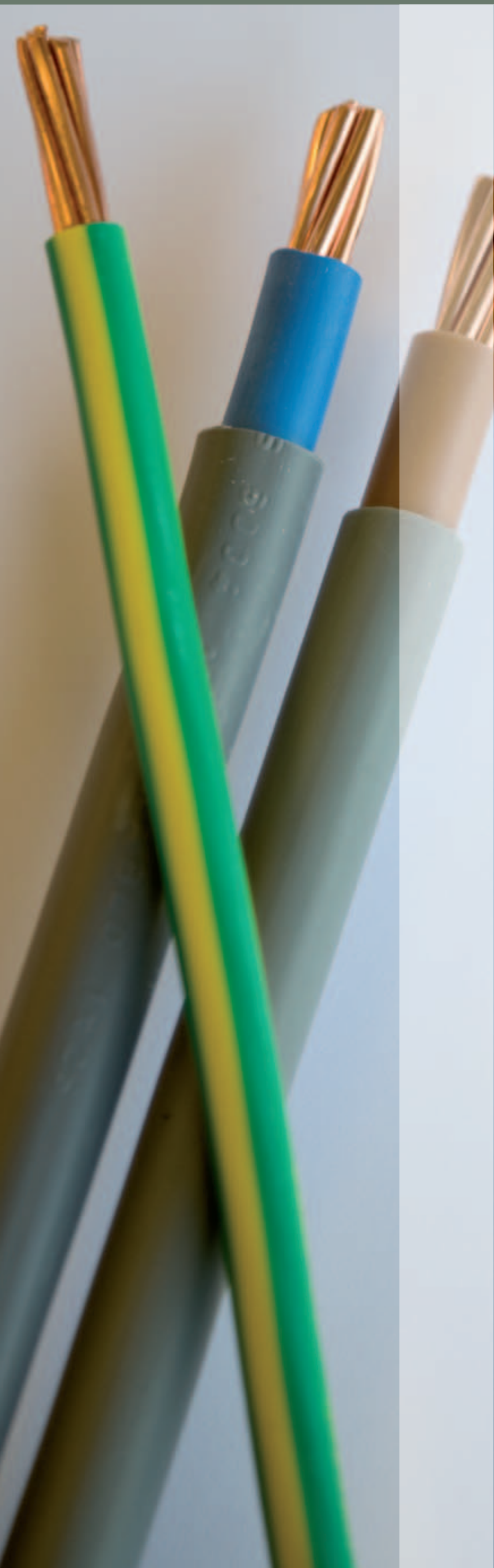
shapes. The 'stick' type gives most of their light output radially while the flat 'double D' type give most of their light output above and below.

Energy-efficient lamps use electricity much more efficiently than an equivalent GLS lamp. For example, a 20 watt energy efficient lamp will give the same light output as a 100 watt GLS lamp. An 11 watt energy efficient lamp is equivalent to a 60 watt GLS lamp. Energy-efficient lamps also have a lifespan of about eight times longer than a GLS lamp and so, they do use energy very efficiently.

However, energy-efficient lamps are expensive to purchase and they do take a few minutes to attain full brilliance after switching on. They cannot always be controlled by a dimmer switch and are unsuitable for incorporating in an automatic presence detector because they are usually not switched on long enough to be worthwhile, but energy efficient lamps are excellent for outside security lighting which is left on for several hours each night.

The electrical contractor, in discussion with a customer, must balance the advantages and disadvantages of energy-efficient lamps compared to other sources of illumination for each individual installation.

Check your Understanding



When you have completed these questions, check out your answers at the back of the book.
Note: More than one multiple choice answer may be correct.

1. An off-peak storage radiator when connected to a 230 V supply was found to take a current of 12 A. The resistance of the element will therefore be:
   a. 52.2 mΩ
   b. 19.2 Ω
   c. 2760 Ω
   d. 2843 Ω.

2. Calculate the resistance of 200 m of 1.5 mm^2 copper cable if the resistivity of copper is taken as 17.5×10^{-9} m.
   a. 1.3 Ω
   b. 2.3 Ω
   c. 233 Ω
   d. 1312 Ω.

3. Resistors of 3 Ω and 6 Ω are connected in series. Their combined resistor will therefore be:
   a. 0.5 Ω
   b. 2.0 Ω
   c. 9.0 Ω
   d. 18.0 Ω.

4. Resistors of 3 Ω and 6 Ω are connected in parallel. Their combined resistance will therefore be:
   a. 0.5 Ω
   b. 2.0 Ω
   c. 9.0 Ω
   d. 18.0 Ω.

5. The maximum value of the 230 V mains supply is:
   a. 207.2 V
   b. 230.0 V
   c. 325.3 V
   d. 400.0 V.

6. Calculate the reactance of a 150 μF capacitor connected to the 50 Hz mains supply:
   a. 3.14 Ω
   b. 21.2 Ω
   c. 18.8 Ω
   d. 471.3 Ω.

7. An electronic circuit resistor is colour coded green, blue, brown, gold. It has a value of:
   a. 56 Ω ± 10%
   b. 65 Ω ± 5%
   c. 560 Ω ± 5%
   d. 650 Ω ± 10%.

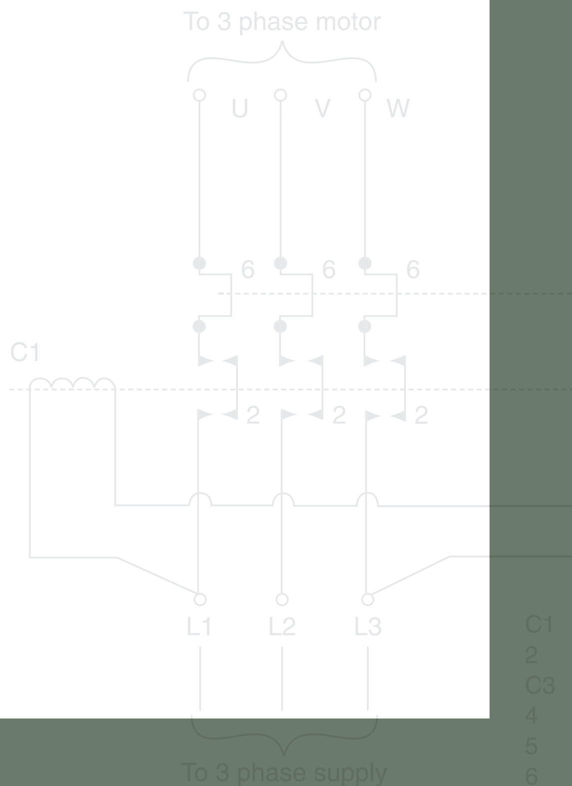
8. An electronic device which will allow current to flow through it in one direction only is a:
   a. light dependent resistor (LDR)
   b. light-emitting diode (LED)
   c. semiconductor diode
   d. thermistor.

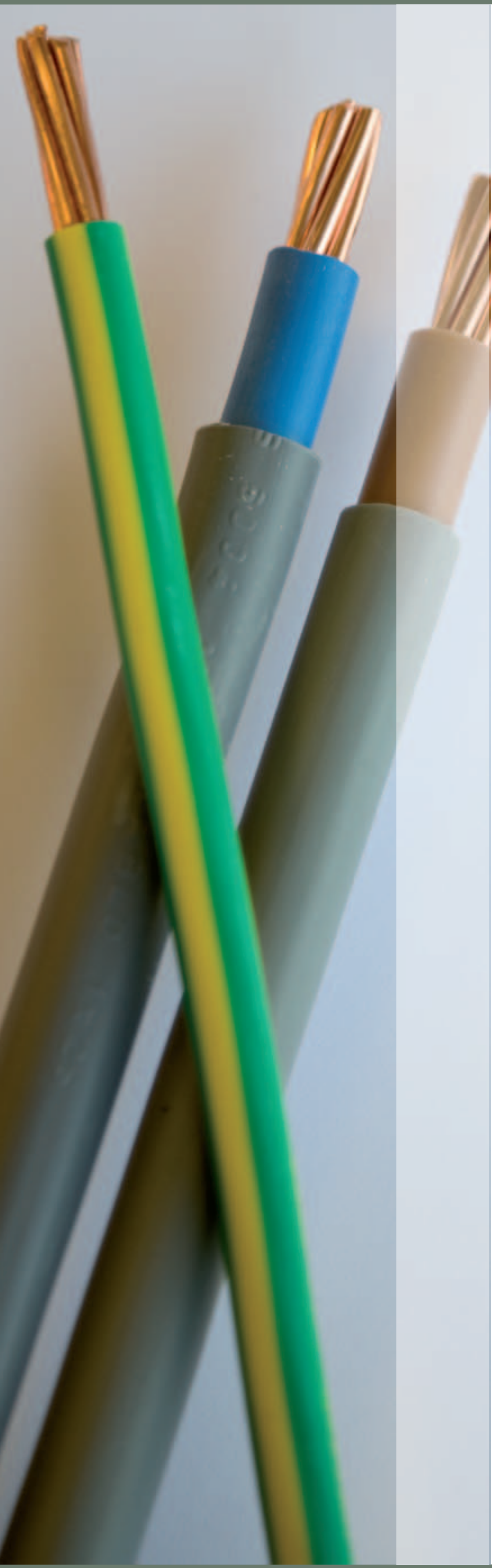
9. An electronic device whose resistance varies with temperature is a:
   a. light dependent resistor (LDR)
   b. light-emitting diode (LED)
   c. semiconductor diode
   d. thermistor.

10. An electronic device which emits red, green, or yellow light when a current of about 10 mA flows through it is:
   a. light dependent resistor (LDR)
   b. light-emitting diode (LED)
   c. semiconductor diode
   d. thermistor.

11. An electronic device whose resistance changes as a result of light energy falling upon it is a:
   a. light dependent resistor (LDR)
   b. light-emitting diode (LED)
   c. semiconductor diode
   d. thermistor.

12. A street lamp has a luminous intensity of 2000 cd and is suspended 5 m above the ground. The illuminance on the pavement below the lamp will be:
   a. 40 lx
   b. 80 lx
   c. 400 lx
   d. 800 lx.





13. The method most frequently used when designing an interior lighting scheme is the:
    a. cosine law
    b. inverse square law
    c. lumen method
    d. reflective index method.
14. Identify the most energy efficient lamps in the following list:
    a. CFLs
    b. fluorescent tubes
    c. GLS lamps
    d. tungsten halogen spots.
15. Briefly state Ohm's law and the three formulae which can be derived from his Law.
16. Briefly describe the meaning of magnetic flux.
17. Sketch the magnetic field lines around a bar magnet, a horseshoe magnet and a current carrying conductor.
18. Briefly describe the meaning of inductance and mutual inductance and give one practical example of each.
19. Use a labelled sketch to describe the construction of a variable capacitor and a waxed paper capacitor. Give one practical example for the use of each.
20. An inductor and a resistor are connected in series to an a.c. supply. Sketch the circuit diagram, the phasor diagram and state the relationship between the circuit current and voltage.
21. A capacitor and resistor are connected in series to an a.c. supply. Sketch the circuit diagram, the phasor diagram and state the relationship between the circuit current and voltage.
22. Sketch and label the graphical symbols for some of the electronic components you have seen at work.

23. Use bullet points and maybe a sketch to describe how to work out the value of a resistor using the resistor colour code.

24. Use a sketch to describe the pin identification of a dual in line IC.

25. Sketch waveforms to describe how a domestic lighting dimmer switch works.

26. Define the meaning of rectification.

27. Sketch waveforms to describe the meaning of smoothing for a full-wave rectified circuit.

28. Sketch the circuit diagram for a battery charger circuit. Label the components and say what each one does.

29. Briefly describe the working principle of a GLS lamp. State one practical use for a GLS lamp. Why is the Government putting pressure on lamp manufacturers that will prevent GLS lamps being made after 2012?

30. Briefly describe how a fluorescent tube and CFLs work. Why are these the Government's preferred choice of lamp for the future?

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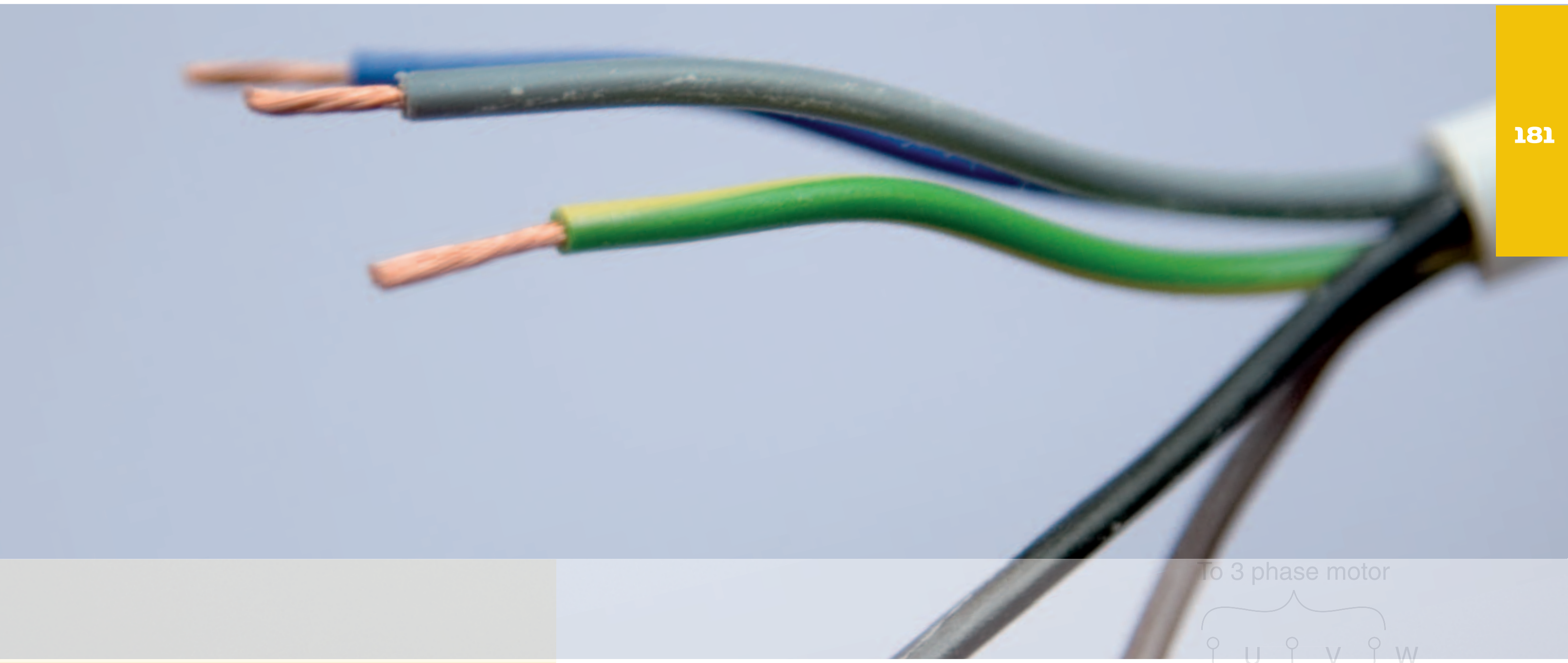
CH 5

Electricity supply systems, protection and earthing



Unit 1 – Application of health and safety and electrical principles – Outcome 5

Underpinning knowledge: when you have completed this chapter you should be able to:

- describe electricity supply systems
- describe industrial distribution systems
- describe the operation of a transformer
- state transformer losses
- describe the need for earthing and protective systems

Electricity supply systems

The generation of electricity in most modern power stations is at 25 kV, and this voltage is then transformed to 400 kV for transmission. Virtually all the generators of electricity throughout the world are three-phase synchronous generators. The generator consists of a prime mover and a magnetic field excitor. The magnetic field is produced electrically by passing a direct current (d.c.) through a winding on an iron core, which rotates inside three-phase windings on the stator of the machine. The magnetic field is rotated by means of a prime mover which may be a steam turbine, water turbine, gas turbine or wind turbine.

The generators in modern power stations are rated between 500 and 1000 MW. A 2000 MW station might contain four 500 MW sets, three 660 MW sets and a 20 MW gas turbine generator or two 1000 MW sets. Having a number of generator sets in a single power station provides the flexibility required for seasonal variations in the load and for maintenance of equipment. When generators are connected to a single system they must rotate at exactly the same speed, hence the term synchronous generator.

FIGURE 5.1
Suspension tower.

Very high voltages are used for transmission systems because, as a general principle, the higher the voltage the cheaper is the supply. Since power in an a.c. system is expressed as $P = VI \cos \theta$, it follows that an increase in voltage will reduce the current for a given amount of power. A lower current will result in reduced cable and switchgear size and the line power losses, given by the equation $P = I^2R$, will also be reduced.

Key Fact

National Grid

The National Grid is a network of some 5000 miles of overhead and underground power cables.

The 132 kV grid and 400 kV supergrid transmission lines are, for the most part, steel-cored aluminium conductors suspended on steel lattice towers, since this is about 16 times cheaper than the equivalent underground cable. Figure 5.1 shows a suspension tower on the National Grid network. The conductors are attached to porcelain insulator strings which are fixed to the cross-members of the tower as shown in Fig. 5.2. Three conductors comprise a single circuit of a three-phase system so that towers with six arms carry two separate circuits.

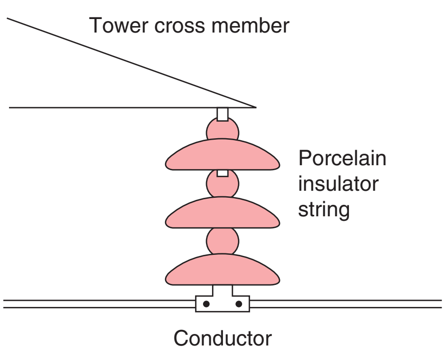


FIGURE 5.2
Steel lattice tower cable supports.

Primary distribution to consumers is from 11 kV substations, which for the most part are fed from 33 kV substations, but direct transformation between 132 and 11 kV is becoming common policy in city areas where over 100 MW can be economically distributed at 11 kV from one site. Figure 5.3 shows a block diagram indicating the voltages at the various stages of the transmission and distribution system and Fig. 5.4 shows a simplified diagram of the transmission and distribution of electricity to the consumer.

Distribution systems at 11 kV may be ring or radial systems but a ring system offers a greater security of supply. The maintenance of a secure supply is an important consideration for any electrical engineer or supply authority because electricity plays a vital part in an industrial society, and a loss of

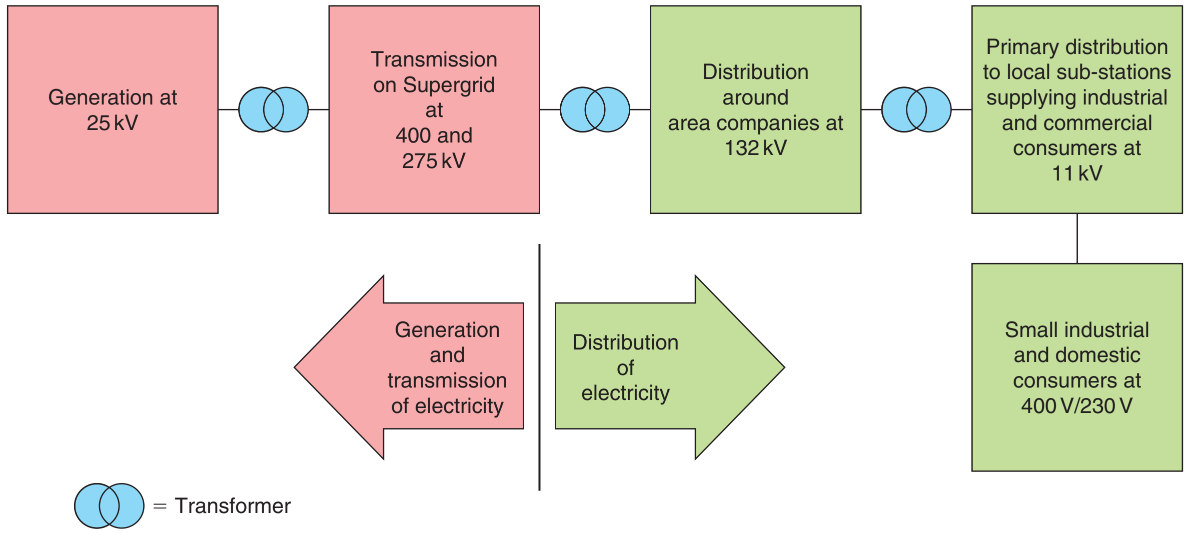


FIGURE 5.3
Generation, transmission and distribution of electrical energy.

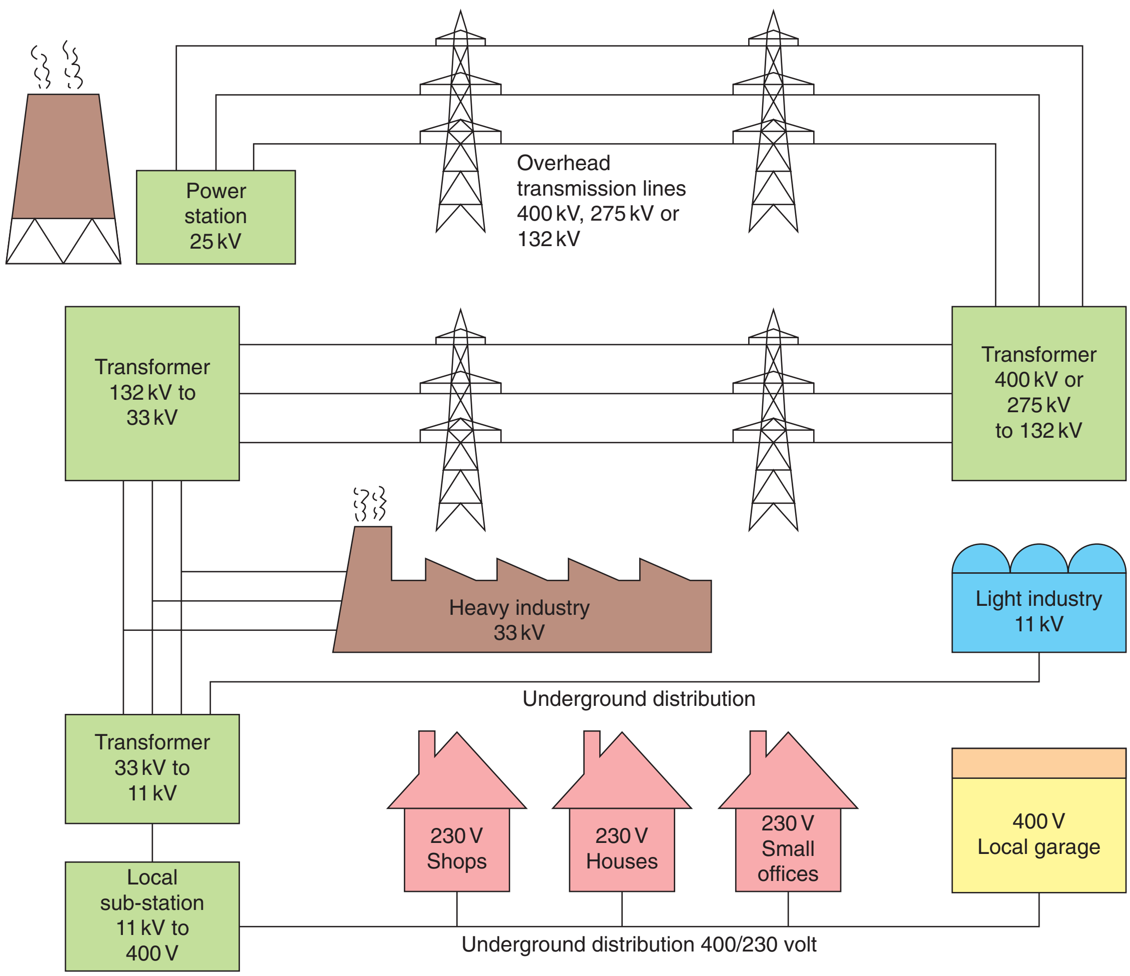


FIGURE 5.4
Simplified diagram of distribution of electricity from power station to consumer.

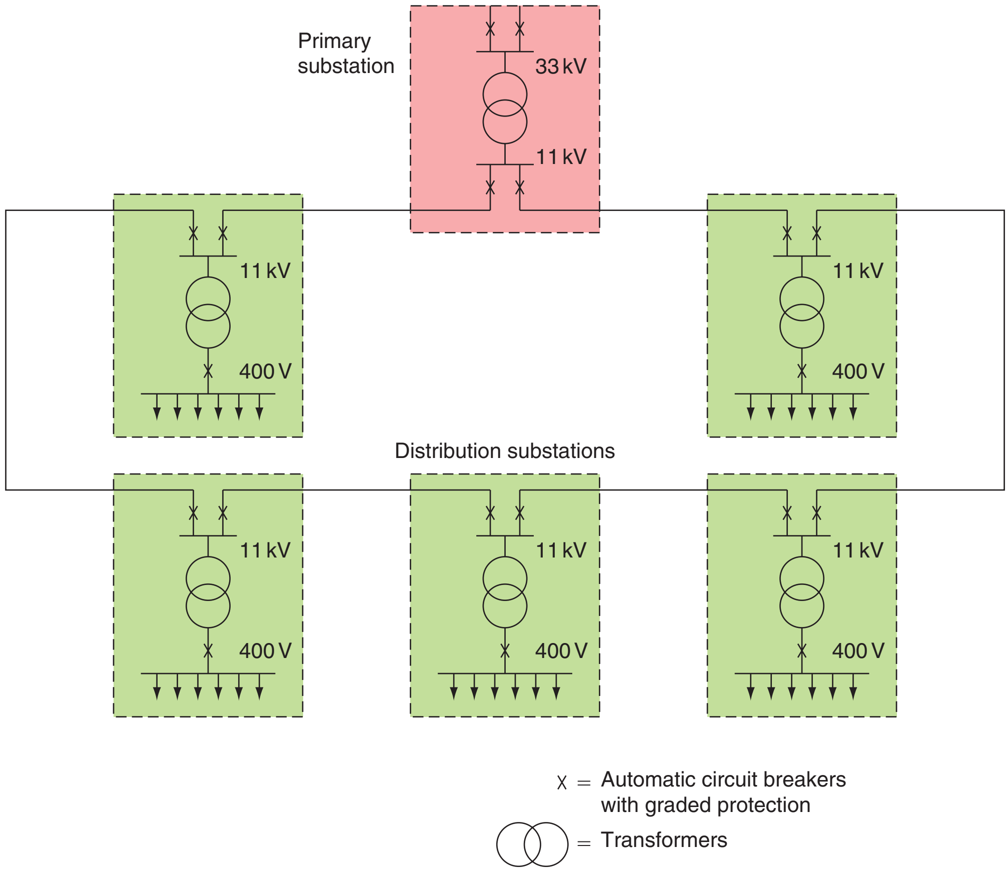


FIGURE 5.5
High-voltage ring main distribution.

supply may cause inconvenience, financial loss or danger to the consumer or the public.

The principle employed with a ring system is that any consumer's substation is fed from two directions, and by carefully grading the overload and cable protection equipment a fault can be disconnected without loss of supply to other consumers.

High-voltage distribution to primary substations is used by the electricity boards to supply small industrial, commercial and domestic consumers. This distribution method is also suitable for large industrial consumers where 11 kV substations, as shown in Fig. 5.5 may be strategically placed at load centres around the factory site. Regulation 9 of the Electricity Supply Regulations and Regulation 31 of the Factories Act require that these substations be protected by 2.44 m high fences or enclosed in some other way so that no unauthorized person may gain access to the potentially dangerous equipment required for 11 kV distribution. In towns and cities the substation equipment is usually enclosed in a brick building, as shown in Fig. 5.6.

The final connections to plant, distribution boards, commercial or domestic loads are usually by simple underground radial feeders at 400V/230V.

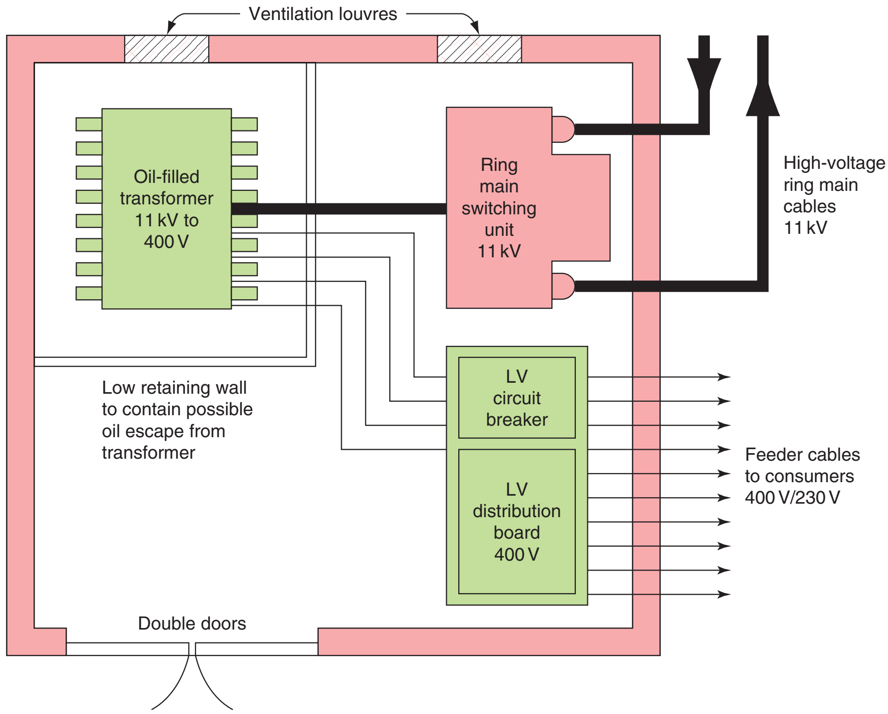


FIGURE 5.6
Typical sub-station layout.

These outgoing circuits are usually protected by circuit breakers in a distribution board.

The 400V/230V is derived from the 11 kV/400V sub-station transformer by connecting the secondary winding in star as shown in Fig. 5.7. The star point is earthed to an earth electrode sunk into the ground below the sub-station, and from this point is taken the fourth conductor, the neutral. Loads connected between phases are fed at 400V, and those fed between one phase and neutral at 230V. A three-phase 400V supply is used for supplying small industrial and commercial loads such as garages, schools and blocks of flats. A single-phase 230V supply is usually provided for individual domestic consumers.

Example

Use a suitable diagram to show how a 400 V three-phase, four-wire supply may be obtained from an 11 kV delta-connected transformer. Assuming that the three-phase four-wire supply feeds a small factory, show how the following loads must be connected:

(a) A three-phase 400 V motor.
(b) A single-phase 400 V welder.
(c) A lighting load made up of discharge lamps arranged in a way which reduces the stroboscopic effect.
(d) State why 'balancing' of loads is desirable.
(e) State the advantages of using a three-phase four-wire supply to industrial premises instead of a single-phase supply.

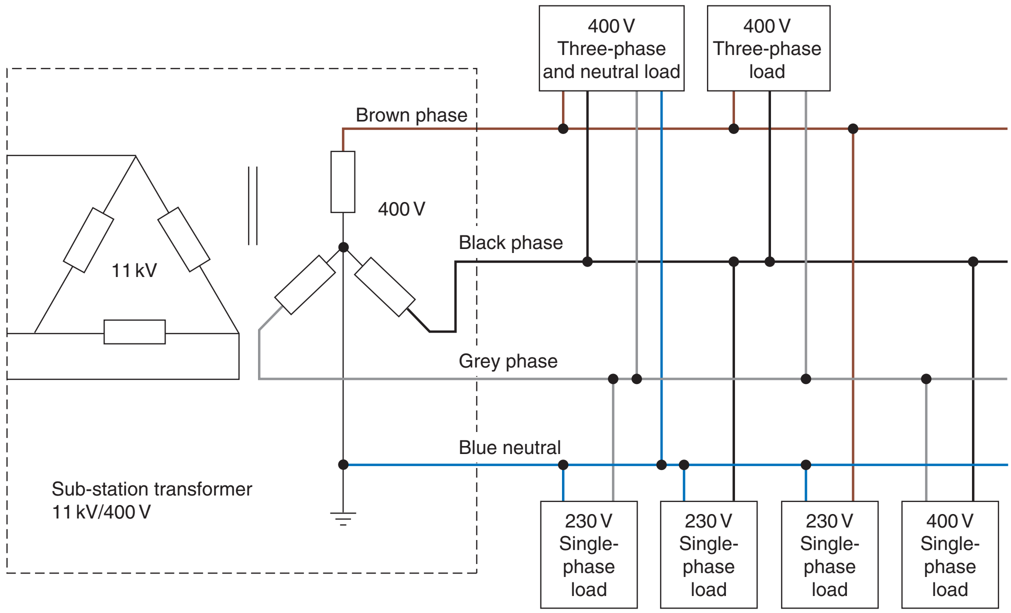


FIGURE 5.7
Three-phase four-wire distribution.

Three-phase load

Figure 5.7 shows the connections of the 11 kV to 400 V supply and the method of connecting a 400 V three-phase load such as a motor and a 400 V single-phase load such as a welder.

Reducing stroboscopic effect

The stroboscopic effect may be reduced by equally dividing the lighting load across the three phases of the supply. For example, if the lighting load were made up of 18 luminaires, then 6 luminaires should be connected to the brown phase and neutral, 6 to the black phase and neutral and 6 to the grey phase and neutral.

Balancing three-phase loads

A three-phase load such as a motor has equally balanced phases since the resistance of each phase winding will be the same. Therefore the current taken by each phase will be equal. When connecting single-phase loads to a three-phase supply, care should be taken to distribute the single-phase loads equally across the three phases so that each phase carries approximately the same current. Equally distributing the single-phase loads across the three-phase supply is known as 'balancing' the load. A lighting load of 18 luminaires would be 'balanced' if six luminaires were connected to each of the three phases.

Advantages of a three-phase four-wire supply

A three-phase four-wire supply gives a consumer the choice of a 400 V three-phase supply and a 230 V single-phase supply. Many industrial

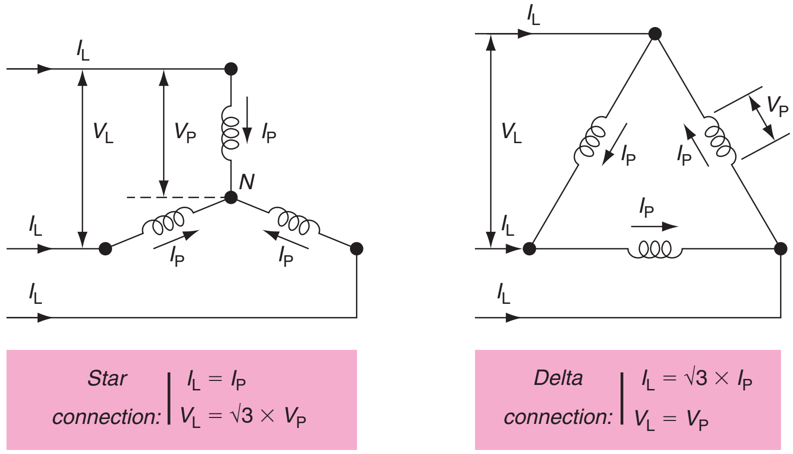


FIGURE 5.8
Star and delta connections.

Key Fact

Balancing Single-phase loads

Connect single-phase loads equally across a three-phase supply, so that each phase carries approximately the same current.

loads such as motors require a three-phase 400 V supply, while the lighting load in a factory, as in a house, will be 230 V. Industrial loads usually demand more power than a domestic load, and more power can be supplied by a 400 V three-phase supply than is possible with a 230 V single-phase supply for a given size of cable since power = $VI \cos \theta$ (watts).

THREE-PHASE A.C.

A three-phase voltage is generated in exactly the same way as a single-phase a.c. voltage. For a three-phase voltage three separate windings, each separated by 120°, are rotated in a magnetic field. The generated voltage will be three identical sinusoidal waveforms each separated by 120°.

Star and delta connections

The three-phase windings may be star connected or delta connected as shown in Fig. 5.8. The important relationship between phase and line currents and voltages is also shown. The square root of 3 ($\sqrt{3}$) is simply a constant for three-phase circuits, and has a value of 1.732. The delta connection is used for electrical power transmission because only three conductors are required. Delta connection is also used to connect the windings of most three-phase motors because the phase windings are perfectly balanced and, therefore, do not require a neutral connection.

Making a star connection has the advantage that two voltages become available – a line voltage between any two phases, and a phase voltage between line and neutral which is connected to the star point.

In any star-connected system currents flow along the lines (I_L), through the load and return by the neutral conductor connected to the star point. In a *balanced* three-phase system all currents have the same value and when they are added up by phasor addition, we find the resultant current is zero. Therefore, no current flows in the neutral and the star point is at zero volts. The star point of the distribution transformer is earthed because earth is also at zero potential. A star-connected system is also called a three-phase four-wire system and allows us to connect single-phase loads to a three-phase system.

Three-phase power

We know from our single-phase theory in Chapter 4 that power can be found from the following formula:

$$\text{Power} = VI \cos\phi \text{ (W)}$$

In any balanced three-phase system, the total power is equal to three times the power in any one phase.

$$\therefore \text{ Total three-phase power} = 3\ V_P I_P \cos\phi \text{ (W)} \tag{5.1}$$

Now for a star connection,

$$V_P = V_L/\sqrt{3} \quad \text{and} \quad I_L = I_P \tag{5.2}$$

Substituting Equation (5.2) into Equation (5.1), we have

$$\text{Total three-phase power} = \sqrt{3}\ V_L L_L \cos\phi \text{ (W)}$$

Now consider a delta connection:

$$V_P = V_L \quad \text{and} \quad I_P = I_L/\sqrt{3} \tag{5.3}$$

Substituting Equation (5.3) into Equation (5.1) we have, for any balanced three-phase load,

$$\text{Total three-phase power} = \sqrt{3}\ V_L L_L \cos\phi \text{ (W)}$$

Example 1

A balanced star-connected three-phase load of 10 Ω per phase is supplied from a 400 V 50 Hz mains supply at unity power factor. Calculate (a) the phase voltage, (b) the line current and (c) the total power consumed.

For a star connection,

$$V_L = \sqrt{3}\ V_P \ \text{ and } \ I_L = I_P$$

For (a),

$$V_P = V_L/\sqrt{3}\ \text{(V)}$$
$$V_P = \frac{400\ \text{V}}{1.732} = 230.9\ \text{V}$$

For (b),

$$I_L = I_P = V_P/R_P\ \ \text{(A)}$$
$$I_L = I_P = \frac{230.9\ \text{V}}{10\ \Omega} = 23.09\ \text{A}$$

For (c),

$$\text{Power} = \sqrt{3}\ V_L\ I_L \cos\ \phi\ \text{(W)}$$
$$\therefore\ \text{Power} = 1.732 \times 400\ \text{V} \times 23.09\ \text{A} \times 1 = 16\ \text{kW}$$

Example 2

A 20 kW 400 V balanced delta-connected load has a power factor of 0.8. Calculate (a) the line current and (b) the phase current.

We have that:

$$\text{Three-phase power} = \sqrt{3}\ V_L\ I_L\ \cos\ \phi\ \text{(W)}$$

For (a),

$$I_L = \frac{\text{Power}}{\sqrt{3}\ V_L\ \cos\ \phi}\text{(A)}$$
$$\therefore\ I_L = \frac{20\ 000\ \text{W}}{1.732 \times 400\ \text{V} \times 0.8}$$
$$I_L = 36.08\ \text{(A)}$$

For delta connection,

$$I_L = \sqrt{3}\ I_P\ \text{(A)}$$

Thus, for (b),

$$I_P = \frac{I_L}{\sqrt{3}}\ \text{(A)}$$
$$\therefore I_P = \frac{36.08\ \text{A}}{1.732} = 20.83\ \text{A}$$

Example 3

Three identical loads each having a resistance of 30 Ω and inductive reactance of 40 Ω are connected first in star and then in delta to a 400 V three-phase supply. Calculate the phase currents and line currents for each connection.

For each load,

$$Z = \sqrt{R^2 + X_L^2}\ (\Omega)\ \text{(from Chapter 4)}$$
$$\therefore Z = \sqrt{30^2 + 40^2}$$
$$Z = \sqrt{2500}$$
$$Z = 50\ \Omega$$

For star connection,

$$V_L = \sqrt{3}\ V_P \quad \text{and} \quad I_L = I_P$$
$$V_P = V_L/\sqrt{3}\ (\text{V})$$
$$\therefore V_P = \frac{400\ \text{V}}{1.732} = 230.9\ \text{V}$$
$$I_P = V_P/Z_P\ (\text{A})$$
$$\therefore I_P = \frac{230.9\ \text{V}}{50\ \Omega} = 4.62\ \text{A}$$
$$I_P = I_L$$

therefore phase and line currents are both equal to 4.62 A.

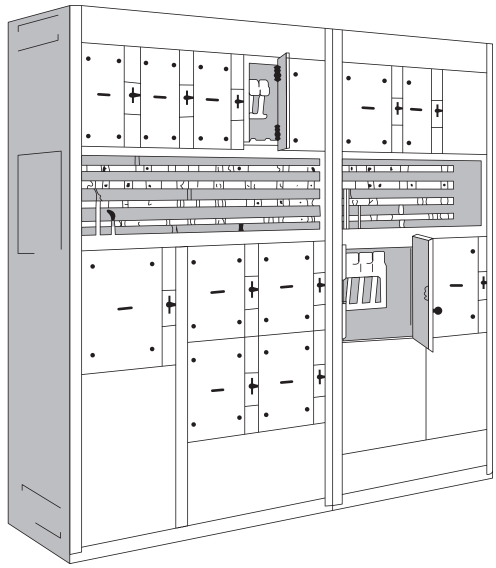
For delta, connection,

$$V_L = V_P \quad \text{and} \quad I_L = \sqrt{3}\ I_P$$
$$V_L = V_P = 400\ \text{V}$$
$$I_P = V_P/Z_P\ (\text{A})$$
$$\therefore I = \frac{400\ \text{V}}{50\ \Omega} = 8\ \text{A}$$
$$I_L = \sqrt{3}\ I_P\ (\text{A})$$
$$\therefore I_L = 1.732 \times 8\ \text{A} = 13.86\ \text{A}$$

INDUSTRIAL DISTRIBUTION SYSTEMS

In domestic installations the final circuits for lights, sockets, cookers, immersion heating, etc. are connected to separate fuseways in the consumer's unit mounted at the service position.

In commercial or industrial installations a three-phase 400 V supply must be distributed to appropriate equipment in addition to supplying single-phase 230 V loads such as lighting. It is now common practice to establish industrial estates speculatively, with the intention of encouraging local industry to use individual units. This presents the electrical contractor with an additional problem. The use and electrical demand of a single industrial unit are



Cubicle switchboards

FIGURE 5.9
Industrial consumer's service position equipment.

often unknown and the electrical supply equipment will need to be flexible in order to meet a changing demand due to expansion or change of use.

Busbar chambers incorporated into cubicle switchboards or on-site assemblies of switchboards are to be found at the incoming service position of commercial and industrial consumers, since this has proved to provide the flexibility required by these consumers. This is shown in Fig. 5.9.

Distribution fuse boards, which may incorporate circuit breakers, are wired by sub-main cables from the service position to load centres in other parts of the building, thereby keeping the length of cable to the final circuit as short as possible. This is shown in Fig. 5.10.

When high-rise buildings such as multi-storey flats have to be wired, it is usual to provide a three-phase four-wire rising main. This may comprise vertical busbars running from top to bottom at some central point in the building. Each floor or individual flat is then connected to the busbar to provide the consumer's supply. When individual dwellings receive a single-phase supply the electrical contractor must balance the load across the three phases. Fig. 5.11 shows a rising main system. The rising main must incorporate fire barriers to prevent the spread of fire throughout the building (Regulations 527.1.2, 527.2.1 and 527.2.4).

Industrial wiring systems are constructed robustly so that they can withstand some minor mechanical damage and vibration, and have the adaptability to respond to the changing needs of an industrial environment. IEE Regulations 522.6 and 522.8.

Cables in trunking with conduit drops or, SWA or Mineral Insulated (MI) cables laid on cable tray, provide a flexible, adaptable electrical installation.

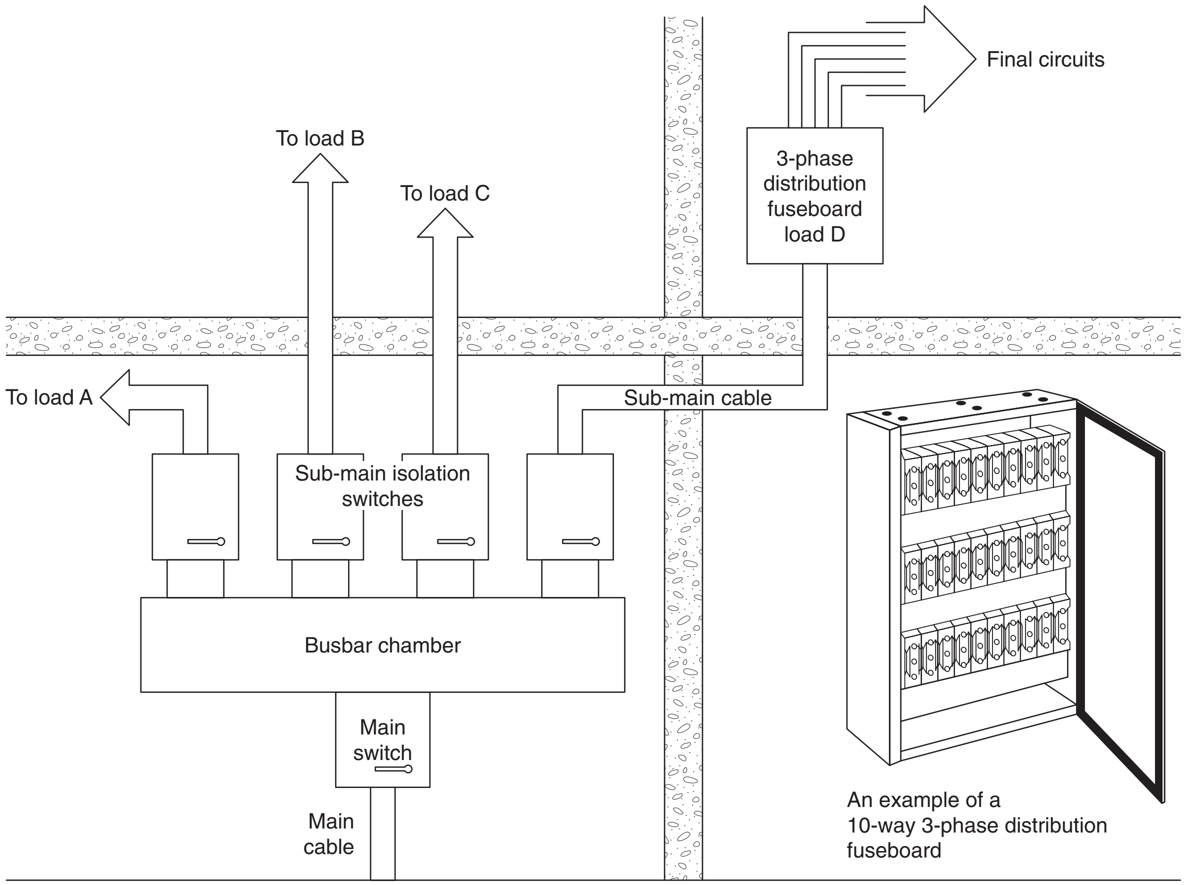


FIGURE 5.10

Typical distribution in commercial or industrial building.

Definition

Most cables can be considered to be constructed in three parts: the *conductor*, which must be of a suitable cross-section to carry the load current; the *insulation*, which has a colour or number code for identification and the *outer sheath*, which may contain some means of providing protection from mechanical damage.

Compare this flexible, adaptable type of installation to the less easily adaptable fixed wiring of domestic installations where cables are buried in the finishing plaster of the walls.

Cables

Most cables can be considered to be constructed in three parts: the **conductor**, which must be of a suitable cross-section to carry the load current; the **insulation**, which has a colour or number code for identification and the **outer sheath**, which may contain some means of providing protection from mechanical damage.

The conductors of a cable are made of either copper or aluminium and may be stranded or solid. Solid conductors are only used in fixed wiring installations and may be shaped in larger cables. Stranded conductors are more flexible and conductor sizes from 4.0 to 25 mm^2 contain seven strands. A 10 mm^2 conductor, for example, has seven 1.35 mm diameter strands which collectively make up the 10 mm^2 cross-sectional area of the cable. Conductors above 25 mm^2 have more than seven strands, depending upon the size of the cable. Flexible cords have multiple strands of very

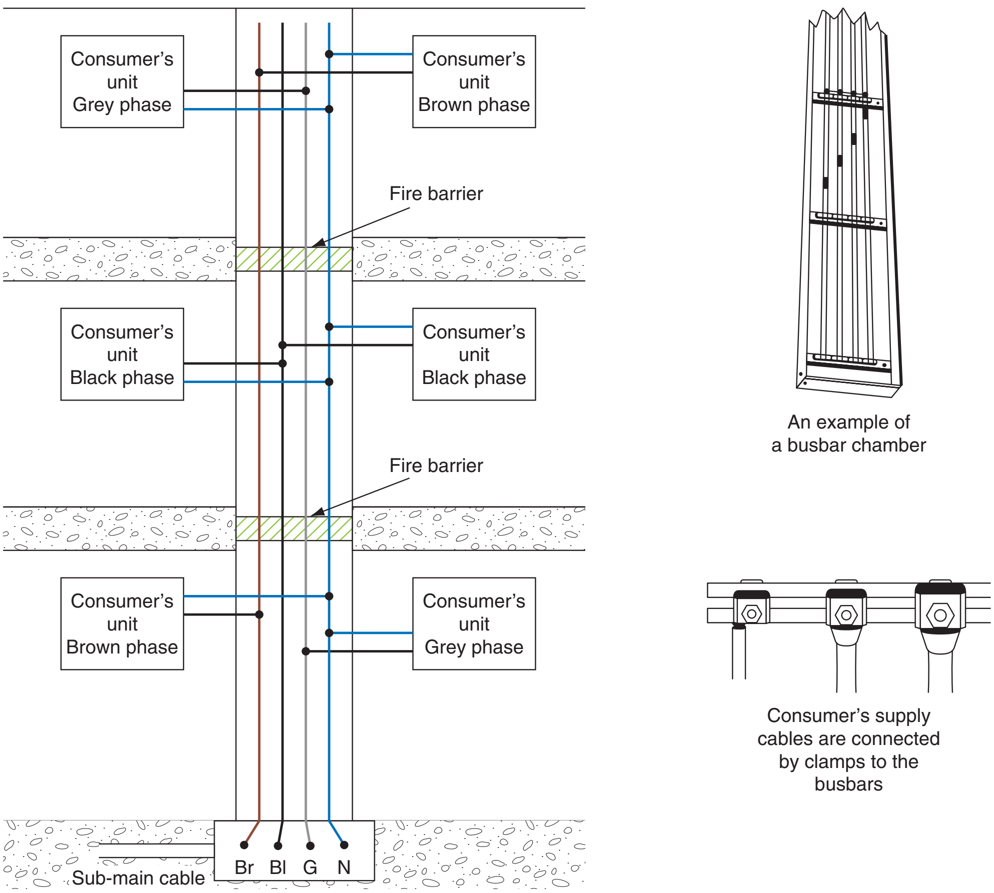


FIGURE 5.11
Busbar rising main system.

fine wire, as fine as one strand of human hair. This gives the cable its very flexible quality.

NEW WIRING COLOURS

Twenty-eight years ago the United Kingdom agreed to adopt the European colour code for flexible cords, that is, brown for live or line conductor, blue for the neutral conductor and green combined with yellow for earth conductors. However, no similar harmonization was proposed for non-flexible cables used for fixed wiring. These were to remain as red for live or line conductor, black for the neutral conductor and green combined with yellow for earth conductors.

On the 31 March 2004 the IEE published Amendment No. 2 to BS 7671: 2001 which specified new cable core colours for all fixed wiring in UK electrical installations. These new core colours will 'harmonize' the United Kingdom with the practice in mainland Europe.

FIXED CABLE CORE COLOURS UP TO 2006

Single-phase supplies – red line conductors, black neutral conductors and green combined with yellow for earth conductors.

Three-phase supplies – red, yellow and blue line conductors, black neutral conductors and green combined with yellow for earth conductors.

These core colours must *not* be used after 31 March 2006.

NEW (HARMONIZED) FIXED CABLE CORE COLOURS

Single-phase supplies – brown line conductors, blue neutral conductors and green combined with yellow for earth conductors (just like the existing flexible cords).

Three-phase supplies – brown, black and grey line conductors, blue neutral conductors and green combined with yellow for earth conductors.

These are the cable core colours to be used from 31 March 2004 onwards.

Extensions or alterations to existing ***single-phase*** installations do not require marking at the interface between the old and new fixed wiring colours. However, a warning notice must be fixed at the consumer unit or distribution fuse board which states:

> *Caution* – This installation has wiring colours to two versions of BS 7671. Great care should be taken before undertaking extensions, alterations or repair that all conductors are correctly identified.

Alterations to ***three-phase*** installations must be marked at the interface L1, L2, L3 for the lines and N for the neutral. Both new and old cables must be marked. These markings are preferred to coloured tape and a caution notice is again required at the distribution board (see Appendix 7 of the IEE Regulations).

PVC INSULATED AND SHEATHED CABLES

Domestic and commercial installations use this cable, which may be clipped direct to a surface, sunk in plaster or installed in conduit or trunking. It is the simplest and least expensive cable. Figure 5.12 shows a sketch of a twin and earth cable.

The conductors are covered with a colour-coded PVC insulation and then contained singly or with others in a PVC outer sheath.

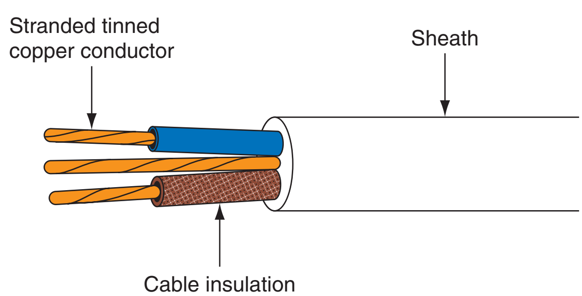


FIGURE 5.12
A twin and earth PVC insulated and sheathed cable.

Definition

PVC insulated steel wire armour cables are used for wiring underground between buildings, for main supplies to dwellings, rising sub-mains and industrial installations. They are used where some mechanical protection of the cable conductors is required.

Definition

An *MI cable* has a seamless copper sheath which makes it waterproof and fire and corrosion-resistant. These characteristics often make it the only cable choice for hazardous or high-temperature installations.

Safety first

PVC cables

- At low temperatures PVC cable insulation can become brittle when handled.
- PVC cables must not be installed when the ambient temperature is 0°C (IEE Reg 522.1.2).

PVC/SWA CABLE

PVC insulated steel wire armour cables are used for wiring underground between buildings, for main supplies to dwellings, rising sub-mains and industrial installations. They are used where some mechanical protection of the cable conductors is required.

The conductors are covered with colour-coded PVC insulation and then contained either singly or with others in a PVC sheath (see Fig. 5.13). Around this sheath is placed an armour protection of steel wires twisted along the length of the cable, and a final PVC sheath covering the steel wires protects them from corrosion. The armour sheath also provides the circuit protective conductor (CPC) and the cable is simply terminated using a compression gland.

MI CABLE

An **MI cable** has a seamless copper sheath which makes it waterproof and fire and corrosion-resistant. These characteristics often make it the only cable choice for hazardous or high-temperature installations such as oil refineries and chemical works, boiler-houses and furnaces, petrol pump and fire alarm installations.

The cable has a small overall diameter when compared to alternative cables and may be supplied as bare copper or with a PVC oversheath. It is colour-coded orange for general electrical wiring, white for emergency lighting or red for fire alarm wiring. The copper outer sheath provides the CPC, and the cable is terminated with a pot and sealed with compound and a compression gland (see Fig. 5.14).

The copper conductors are embedded in a white powder, magnesium oxide, which is non-ageing and non-combustible, but which is hygroscopic, which means that it readily absorbs moisture from the surrounding air, unless adequately terminated. The termination of an MI cable is a

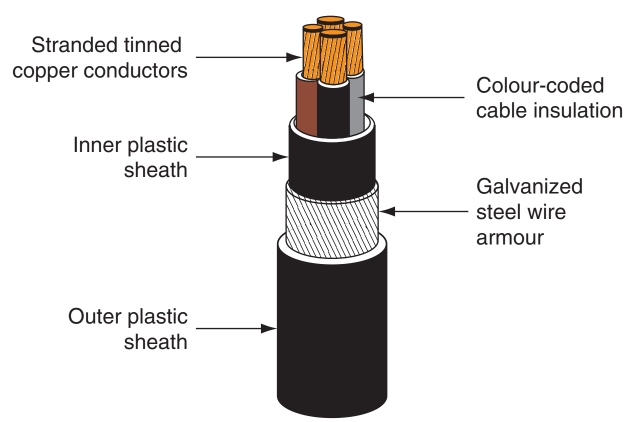


FIGURE 5.13
A four-core PVC/SWA cable.

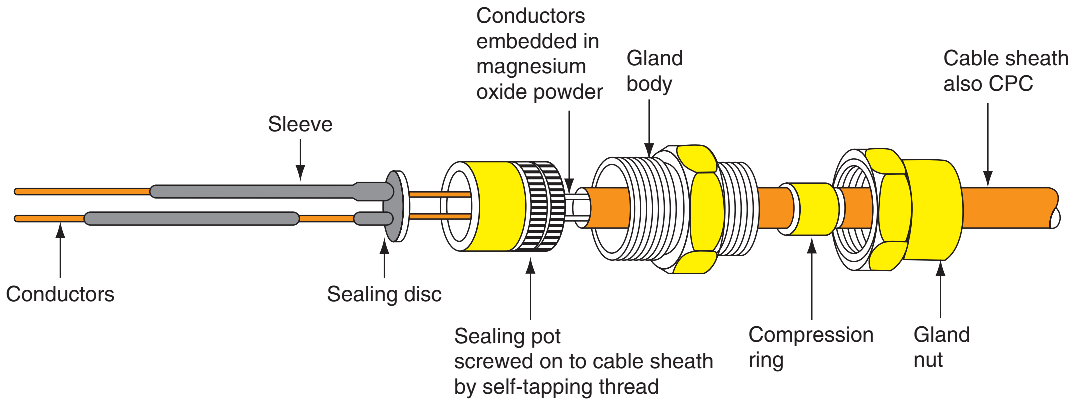


FIGURE 5.14
MI cable with terminating seal and gland.

complicated process requiring the electrician to demonstrate a high level of practical skill and expertise for the termination to be successful.

FP 200 CABLE

FP 200 cable is similar in appearance to an MI cable in that it is a circular tube, or the shape of a pencil, and is available with a red or white sheath. However, it is much simpler to use and terminate than an MI cable.

The cable is available with either solid or stranded conductors that are insulated with 'insudite' a fire resistant insulation material. The conductors are then screened by wrapping an aluminium tape around the insulated conductors, that is, between the insulated conductors and the outer sheath. This aluminium tape screen is applied metal side down and in contact with the bare CPC.

The sheath is circular and made of a robust thermoplastic low smoke, zero halogen material.

Definition

FP 200 cable is similar in appearance to an MI cable in that it is a circular tube, or the shape of a pencil, and is available with a red or white sheath. However, it is much simpler to use and terminate than an MI cable.

FP 200 is available in 2, 3, 4, 7, 12 and 19 cores with a conductor size range from 1.0 mm to 4.0 mm. The core colours are: two core, brown and blue; three core, brown, black and grey and four core, black, red, yellow and blue.

The cable is as easy to use as a PVC insulated and sheathed cable. No special terminations are required, the cable may be terminated through a grommet into a knock out box or terminated through a simple compression gland.

The cable is a fire resistant cable, primarily intended for use in fire alarms and emergency lighting installations or it may be embedded in plaster.

Definition

Low smoke and fume cables give off very low smoke and fumes if they are burned in a burning building. Most standard cable types are available as LSF cables.

LSF CABLES

Low smoke and fume (LSF) cables give off very low smoke and fumes if they are burned in a burning building. Most standard cable types are available as LSF cables.

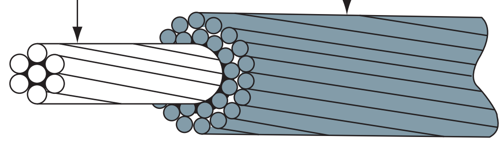


FIGURE 5.15
132 kV overhead cable construction.

HIGH-VOLTAGE POWER CABLES

The cables used for high-voltage power distribution require termination and installation expertise beyond the normal experience of a contracting electrician. The regulations covering high-voltage distribution are beyond the scope of the IEE Regulations for electrical installations. Operating at voltages in excess of 33 kV and delivering thousands of kilowatts, these cables are either suspended out of reach on pylons or buried in the ground in carefully constructed trenches.

HIGH-VOLTAGE OVERHEAD CABLES

Suspended from cable towers or pylons, overhead cables must be light, flexible and strong.

The cable is constructed of stranded aluminium conductors formed around a core of steel stranded conductors (see Fig. 5.15). The aluminium conductors carry the current and the steel core provides the tensile strength required to suspend the cable between pylons. The cable is not insulated since it is placed out of reach and insulation would only add to the weight of the cable.

HIGH-VOLTAGE UNDERGROUND CABLES – PILCSWA

Definition

Paper insulated lead covered steel wire armour cables are only used in systems above 11 kV. Very high-voltage cables are only buried underground in special circumstances when overhead cables would be unsuitable, for example, because they might spoil a view of natural beauty.

Paper insulated lead covered steel wire armour (PILCSWA) cables are only used in systems above 11 kV. Very high-voltage cables are only buried underground in special circumstances when overhead cables would be unsuitable, for example, because they might spoil a view of natural beauty. Underground cables are very expensive because they are much more complicated to manufacture than overhead cables. In transporting vast quantities of power, heat is generated within the cable. This heat is removed by passing oil through the cable to expansion points, where the oil is cooled. The system is similar to the water cooling of an internal combustion engine. Figure 5.16 shows a typical high-voltage cable construction.

The conductors may be aluminium or copper, solid or stranded. They are insulated with oil-impregnated brown paper wrapped in layers around the conductors. The oil ducts allow the oil to flow through the cable, removing excess heat. The whole cable within the lead sheath is saturated with oil, which is a good insulator. The lead sheath keeps the oil in and moisture

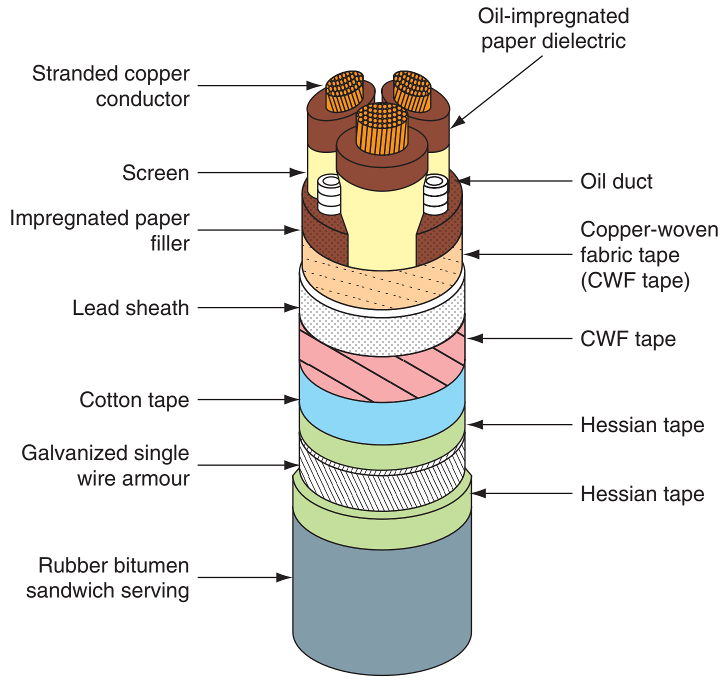


FIGURE 5.16
132 kV underground cable construction.

out of the cable, and this is supported by the copper-woven fabric tape. The cable is protected by steel wire armouring, which has bitumen or PVC serving over it to protect the armour sheath from corrosion. The termination and installation of these cables is a very specialized job, undertaken by the supply authorities only.

Installing cables

The final choice of a wiring system must rest with those designing the installation and those ordering the work, but whatever system is employed, good workmanship by competent persons and the use of proper materials is essential for compliance with the IEE Regulation 134.1.1. The necessary skills can be acquired by an electrical trainee who has the correct attitude and dedication to his craft.

PVC insulated and sheathed wiring systems are used extensively for lighting and socket installations in domestic dwellings. Mechanical damage to the cable caused by impact, abrasion, penetration, compression or tension must be minimized during installation (Regulation 522.6.1). The cables are generally fixed using plastic clips incorporating a masonry nail, which means the cables can be fixed to wood, plaster or brick with almost equal ease. Cables should be run horizontally or vertically, not diagonally, down a wall. All kinks should be removed so that the cable is run straight and neatly between clips fixed at equal distances providing adequate support for the cable so that it does not become damaged by its own weight (Regulation

522.8.4 and Table 4A of the *On Site Guide*). Where cables are bent, the radius of the bend should not cause the conductors to be damaged (Regulation 522.8.3 and Table 4E of the *On Site Guide*).

Terminations or joints in the cable may be made in ceiling roses, junction boxes, or behind sockets or switches, provided that they are enclosed in a non-ignitable material, are properly insulated and are mechanically and electrically secure (IEE Regulation 526). All joints must be accessible for inspection testing and maintenance when the installation is completed (IEE Regulation 526.3).

Try This

Definition

What do we mean by a 'competent person'?

Where PVC insulated and sheathed cables are concealed in walls, floors or partitions, they must be provided with a box incorporating an earth terminal at each outlet position. PVC cables do not react chemically with plaster, as do some cables, and consequently PVC cables may be buried under plaster. Further protection by channel or conduit is only necessary outside of designated zones if mechanical protection from nails or screws is required, or to protect them from the plasterer's trowel. However, Regulation 522.6.6 now tells us that where PVC cables are to be embedded in a wall or partition at a depth of less than 50 mm they should be run along one of the permitted routes. To identify the most probable cable routes, Regulation 522.6.6 tells us that outside a zone formed by a 150 mm border all around a wall edge, cables can only be run horizontally or vertically to a point or accessory unless they are contained in a substantial earthed enclosure, such as a conduit, which can withstand nail penetration. This is shown in Fig. 14.22 in Chapter 14 of *Basic Electrical Installation Work*, 5th edition.

Where the accessory or cable is fixed to a wall which is less than 100 mm thick, protection must also be extended to the reverse side of the wall if a position can be determined.

Where none of this protection can be complied with and the installation is to be used by ordinary people, then the cable must be given additional protection with a 30 mA residual current device (RCD) (IEE Regulation 522.6.7).

Key Fact

Conduit

Burrs must be removed from the cut ends of conduit so that the cable sheath will not become damaged when drawn into the conduit (IEE Regulation 522.8.1).

Try This

Definitions

What do we mean by an 'ordinary person'. Perhaps you could write a definition in the margin.

Where cables and wiring systems pass through walls, floors and ceilings the hole should be made good with incombustible material such as mortar or plaster to prevent the spread of fire (Regulation 527.2.1). Cables passing through metal boxes should be bushed with a rubber grommet to prevent abrasion of the cable. Holes drilled in floor joists through which cables are run should be 50 mm below the top or 50 mm above the bottom of the joist to prevent damage to the cable by nail penetration (Regulation 522.6.5). PVC cables should not be installed when the surrounding temperature is below 0°C or when the cable temperature has been below 0°C for the previous 24 hours because the insulation becomes brittle at low temperatures and may be damaged during installation (Regulation 522.1.2).

CONDUIT INSTALLATIONS

Definition

A *conduit* is a tube, channel or pipe in which insulated conductors are contained.

A **conduit** is a tube, channel or pipe in which insulated conductors are contained. The conduit, in effect, replaces the PVC outer sheath of a cable, providing mechanical protection for the insulated conductors. A conduit installation can be rewired easily or altered at any time, and this flexibility, coupled with mechanical protection, makes conduit installations popular for commercial and industrial applications. There are three types of conduit used in electrical installation work: steel, PVC and flexible.

Steel conduit

Steel conduits are made to a specification defined by BS 4568 and are either heavy gauge welded or solid drawn. Heavy gauge is made from a sheet of steel welded along the seam to form a tube and is used for most electrical installation work. Solid drawn conduit is a seamless tube which is much more expensive and only used for special gas-tight, explosion-proof or flame-proof installations.

Conduit is supplied in 3.75 m lengths and typical sizes are 16, 20, 25 and 32 mm. Conduit tubing and fittings are supplied in a black enamel finish for internal use or hot galvanized finish for use on external or damp installations. A wide range of fittings is available and the conduit is fixed using saddles or pipe hooks, as shown in Fig. 5.17.

Metal conduits are threaded with stocks and dies and bent using special bending machines. The metal conduit is also utilized as the CPC and, therefore, all connections must be screwed up tightly and all burrs removed so that cables will not be damaged as they are drawn into the conduit. Metal conduits containing a.c. circuits must contain phase and neutral conductors in the same conduit to prevent eddy currents flowing, which would result in the metal conduit becoming hot (Regulations 521.5.2, 522.8.1 and 522.8.11).

PVC conduit

PVC conduit used on typical electrical installations is heavy gauge standard impact tube manufactured to BS 4607. The conduit size and range of fittings are the same as those available for metal conduit. PVC conduit is most often joined by placing the end of the conduit into the appropriate fitting and fixing with a PVC solvent adhesive. PVC conduit can be bent by hand using a

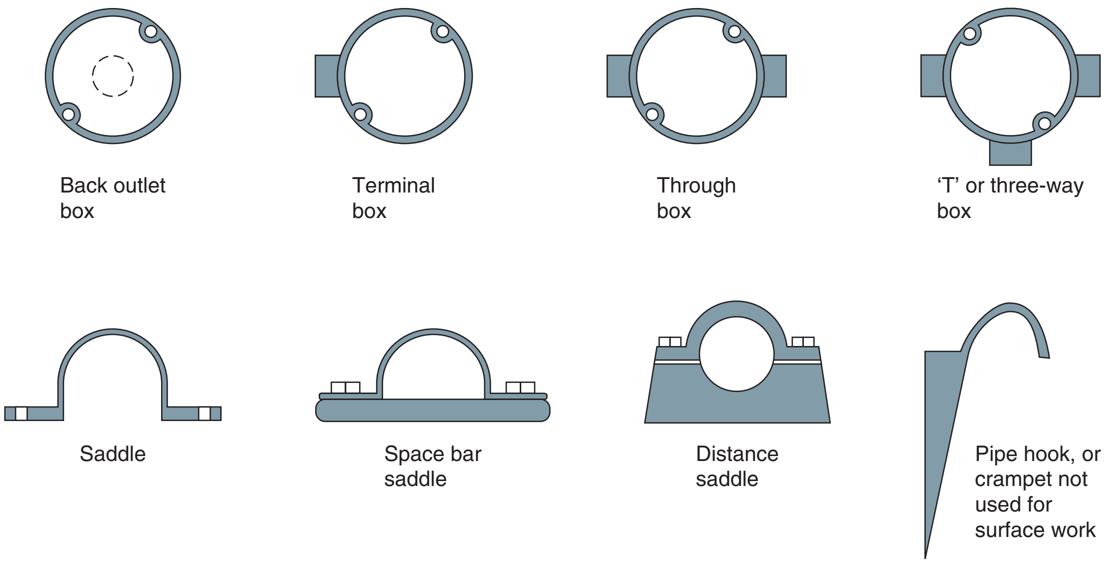


FIGURE 5.17
Conduit fittings and saddles.

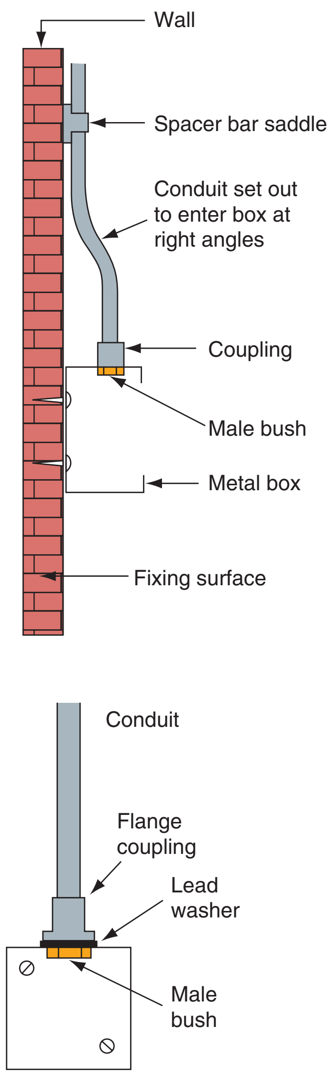


FIGURE 5.18
Terminating conduits.

bending spring of the same diameter as the inside of the conduit. The spring is pushed into the conduit to the point of the intended bend and the conduit then bent over the knee. The spring ensures that the conduit keeps its circular shape. In cold weather, a little warmth applied to the point of the intended bend often helps to achieve a more successful bend.

The advantages of a PVC conduit system are that it may be installed much more quickly than steel conduit and is non-corrosive, but it does not have the mechanical strength of steel conduit. Since PVC conduit is an insulator it cannot be used as the CPC and a separate earth conductor must be run to every outlet. It is not suitable for installations subjected to temperatures below 25°C or above 60°C. Where luminaires are suspended from PVC conduit boxes, precautions must be taken to ensure that the lamp does not raise the box temperature or that the mass of the luminaire supported by each box does not exceed the maximum recommended by the manufacturer (IEE Regulations 522.1 and 522.2). PVC conduit also expands much more than metal conduit and so long runs require an expansion coupling to allow for conduit movement and help to prevent distortion during temperature changes.

All conduit installations must be erected first before any wiring is installed (IEE Regulation 522.8.2). The radius of all bends in conduit must not cause the cables to suffer damage, and therefore the minimum radius of bends given in Table 4E of the *On Site Guide* applies (IEE Regulation 522.8.3). All conduits should terminate in a box or fitting and meet the boxes or fittings at right angles, as shown in Fig. 5.18. Any unused conduit box entries should be blanked off and all boxes covered with a box lid, fitting or accessory to provide complete enclosure of the conduit system. Conduit runs should be separate from other services, unless intentionally bonded, to

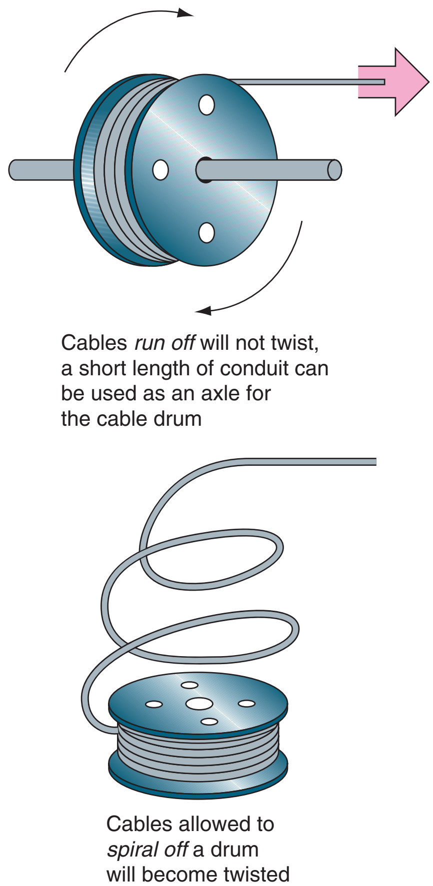


FIGURE 5.19
Running off cable from a drum.

Definition

Flexible conduit is made of interlinked metal spirals often covered with a PVC sleeving.

Definition

Single PVC insulated conductors are usually drawn into the installed conduit to complete the installation.

prevent arcing occurring from a faulty circuit within the conduit, which might cause the pipe of another service to become punctured.

When drawing cables into conduit they must first be *run off* the cable drum. That is, the drum must be rotated as shown in Fig. 5.19 and not allowed to *spiral off*, which will cause the cable to twist.

Cables should be fed into the conduit in a manner which prevents any cable crossing over and becoming twisted inside the conduit. The cable insulation must not be damaged on the metal edges of the draw-in box. Cables can be pulled in on a draw wire if the run is a long one. The draw wire itself may be drawn in on a fish tape, which is a thin spring steel or plastic tape.

A limit must be placed on the number of bends between boxes in a conduit run and the number of cables which may be drawn into a conduit to prevent the cables being strained during wiring. Appendix 5 of the *On Site Guide* gives a guide to the cable capacities of conduits and trunking.

Flexible conduit

Flexible conduit is made of interlinked metal spirals often covered with a PVC sleeving. The tubing must not be relied upon to provide a continuous earth path and, consequently, a separate CPC must be run either inside or outside the flexible tube (Regulation 543.2.1).

Flexible conduit is used for the final connection to motors so that the vibrations of the motor are not transmitted throughout the electrical installation and to allow for modifications to be made to the final motor position and drive belt adjustments.

Conduit capacities

Single PVC insulated conductors are usually drawn into the installed conduit to complete the installation. Having decided upon the type, size and number of cables required for a final circuit, it is then necessary to select the appropriate size of conduit to accommodate those cables.

The tables in Appendix 5 of the *On Site Guide* describe a 'factor system' for determining the size of conduit required to enclose a number of conductors. The tables are shown in Tables 5.1 and 5.2. The method is as follows:

- Identify the cable factor for the particular size of conductor. (This is given in Table 5A for straight conduit runs and Table 5C for cables run in conduits which incorporate bends, see Table 5.1.)
- Multiply the cable factor by the number of conductors, to give the sum of the cable factors.
- Identify the appropriate part of the conduit factor table given by the length of run and number of bends. (For straight runs of conduit less

Table 5.1 Conduit Cable Factors. Adapted from the *IEE On Site Guide* by kind permission of the Institution of Electrical Engineers.

TABLE 5C
Cable factors for use in conduit in long straight runs over 3 m, or runs of any length incorporating bends

Type of conductor	Conductor cross-sectional area (mm^2)	Cable factor
Solid or stranded	1	16
	1.5	22
	2.5	30
	4	43
	6	58
	10	105
	16	145
	25	217

The inner radius of a conduit bend should be not less than 2.5 times the outside diameter of the conduit.

than 3 m in length, the conduit factors are given in Table 5B. For conduit runs in excess of 3 m or incorporating bends, the conduit factors are given in Table 5D, see Table 5.2.)

- The correct size of conduit to accommodate the cables is that conduit which has a factor equal to or greater than the sum of the cable factors.

Example 1

Six 2.5 mm^2 PVC insulated cables are to be run in a conduit containing two bends between boxes 10 m apart. Determine the minimum size of conduit to contain these cables.

From Table 5C, shown in Table 5.1

The factor for one 2.5 mm^2 cable	$= 30$
The sum of the cable factors	$= 6 \times 30$
	$= 180$

From Table 5D shown in Table 5.2, a 25 mm conduit, 10 m long and containing two bends, has a factor of 260. A 20 mm conduit containing two bends only has a factor of 141 which is less than 180, the sum of the cable factors and, therefore, 25 mm conduit is the minimum size to contain these cables.

Example 2

Ten 1.0 mm^2 PVC insulated cables are to be drawn into a plastic conduit which is 6 m long between boxes and contains one bend. A 4.0 mm PVC insulated CPC is also included. Determine the minimum size of conduit to contain these conductors.

Table 5.2 Conduit Cable Factors for Bends and Long Straight Runs. Adapted from the *IEE On Site Guide* by kind permission of the Institution of Electrical Engineers.
TABLE 5D
Cable factors for runs incorporating bends and long straight runs

	Conduit diameter (mm)																			
Length of run (m)	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32
	Straight				One bend				Two bends				Three bends				Four bends			
1	Covered by				188	303	543	947	177	286	514	900	158	256	463	818	130	213	388	692
1.5					182	294	528	923	167	270	487	857	143	233	422	750	111	182	333	600
2	Tables				177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529
2.5					171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474
3	A and B				167	270	487	857	143	233	422	750	111	182	333	600				
3.5	179	290	521	911	162	263	475	837	136	222	404	720	103	169	311	563				
4	177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529				
4.5	174	282	507	889	154	250	452	800	125	204	373	667	91	149	275	500				
5	171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474				
6	167	270	487	857	143	233	422	750	111	182	333	600								
7	162	263	475	837	136	222	404	720	103	169	311	563								
8	158	256	463	818	130	213	388	692	97	159	292	529								
9	154	250	452	800	125	204	373	667	91	149	275	500								
10	150	244	442	783	120	196	358	643	86	141	260	474								

Additional factors: For 38 mm diameter use ...... 1.4 × (32 mm factor)
For 50 mm diameter use ...... 2.6 × (32 mm factor)
For 63 mm diameter use ...... 4.2 × (32 mm factor)

From Table 5.1

The factor for one 1.0 mm cable = 16
The factor for one 4.0 mm cable = 43.
The sum of the cable factors = $(10 \times 16) + (1 \times 43) = 203$.

From Table 5.2, a 20 mm conduit, 6 m long and containing one bend, has a factor of 233. A 16 mm conduit containing one bend only has a factor of 143 which is less than 203, the sum of the cable factors and, therefore, 20 mm conduit is the minimum size to contain these cables.

Definition

A *trunking* is an enclosure provided for the protection of cables which is normally square or rectangular in cross-section, having one removable side. Trunking may be thought of as a more accessible conduit system.

TRUNKING INSTALLATIONS

A **trunking** is an enclosure provided for the protection of cables which is normally square or rectangular in cross-section, having one removable side. Trunking may be thought of as a more accessible conduit system and for industrial and commercial installations it is replacing the larger conduit sizes. A trunking system can have great flexibility when used in conjunction with conduit; the trunking forms the background or framework for the installation, with conduits running from the trunking to the point controlling the current using apparatus. When an alteration or extension is required it is easy to drill a hole in the side of the trunking and run a conduit to the new point. The new wiring can then be drawn through the new conduit and the existing trunking to the supply point.

Trunking is supplied in 3 m lengths and various cross-sections are measured in millimetres from 50×50 up to 300×150. Most trunking is available in either steel or plastic.

Metallic trunking

Definition

Metallic trunking is formed from mild steel sheet, coated with grey or silver enamel paint for internal use or a hot-dipped galvanized coating where damp conditions might be encountered.

Metallic trunking is formed from mild steel sheet, coated with grey or silver enamel paint for internal use or a hot-dipped galvanized coating where damp conditions might be encountered and made to a specification defined by BS EN 50085. A wide range of accessories is available, such as 45° bends, 90° bends, tee and four-way junctions, for speedy on-site assembly. Alternatively, bends may be fabricated in lengths of trunking, as shown in Fig. 5.20. This may be necessary or more convenient if a bend or set is non-standard, but it does take more time to fabricate bends than merely to bolt on standard accessories.

When fabricating bends the trunking should be supported with wooden blocks for sawing and filing, in order to prevent the sheet-steel vibrating or becoming deformed. Fish plates must be made and riveted or bolted to the trunking to form a solid and secure bend. When manufactured bends are used, the continuity of the earth path must be ensured across the joint by making all fixing screw connections very tight, or fitting a separate copper strap between the trunking and the standard bend. If an earth continuity test on the trunking is found to be unsatisfactory, an insulated CPC must be installed inside the trunking. The size of the protective conductor will be determined by the largest cable contained in the trunking, as described by Table 54.7 of the IEE Regulations. If the circuit conductors are less than 16 mm^2, then a 16 mm^2 CPC will be required.

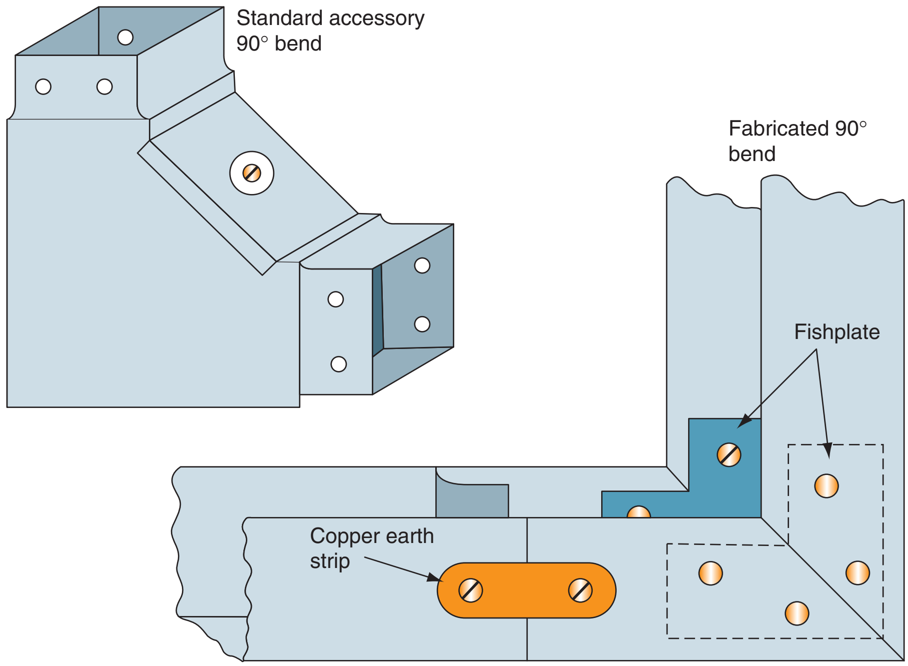


FIGURE 5.20
Alternative trunking bends.

Non-metallic trunking

Trunking and trunking accessories are also available in high-impact PVC. The accessories are usually secured to the lengths of trunking with a PVC solvent adhesive. PVC trunking, like PVC conduit, is easy to install and is non-corrosive. A separate CPC will need to be installed and non-metallic trunking may require more frequent fixings because it is less rigid than metallic trunking. All trunking fixings should use round-headed screws to prevent damage to cables since the thin sheet construction makes it impossible to countersink screw heads.

Definition

Mini-trunking is very small PVC trunking, ideal for surface wiring in domestic and commercial installations such as offices.

Mini-trunking

Mini-trunking is very small PVC trunking, ideal for surface wiring in domestic and commercial installations such as offices. The trunking has a cross-section of 16 × 16 mm, 25 × 16 mm, 38 × 16 mm or 38 × 25 mm and is ideal for switch drops or for housing auxiliary circuits such as telephone or audio equipment wiring. The modern square look in switches and sockets is complemented by the mini-trunking which is very easy to install (see Fig. 5.21).

Definition

A *trunking manufactured from PVC or steel* and in the shape of a skirting board is frequently used in commercial buildings such as hospitals, laboratories and offices.

Skirting trunking

A **trunking manufactured from PVC or steel** and in the shape of a skirting board is frequently used in commercial buildings such as hospitals, laboratories and offices. The trunking is fitted around the walls of a room and contains the wiring for socket outlets and telephone points which are mounted on the lid, as shown in Fig. 5.21.

Key Fact

Fire Safety

Where the wiring system passes through elements of building construction such as floors and walls, any damage must be made good (IEE REG 527.2).

Where any trunking passes through walls, partitions, ceilings or floors, short lengths of lid should be fitted so that the remainder of the lid may be removed later without difficulty. Any damage to the structure of the buildings must be made good with mortar, plaster or concrete in order to prevent the spread of fire. Fire barriers must be fitted inside the trunking every 5 m, or at every floor level or room dividing wall, if this is a shorter distance, as shown in Fig. 5.22(a).

Where trunking is installed vertically, the installed conductors must be supported so that the maximum unsupported length of non-sheathed cable does not exceed 5 m. Figure 5.22(b) shows cables woven through insulated pin supports, which is one method of supporting vertical cables.

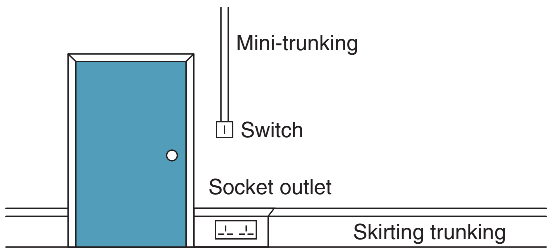


FIGURE 5.21
Typical installation of skirting trunking and mini-trunking.

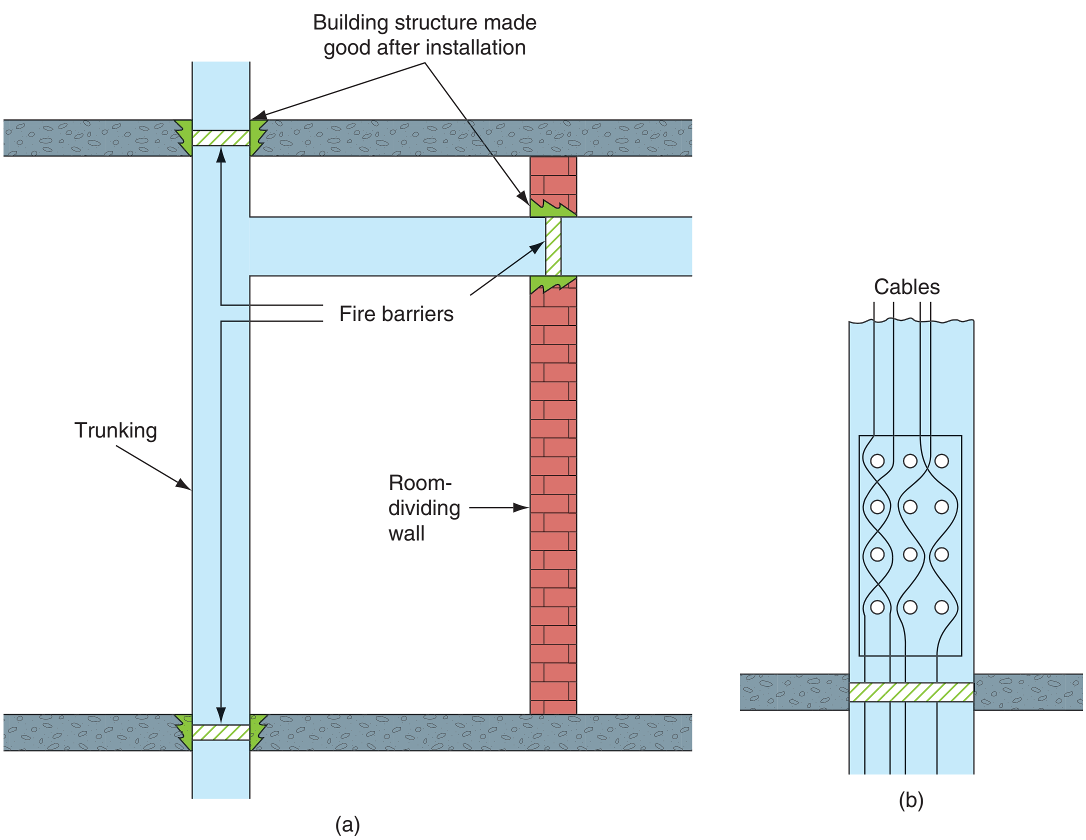


FIGURE 5.22
Installation of trunking.

PVC insulated cables are usually drawn into an erected conduit installation or laid into an erected trunking installation. Table 5D of the *On Site Guide* only gives factors for conduits up to 32 mm in diameter, which would indicate that conduits larger than this are not in frequent or common use. Where a cable enclosure greater than 32 mm is required because of the number or size of the conductors, it is generally more economical and convenient to use trunking.

Trunking capacities

Definition

The ratio of the space occupied by all the cables in a conduit or trunking to the whole space enclosed by the conduit or trunking is known as the *space factor*.

The ratio of the space occupied by all the cables in a conduit or trunking to the whole space enclosed by the conduit or trunking is known as the **space factor**. Where sizes and types of cable and trunking are not covered by the tables in Appendix 5 of the *On Site Guide* a space factor of 45% must not be exceeded. This means that the cables must not fill more than 45% of the space enclosed by the trunking. The tables of Appendix 5 take this factor into account.

To calculate the size of trunking required to enclose a number of cables:

- Identify the cable factor for the particular size of conductor. See Table 5.3.
- Multiply the cable factor by the number of conductors to give the sum of the cable factors.
- Consider the factors for trunking and shown in Table 5.4. The correct size of trunking to accommodate the cables is that trunking which has a factor equal to or greater than the sum of the cable factors.

Table 5.3 Trunking, Cable Factors. Adapted from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers.

TABLE 5E
Cable factors for trunking

Type of conductor	Conductor cross-sectional area (mm^2)	PVC, BS 6004 Cable factor	Thermosetting BS 7211 Cable factor
Solid	1.5	8.0	8.6
	2.5	11.9	11.9
Stranded	1.5	8.6	9.6
	2.5	12.6	13.9
	4	16.6	18.1
	6	21.2	22.9
	10	35.3	36.3
	16	47.8	50.3
	25	73.9	75.4

Note: (i) These factors are for metal trunking and may be optimistic for plastic trunking where the cross-sectional area available may be significantly reduced from the nominal by the thickness of the wall material. (ii) The provision of spare space is advisable; however, any circuits added at a later date must take into account grouping. Appendix 4, BS 7671.

Example

Calculate the minimum size of trunking required to accommodate the following single-core PVC cables:

20×1.5 mm solid conductors
20×2.5 mm solid conductors
21×4.0 mm stranded conductors
16×6.0 mm stranded conductors

From Table 5.3, the cable factors are:

for 1.5 mm solid cable	–	8.0
for 2.5 mm solid cable	–	11.9
for 4.0 mm stranded cable	–	16.6
for 6.0 mm stranded cable	–	21.2

The sum of the cable terms is:

$$(20 \times 8.0) + (20 \times 11.9) + (21 \times 16.6) + (16 \times 21.2) = 1085.8.$$

From Table 5.4, 75×38 mm trunking has a factor of 1146 and, therefore, the minimum size of trunking to accommodate these cables is 75×38 mm, although a larger size, say 75×50 mm would be equally acceptable if this was more readily available as a standard stock item.

SEGREGATION OF CIRCUITS

Where an installation comprises a mixture of low-voltage and very low-voltage circuits such as mains lighting and power, fire alarm and telecommunication circuits, they must be separated or *segregated* to prevent electrical contact (IEE Regulation 528.1).

For the purpose of these regulations various circuits are identified by one of two bands as follows:

Band I telephone, radio, bell, call and intruder alarm circuits, emergency circuits for fire alarm and emergency lighting.

Band II mains voltage circuits.

When Band I circuits are insulated to the same voltage as Band II circuits, they may be drawn into the same compartment.

When trunking contains rigidly fixed metal barriers along its length, the same trunking may be used to enclose cables of the separate Bands without further precautions, provided that each Band is separated by a barrier, as shown in Fig. 5.23.

Multi-compartment PVC trunking cannot provide band segregations since there is no metal screen between the Bands. This can only be provided in PVC trunking if screened cables are drawn into the trunking.

Table 5.4 Trunking Cable Factors. Adapted from the *IEE On Site Guide* by kind permission of the Institution of Electrical Engineers. Factors for trunking

Dimensions of trunking (mm × mm)	Factor	Dimensions of trunking (mm × mm)	Factor
50 × 38	767	200 × 100	8572
50 × 50	1037	200 × 150	13001
75 × 25	738	200 × 200	17429
75 × 38	1146	225 × 38	3474
75 × 50	1555	225 × 50	4671
75 × 75	2371	225 × 75	7167
100 × 25	993	225 × 100	9662
100 × 38	1542	225 × 150	14652
100 × 50	2091	225 × 200	19643
100 × 75	3189	225 × 225	22138
100 × 100	4252	300 × 38	4648
150 × 38	2999	300 × 50	6251
150 × 50	3091	300 × 75	9590
150 × 75	4743	300 × 100	12929
150 × 100	6394	300 × 150	19607
150 × 150	9697	300 × 200	26285
200 × 38	3082	300 × 225	29624
200 × 50	4145	300 × 300	39428
200 × 75	6359		

Space factor – 45% with trunking thickness taken into account

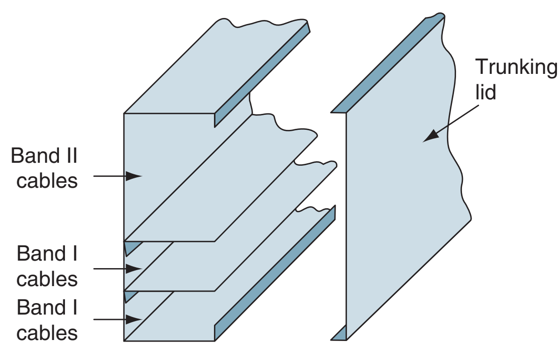


FIGURE 5.23
Segregation of cables in trunking.

CABLE TRAY INSTALLATIONS

Cable tray is a sheet-steel channel with multiple holes. The most common finish is hot-dipped galvanized but PVC-coated tray is also available. It is used extensively on large industrial and commercial installations for supporting MI and SWA cables which are laid on the cable tray and secured with cable ties through the tray holes.

Definition

Cable tray is a sheet-steel channel with multiple holes. The most common finish is hot-dipped galvanized but PVC-coated tray is also available. It is used extensively on large industrial and commercial installations for supporting MI and SWA cables which are laid on the cable tray and secured with cable ties through the tray holes.

Cable tray should be adequately supported during installation by brackets which are appropriate for the particular installation. The tray should be bolted to the brackets with round-headed bolts and nuts, with the round head inside the tray so that cables drawn along the tray are not damaged.

The tray is supplied in standard widths from 50 to 900 mm, and a wide range of bends, tees and reducers is available. Figure 5.24 shows a factory-made 90° bend at B. The tray can also be bent using a cable tray bending machine to create bends such as that shown at A in Fig. 5.24. The installed tray should be securely bolted with round-headed bolts where lengths or accessories are attached, so that there is a continuous earth path which may be bonded to an electrical earth. The whole tray should provide a firm support for the cables and therefore the tray fixings must be capable of supporting the weight of both the tray and cables.

PVC/SWA CABLE INSTALLATIONS

Definition

Steel wire armoured PVC insulated cables are now extensively used on industrial installations and often laid on cable tray.

Steel wire armoured PVC insulated cables are now extensively used on industrial installations and often laid on cable tray. This type of installation has the advantage of flexibility, allowing modifications to be made speedily as the need arises. The cable has a steel wire armouring giving mechanical protection and permitting it to be laid directly in the ground or in ducts, or it may be fixed directly or laid on a cable tray. Figure 5.13 shows a PVC/SWA cable.

It should be remembered that when several cables are grouped together the current rating will be reduced according to the correction factors given in Appendix 4. Table 4C1 of the IEE Regulations and Table 6C of the *On Site Guide*.

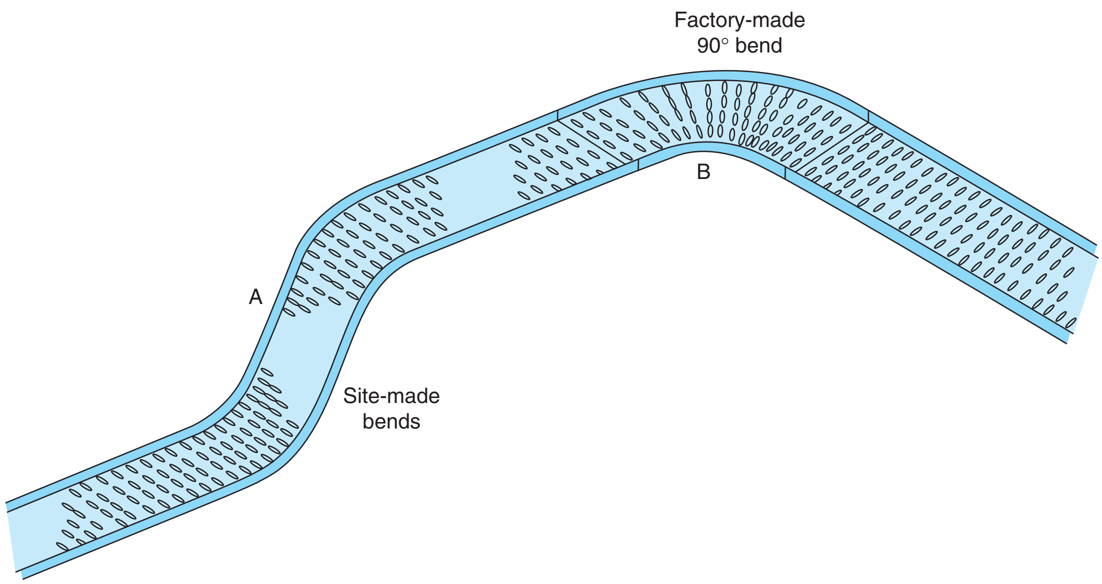


FIGURE 5.24
Cable tray with bends.

The cable is easy to handle during installation, is pliable and may be bent to a radius of eight times the cable diameter. The PVC insulation would be damaged if installed in ambient temperatures over 70°C or below 0°C, but once installed the cable can operate at low temperatures.

The cable is terminated with a simple gland which compresses a compression ring onto the steel wire armouring to provide the earth continuity between the switchgear and the cable.

MI CABLE INSTALLATIONS

MI cables are available for general wiring as:

- light-duty MI cables for voltages up to 600V and sizes from 1.0 to 10 mm^2 and
- heavy-duty MI cables for voltages up to 1000V and sizes from 1.0 to 150 mm^2.

Figure 5.14 shows an MI cable and termination. The cables are available with bare sheaths or with a PVC oversheath. The cable sheath provides sufficient mechanical protection for all but the most severe situations, where it may be necessary to fit a steel sheath or conduit over the cable to give extra protection, particularly near floor level in some industrial situations.

The cable may be laid directly in the ground, in ducts, on cable tray or clipped directly to a structure. It is not affected by water, oil or the cutting fluids used in engineering and can withstand very high temperature or even fire. The cable diameter is small in relation to its current carrying capacity and it should last indefinitely if correctly installed because it is made from inorganic materials. These characteristics make the cable ideal for Band I emergency circuits, boiler-houses, furnaces, petrol stations and chemical plant installations.

The cable is supplied in coils and should be run off during installation and not spiralled off, as described in Fig. 5.19 for conduit. The cable can be work-hardened if over-handled or over-manipulated. This makes the copper outer sheath stiff and may result in fracture. The outer sheath of the cable must not be penetrated, otherwise moisture will enter the magnesium oxide insulation and lower its resistance. To reduce the risk of damage to the outer sheath during installation, cables should be straightened and formed by hammering with a hide hammer or a block of wood and a steel hammer. When bending MI cables the radius of the bend should not cause the cable to become damaged and clips should provide adequate support (Regulations 522.8.5).

The cable must be prepared for termination by removing the outer copper sheath to reveal the copper conductors. This can be achieved by using a rotary stripper tool or, if only a few cables are to be terminated, the outer sheath can be removed with side cutters, peeling off the cable in a similar way to peeling the skin from a piece of fruit with a knife. When enough conductor has been revealed, the outer sheath must be cut off square to facilitate the fitting of the sealing pot, and this can be done with a ringing tool. All excess magnesium oxide powder must be wiped from the conductors with a clean cloth. This is to prevent moisture from penetrating the seal by capillary action.

Cable ends must be terminated with a special seal to prevent the entry of moisture. Figure 5.14 shows a brass screw-on seal and gland assembly, which allows termination of the MI cables to standard switchgear and conduit fittings. The sealing pot is filled with a sealing compound, which is pressed in from one side only to prevent air pockets forming, and the pot closed by crimping home the sealing disc. Such an assembly is suitable for working temperatures up to 105°C. Other compounds or powdered glass can increase the working temperature up to 250°C.

The conductors are not identified during the manufacturing process and so it is necessary to identify them after the ends have been sealed. A simple continuity or polarity test, as described in Chapter 8 of this book can identify the conductors which are then sleeved or identified with coloured markers.

Connection of MI cables can be made directly to motors, but to absorb the vibrations a 360° loop should be made in the cable just before the termination. If excessive vibration is to be expected the MI cable should be terminated in a conduit through-box and the final connection made by flexible conduit.

Copper MI cables may develop a green incrustation or patina on the surface, even when exposed to normal atmospheres. This is not harmful and should not be removed. However, if the cable is exposed to an environment which might encourage corrosion, an MI cable with an overall PVC sheath should be used.

Transformers

You have seen so far in this chapter that:

- electricity is generated as an alternating a.c. power supply,
- it is generated at 11 kV and then transformed up to 132 or 400 kV for transmission and distribution on the National Grid network,
- it is then transformed down for local underground distribution at 11 kV and then,
- further reduced to 400V and 230V for industrial, commercial and domestic consumers.

All of this is only possible because of one piece of electrical equipment, the transformer.

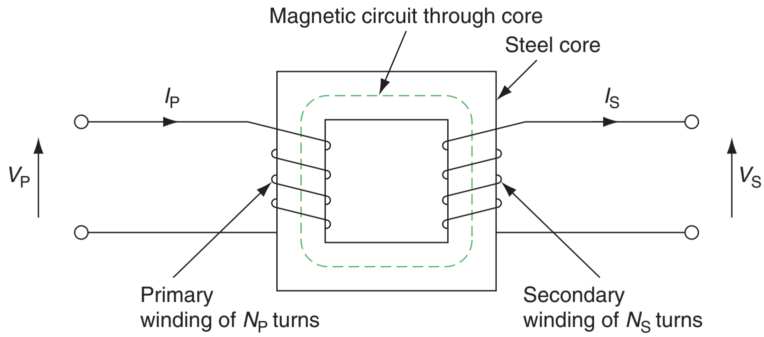


FIGURE 5.25
A simple transformer.

Definition

A *transformer* is an electrical machine which is used to change the value of an alternating voltage. They vary in size from miniature units used in electronics to huge power transformers used in power stations.

A **transformer** is an electrical machine which is used to change the value of an alternating voltage. They vary in size from miniature units used in electronics to huge power transformers used in power stations. A transformer will only work when an alternating voltage is connected. It will not normally work from a d.c. supply such as a battery.

A transformer, as shown in Fig. 5.25, consists of two coils, called the primary and secondary coils, or windings, which are insulated from each other and wound onto the same steel or iron core.

An alternating voltage applied to the primary winding produces an alternating current, which sets up an alternating magnetic flux throughout the core. This magnetic flux induces an electromotive force (emf) in the secondary winding, as described by Faraday's law, which says that when a conductor is cut by a magnetic field, an emf is induced in that conductor. Since both windings are linked by the same magnetic flux, the induced emf per turn will be the same for both windings. Therefore, the emf in both windings is proportional to the number of turns. In symbols,

$$\frac{V_P}{N_P} = \frac{V_S}{N_S} \tag{5.4}$$

Most practical power transformers have a very high efficiency, and for an ideal transformer having 100% efficiency the primary power is equal to the secondary power:

$$\text{Primary power} = \text{Secondary power}$$

and, since

$$\text{Power} = \text{Voltage} \times \text{Current} \tag{5.5}$$

then,

$$V_P \times I_P = V_S \times I_S$$

Combining Equations (5.4) and (5.5), we have

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

Example

A 230 V to 12V bell transformer is constructed with 800 turns on the primary winding. Calculate the number of secondary turns and the primary and secondary currents when the transformer supplies a 12V 12W alarm bell.

Collecting the information given in the question into a usable form, we have:

$$V_P = 230 \text{ V}$$
$$V_S = 12 \text{ V}$$
$$N_P = 800$$

Power = 12W

Information required: N_S, I_S and I_P

Secondary turns,

$$N_S = \frac{N_P V_S}{V_P}$$
$$\therefore\ N_S = \frac{800 \times 12 \text{ V}}{230 \text{ V}} = 42 \text{ turns}$$

Secondary current,

$$I_S = \frac{\text{Power}}{V_S}$$
$$\therefore\ I_S = \frac{12 \text{ W}}{12 \text{ V}} = 1 \text{ A}$$

Primary current,

$$I_P = \frac{I_S \times V_S}{V_P}$$
$$\therefore\ I_P = \frac{1 \text{ A} \times 12 \text{ V}}{230 \text{ V}} = 0.052 \text{ A}$$

Transformer rating

Definition

Transformers are *rated* in kVA (kilovolt-amps) rather than power in watts because the output current and power factor will be affected by the load connected to the transformer.

Transformers are **rated** in kVA (kilovolt-amps) rather than power in watts because the output current and power factor will be affected by the load connected to the transformer.

The kVA rating of a transformer tells us the current that can be delivered for a known voltage. Thus a 5 kVA transformer can deliver 12.5 A at 400V.

Definition

As they have no moving parts causing frictional losses, most transformers have a very high efficiency, usually better than 90%. However, the losses which do occur in a transformer can be grouped under two general headings: *copper losses* and *iron losses*.

Definition

Copper losses occur because of the small internal resistance of the windings.

Definition

Iron losses are made up of hysteresis loss and eddy current loss. The hysteresis loss depends upon the type of iron used to construct the core and consequently core materials are carefully chosen.

Definition

Eddy currents are circulating currents created in the core material by the changing magnetic flux. These are reduced by building up the core of thin slices or laminations of iron and insulating the separate laminations from each other.

Transformer losses

As they have no moving parts causing frictional losses, most transformers have a very high efficiency, usually better than 90%. However, the losses which do occur in a transformer can be grouped under two general headings: **copper losses** and **iron losses**.

Copper losses occur because of the small internal resistance of the windings. They are proportional to the load, increasing as the load increases because copper loss is an 'I^2R' loss.

Iron losses are made up of *hysteresis loss* and *eddy current loss*. The hysteresis loss depends upon the type of iron used to construct the core and consequently core materials are carefully chosen. We looked at magnetic hysteresis loops at Fig. 4.21 in the last chapter. Transformers will only operate on an alternating supply. Thus, the current which establishes the core flux is constantly changing from positive to negative. Each time there is a current reversal, the magnetic flux reverses and it is this build-up and collapse of magnetic flux in the core material which accounts for the hysteresis loss.

Eddy currents are circulating currents created in the core material by the changing magnetic flux. These are reduced by building up the core of thin slices or laminations of iron and insulating the separate laminations from each other. The iron loss is a constant loss consuming the same power from no load to full load.

Transformer efficiency

The efficiency of any machine is determined by the losses incurred by the machine in normal operation. The efficiency of rotating machines is usually in the region of 50–60% because they incur windage and friction losses; but the transformer has no moving parts so, therefore, these losses do not occur. However, the efficiency of a transformer can be calculated in the same way as for any other machine. The efficiency of a machine is generally given by:

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

(η is the Greek letter 'eta'). However, the input to the transformer must supply the output plus any losses which occur within the transformer. We can therefore say:

$$\text{Input power} = \text{Output power} + \text{Losses}$$

Rewriting the basic formula, we have:

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Losses}}$$

Example

A 100 kVA power transformer feeds a load operating at a power factor of 0.8. Find the efficiency of the transformer if the combined iron and copper loss at this load is 1 kW.

$$\text{Output power} = \text{kVA} \times \text{p.f}$$
$$\therefore \text{Output power} = 100\ \text{kVA} \times 0.8$$
$$\text{Output power} = 80\ \text{kW}$$
$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{losses}}$$
$$\eta = \frac{80\,\text{kW}}{80\,\text{kW} + 1\,\text{kW}}$$
$$\eta = 0.987$$

or, multiplying by 100 to give a percentage, the transformer has an efficiency of 98.7%.

Transformer construction

Transformers are constructed in a way which reduces the losses to a minimum. The core is usually made of silicon–iron laminations, because at fixed low frequencies silicon–iron has a small hysteresis loss and the laminations reduce the eddy current loss. The primary and secondary windings are wound close to each other on the same limb. If the windings are spread over two limbs, there will usually be half of each winding on each limb, as shown in Fig. 5.26.

AUTO-TRANSFORMERS

Transformers having a separate primary and secondary winding, as shown in Fig. 5.26, are called double-wound transformers, but it is possible to construct a transformer which has only one winding which is common to the primary and secondary circuits. The secondary voltage is supplied by means of a 'tapping' on the primary winding. An arrangement such as this is called an auto-transformer.

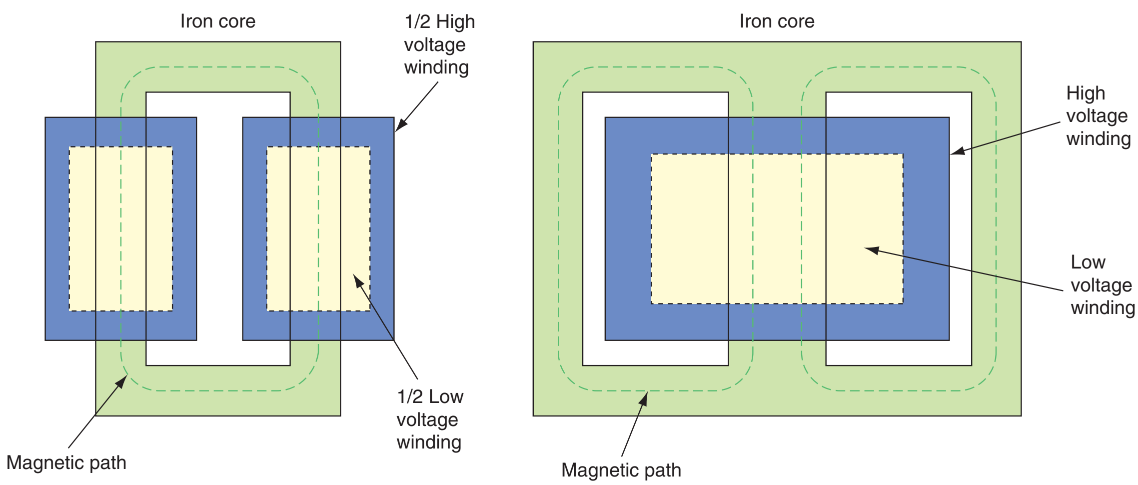


FIGURE 5.26
Transformer construction.

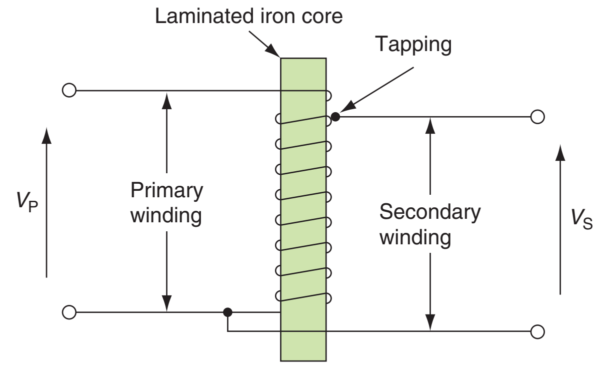


FIGURE 5.27
An auto-transformer.

The auto-transformer is much cheaper and lighter than a double-wound transformer because less copper and iron are used in its construction. However, the primary and secondary windings are not electrically separate and a short circuit on the upper part of the winding shown in Fig. 5.27 would result in the primary voltage appearing across the secondary terminals. For this reason auto-transformers are mostly used where only a small difference is required between the primary and secondary voltages. When installing transformers, the regulations of Section 555 must be complied with, in addition to any other regulations relevant to the particular installation.

THREE-PHASE TRANSFORMERS

Most of the transformers used in industrial applications are designed for three-phase operation. In the double-wound type construction, as shown in Fig. 5.25, three separate single-phase transformers are wound onto a common laminated silicon–steel core to form the three-phase transformer. The primary and secondary windings may be either star or delta connected but in distribution transformers the primary is usually connected in delta and the secondary in star. This has the advantage of providing two secondary voltages, typically 400 V between phases and 230 V between phase and neutral from an 11 kV primary voltage. The coil arrangement is shown in Fig. 5.28.

The construction of the three-phase transformer is the same as the single-phase transformer, but because of the larger size the core is often cooled by oil.

OIL-IMMERSED CORE

As the rating of a transformer increases so does the problem of dissipating the heat generated in the core. In power distribution transformers the most common solution is to house the transformer in a steel casing containing insulating oil which completely covers the core and the windings. The oil is a coolant and an insulating medium for the core. On load the transformer heats up and establishes circulating convection currents in the oil which flows through the external tubes. Air passing over the tubes carries the heat away and cools the transformer. Figure 5.29 shows the construction of

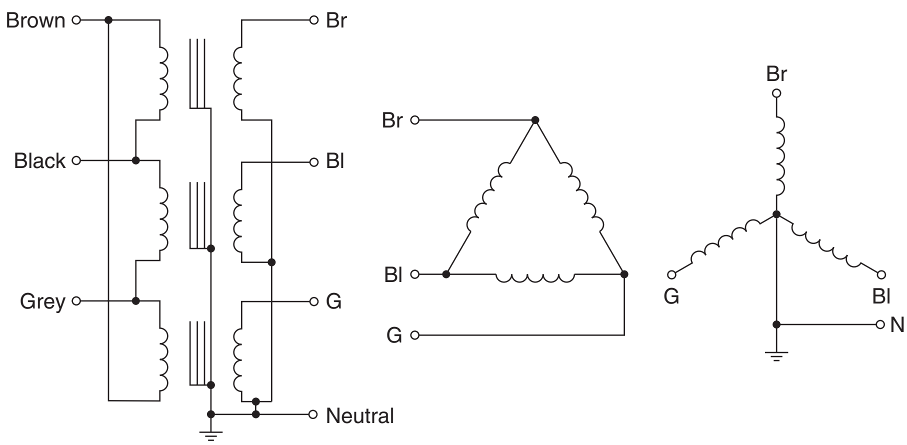


FIGURE 5.28
Delta-star connected three-phase transformer.

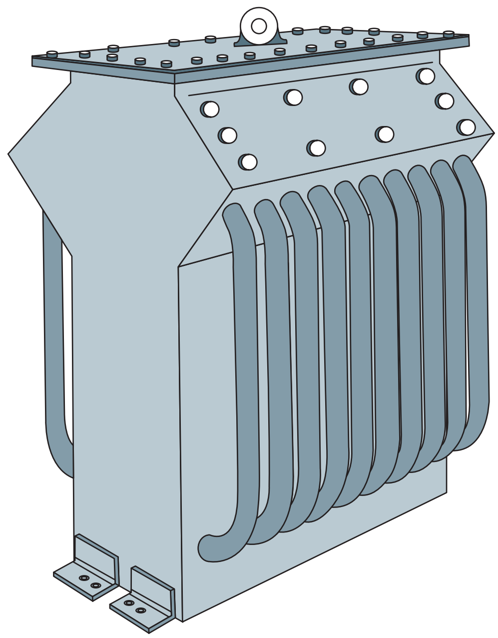


FIGURE 5.29
Typical oil-filled power transformer.

a typical oil-filled transformer, and the arrangement is typical of a distribution transformer used in a sub-station.

TAP CHANGING

Under load conditions the secondary voltage of a transformer may fall and become less than that permitted by the Regulations. The tolerance permitted by the Regulations in 2008 is the open-circuit voltage plus 10% or minus 6%. However, it is proposed that these tolerance levels will be adjusted to ±10% of the declared nominal voltage. Because the voltage of a transformer is proportional to the number of turns, one solution is to vary the number of turns on either the primary or secondary winding, to achieve the desired voltage. This process is called tap changing, and most distribution transformers are fitted with a tap changing switch on the high-voltage winding so that the number of turns can be varied. These switches are always off load devices and, therefore, the transformer must be isolated before the tap changing operation is carried out. The switch is usually padlocked to prevent unauthorized operation.

Earthing and protection systems

We know from the earlier chapters in this book that using electricity is one of the causes of accidents in the workplace. Using electricity is a hazard because it has the potential, the possibility, to cause harm and, therefore, the provision of protective devices in an electrical installation is fundamental to the whole concept of the safe use of electricity.

The consumer's mains equipment is fixed close to the point at which the supply cable enters the building. The IEE Regulations require the consumer's mains equipment to provide:

- Protection against electric shock (Chapter 41)
- Protection against overcurrent (Chapter 43)
- Isolation and switching (Chapter 53).

Protection against electric shock, both 'Basic Protection' and 'Fault Protection' is provided by placing live parts out of reach in suitable enclosures, by insulation and by earthing and bonding metalwork for the purpose of safety. Also by providing fuses or circuit breakers so that the supply is automatically disconnected under fault conditions.

Protection against overcurrent is achieved by providing a device which will automatically disconnect the supply before the overcurrent can cause a rise in temperature that would damage the installation. A fuse or miniature circuit board (MCB) would meet these requirements.

Definition

An *isolator* is a mechanical device that is operated manually and is provided so that the whole of the installation, one circuit or one piece of equipment, may be cut off from the live supply.

An **isolator** is a mechanical device that is operated manually and is provided so that the whole of the installation, one circuit or one piece of equipment, may be cut off from the live supply.

In addition, a means of switching off for maintenance or emergency switching, must be provided. A switch may provide the means of isolation but an isolator differs from a switch in that it is intended to be opened when the circuit is not carrying current. Its purpose is to ensure the safety of those working on the circuit by making dead those parts that are live in normal service.

Definition

The switching of electrical equipment in normal service is called '*functional switching*'.

One device may provide both isolation and switching functions. The switching of electrical equipment in normal service is called '**functional switching**'.

All electrical installation circuits are controlled by switchgear that is assembled so that the individual circuits may be operated safely under normal conditions, isolated automatically under fault conditions or isolated manually for safe maintenance or repair work. These requirements are met by good workmanship carried out by competent persons using approved British Standard cables equipment and accessories.

Earthing systems and protection systems are described in detail in Chapter 7 of this book.

Try This

Definitions

Write down the meaning of

- functional switching and
- isolation switching.

Check your Understanding

When you have completed these questions, check out your answers at the back of the book.
Note: more than one multiple choice answer may be correct.

1. The most suitable cable for a hazardous or high-temperature installation is:
   a. PVC insulated and sheathed cables
   b. PVC/SWA cable
   c. PILCSWA cables
   d. MI cables.

2. The part of the cable which sometimes requires some means of mechanical protection is the:
   a. conductor
   b. cable insulation
   c. outer sheath
   d. PVC/SWA.

3. The most suitable cable for wiring underground when some mechanical protection is required is:
   a. PVC insulated and sheathed cable
   b. PVC/SWA cable
   c. FP 200 cable
   d. MI cable.

4. The most suitable cable for wiring domestic installations is:
   a. PVC insulated and sheathed cable
   b. PVC/SWA cable
   c. FP 200 cable
   d. MI cable.

5. The most suitable cable for wiring a fire alarm in fire resistant cable is:
   a. PVC insulated and sheathed cable
   b. PVC/SWA cable
   c. FP 200 cable
   d. MI cable.

6. It is a tube, a channel or pipe in which insulated conductors are contained is one definition of a:
   a. flexible conduit
   b. steel conduit
   c. tray
   d. trunking.

7. It is an enclosure provided for the protection of cables that is normally square or rectangular with one removable side, is one definition of:
   a. flexible conduit
   b. steel conduit
   c. tray
   d. trunking.

8. A 12 V mini-spot lamp transformer has 1400 turns on the primary winding. When connected to the 230 V mains supply the number of secondary turns will be approximately:
   a. 2
   b. 73
   c. 386
   d. 4000.

9. A 12 V 12 W mini-spot lamp transformer is connected to the 230 V mains supply. The primary current will be:
   a. 52.2 mA
   b. 62.6 mA
   c. 19.2 A
   d. 33.12 A.

10. Transformer losses are:
    a. copper loss
    b. current loss
    c. iron loss
    d. voltage loss.

11. Use a labelled sketch to describe the electricity supply system from generation, transmission and distribution to the end user. State all voltages.

12. Use a labelled sketch to show how a 230 V and 400 V supply is obtained from an 11 kV sub-station transformer.

13. Use a labelled sketch to show a delta-star connected transformer. State the formulae for calculating the voltage and current for each type of connection.

14. Use a labelled sketch to describe the construction of a PVC/SWA cable. State one suitable application for this type of cable.

15. Use a labelled sketch to describe a trunking plus conduit installation in an industrial environment. State the method to be used to prevent the spread of fire through the fabric of the building and internally through the trunking where it passes through walls and ceilings.

16. Use a labelled sketch to describe how you would fix to a brick wall:
    a. conduit
    b. trunking.

    State the type of screws to be used in each case.

17. Use the Tables 5.1 and 5.2 in this chapter to calculate the maximum number of 1.5 mm PVC cables which can be drawn into a 20 mm conduit having one bend in a 4 m length of run.

18. Using the information given in question 17, calculate the maximum number of 2.5 mm cables.

19. Use the Tables 5.3 and 5.4 in this chapter to calculate the maximum number of solid 2.5 mm PVC cables which can be drawn into a 100 × 50 trunking.

20. List all the losses that occur in a transformer and state how the losses are reduced to a minimum.

21. Describe what we mean by a 'transformer's rating' and calculate the current which a 2 kVA site transformer can deliver at 110 V.

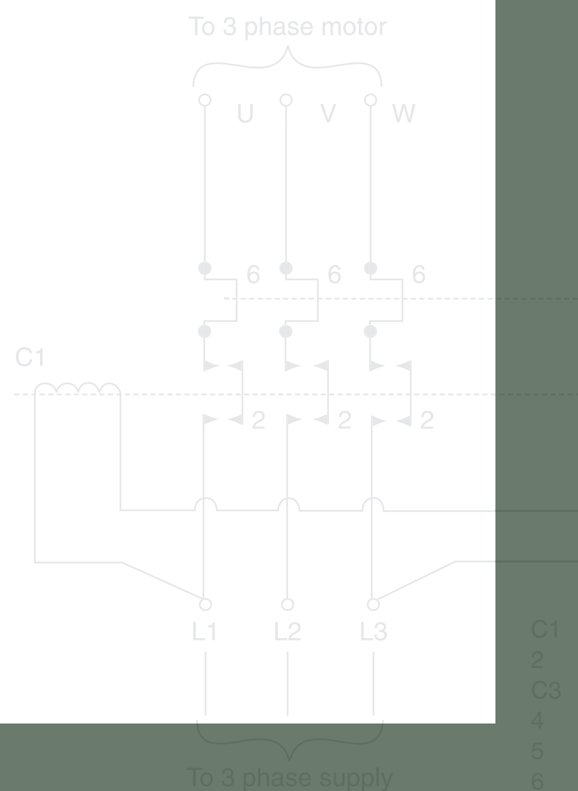
22. Describe the meaning of
    a. Basic Protection and
    b. Fault Protection.

    Note: There are definitions in this book and in Part 2 of the IEE Regulations.

23. Describe how an electrical installation provides protection from electric shock.

24. Describe how an electrical installation is protected against overcurrent.

25. Explain the difference between switching for isolation purposes and functional switching.



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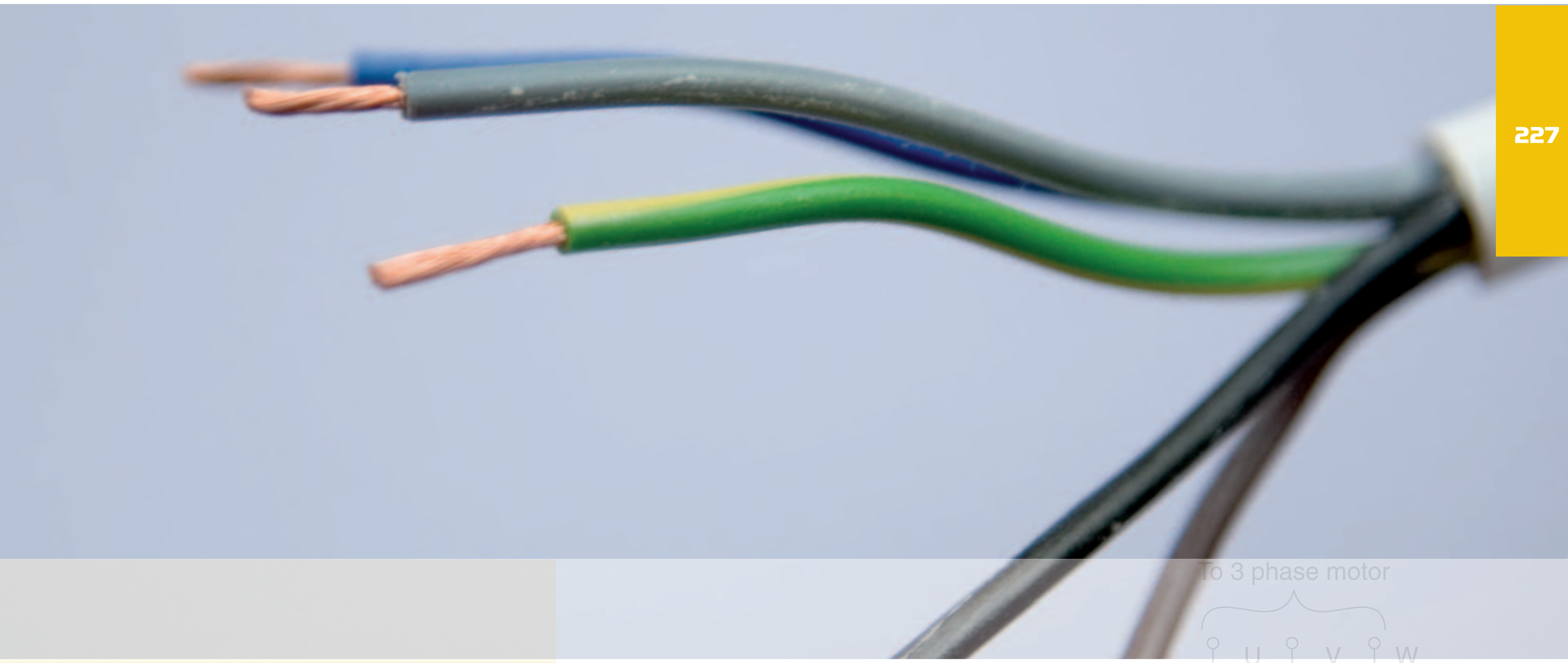
CH 6

Electrical machines and motors



Unit 1 – Application of health and safety and electrical principles – Outcome 6

Underpinning knowledge: when you have completed this chapter you should be able to:

- describe the operation of electrical rotating machines
- identify a three-phase induction motor
- describe the production of a three-phase rotating magnetic field
- identify single-phase a.c. motors
- identify the basic principles of motor starting and speed control

Electrical machines and motors

The fundamental principles of electrical machines were laid down in *Basic Electrical Installation Work*. In this chapter we will essentially be looking at d.c. and a.c. motors, their control equipment and maintenance.

Direct current motors

If a current carrying conductor is placed into the field of a permanent magnet as shown in Fig. 6.1(c) a force F will be exerted on the conductor to push it out of the magnetic field.

To understand the force, let us consider each magnetic field acting alone. Figure 6.1(a) shows the magnetic field due to the current carrying conductor only. Figure 6.1(b) shows the magnetic field due to the permanent magnet in which is placed the conductor carrying no current. Figure 6.1(c) shows the effect of the combined magnetic fields which are distorted and, because lines of magnetic flux never cross, but behave like stretched elastic bands, always trying to find the shorter distance between a north and south pole, the force F is exerted on the conductor, pushing it out of the permanent magnetic field.

This is the basic motor principle, and the force F is dependent upon the strength of the magnetic field B, the magnitude of the current flowing in the conductor I and the length of conductor within the magnetic field l. The following equation expresses this relationship:

$$F = BlI \text{ (N)}$$

where B is in teslas, l is in metres, I is in amperes and F is in newtons.

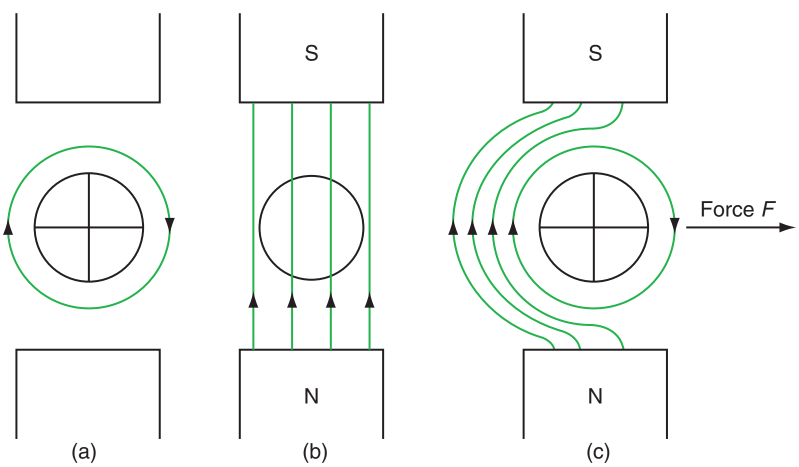


FIGURE 6.1
Force on a conductor in a magnetic field.

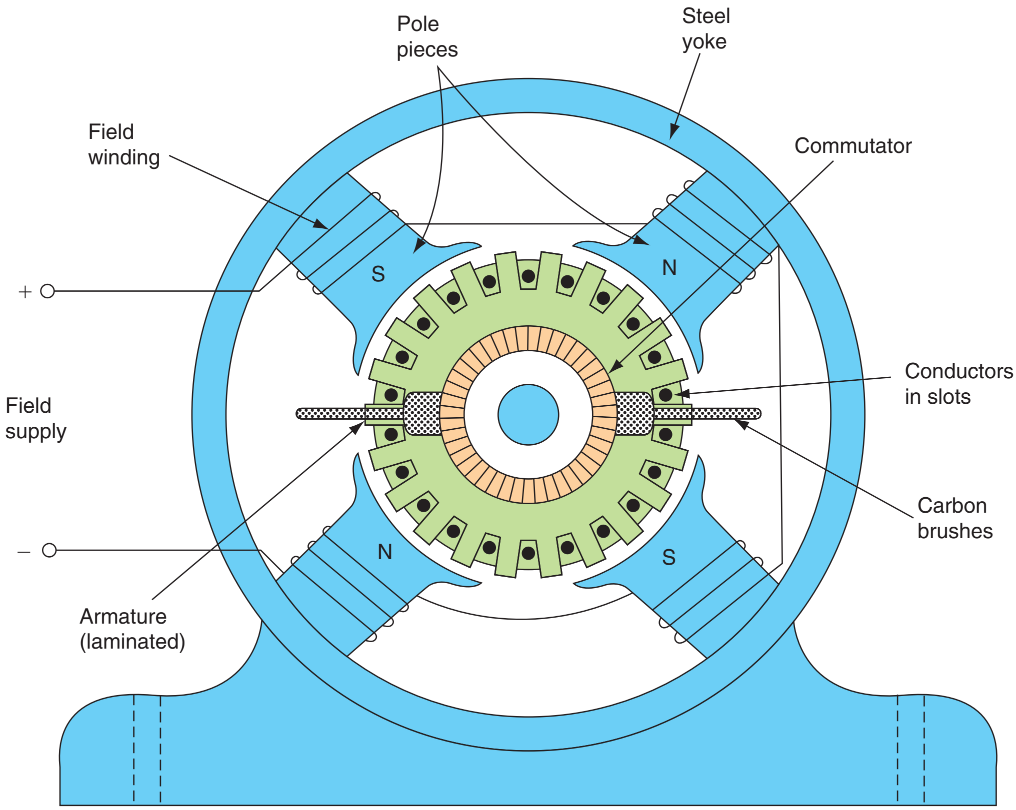


FIGURE 6.2
Showing d.c. machine construction.

Definition

Direct current motors are classified by the way in which the field and armature windings are connected, which may be in series or in parallel.

Example

A coil which is made up of a conductor some 15 m in length, lies at right angles to a magnetic field of strength 5 T. Calculate the force on the conductor when 15 A flows in the coil.

$$F = Bll \text{ (N)}$$

$$F = 5\,\text{T} \times 15\,\text{m} \times 15\,\text{A} = 1125\text{ (N)}$$

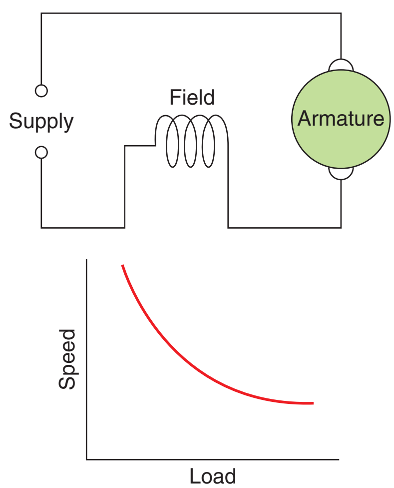


FIGURE 6.3
Series motor connections and characteristics.

PRACTICAL D.C. MOTORS

Practical motors are constructed as shown in Fig. 6.2. All d.c. motors contain a field winding wound on pole pieces attached to a steel yoke. The armature winding rotates between the poles and is connected to the commutator. Contact with the external circuit is made through carbon brushes rubbing on the commutator segments. **Direct current motors** are classified by the way in which the field and armature windings are connected, which may be in series or in parallel.

Series motor

The field and armature windings are connected in series and consequently share the same current. The series motor has the characteristics of a high starting torque but a speed which varies with load. Theoretically the motor would speed up to self-destruction, limited only by the windage of the rotating armature and friction, if the load were completely removed. Figure 6.3 shows

Definition

Series motor: the machine will run on both a.c. or d.c. and is, therefore, sometimes referred to as a '*universal*' motor.

Key Fact

Series motor

- an electric drill motor,
- a vacuum cleaner motor,
- an electric train motor,
- are all series motors.

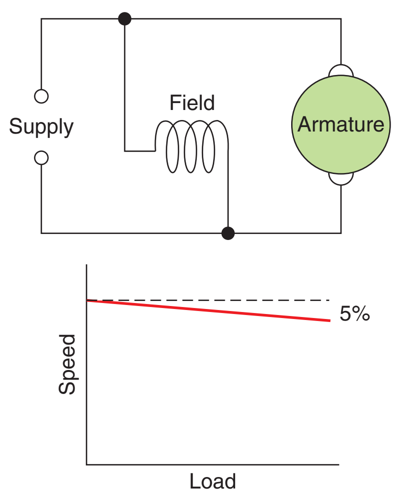


FIGURE 6.4
Shunt motor connections and characteristics.

Definition

One of the *advantages of a d.c. machine* is the ease with which the speed may be controlled.

series motor connections and characteristics. For this reason the motor is only suitable for direct coupling to a load, except in very small motors, such as vacuum cleaners and hand drills, and is ideally suited for applications where the machine must start on load, such as electric trains, cranes and hoists.

Reversal of rotation may be achieved by reversing the connections of either the field or armature windings but not both. This characteristic means that the machine will run on both a.c. or d.c. and is, therefore, sometimes referred to as a '**universal**' motor.

Shunt motor

The field and armature windings are connected in parallel (see Fig. 6.4). Since the field winding is across the supply, the flux and motor speed are considered constant under normal conditions. In practice, however, as the load increases the field flux distorts and there is a small drop in speed of about 5% at full load, as shown in Fig. 6.4. The machine has a low starting torque and it is advisable to start with the load disconnected. The shunt motor is a very desirable d.c. motor because of its constant speed characteristics. It is used for driving power tools, such as lathes and drills. Reversal of rotation may be achieved by reversing the connections to either the field or armature winding but not both.

Compound motor

The compound motor has two field windings – one in series with the armature and the other in parallel. If the field windings are connected so that the field flux acts in opposition, the machine is known as a *short shunt* and has the characteristics of a series motor. If the fields are connected so that the field flux is strengthened, the machine is known as a *long shunt* and has constant speed characteristics similar to a shunt motor. The arrangement of compound motor connections is given in Fig. 6.5. The compound motor may be designed to possess the best characteristics of both series and shunt motors, that is, good starting torque together with almost constant speed. Typical applications are for electric motors in steel rolling mills, where a constant speed is required under varying load conditions.

SPEED CONTROL OF D.C. MACHINES

One of the **advantages of a d.c. machine** is the ease with which the speed may be controlled. The speed of a d.c. motor is inversely proportional to the strength of the magnetic flux in the field winding. The magnetic flux in the field winding can be controlled by the field current and, as a result, controlling the field current will control the motor speed.

A variable resistor connected into the field circuit, as shown in Fig. 6.6 provides one method of controlling the field current and the motor speed. This method has the disadvantage that much of the input energy is dissipated in the variable resistor and an alternative, when an a.c. supply is available, is to use thyristor control.

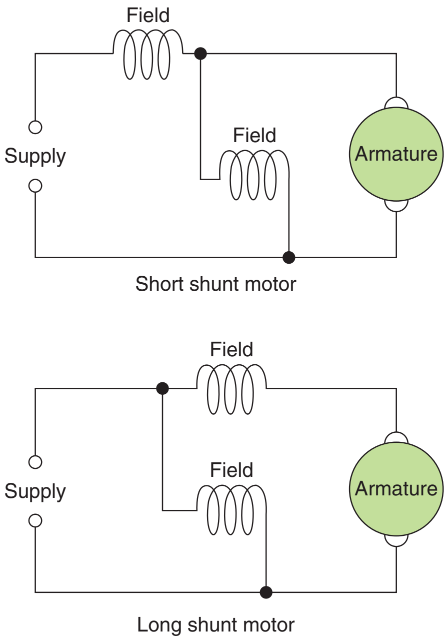


FIGURE 6.5
Compound motor connections.

BACK EMF AND MOTOR STARTING

When the armature conductors cut the magnetic flux of the main field, an emf is induced in the armature, as described earlier in Chapter 4 (Fig. 4.20). This induced emf is known as the back emf, since it acts in opposition to the supply voltage. During normal running, the back emf is always a little smaller than the supply voltage, and acts as a limit to the motor current. However, when the motor is first switched on, the back emf does not exist because the conductors are stationary and so a motor starter is required to limit the starting current to a safe value. This applies to all but the very smallest of motors and is achieved by connecting a resistor in series with the armature during starting, so that the resistance can be gradually reduced as the speed builds up.

The control switch of Fig. 6.7 is moved to the start position, which connects the variable resistors in series with the motor, thereby limiting the starting current. The control switch is moved progressively over the variable resistor contacts to the run position as the motor speed builds up. A practical motor starter is designed so that the control switch returns automatically to the 'off' position whenever the motor stops, so that the starting resistors are connected when the machine is once again switched on.

Definition

If a *three-phase supply* is connected to three separate windings equally distributed around the stationary part or stator of an electrical machine, an alternating current circulates in the coils and establishes a magnetic flux.

Three-phase a.c. motors

If a **three-phase supply** is connected to three separate windings equally distributed around the stationary part or stator of an electrical machine, an alternating current circulates in the coils and establishes a magnetic flux. The magnetic field established by the three-phase currents travels in a clockwise direction around the stator, as can be seen by considering

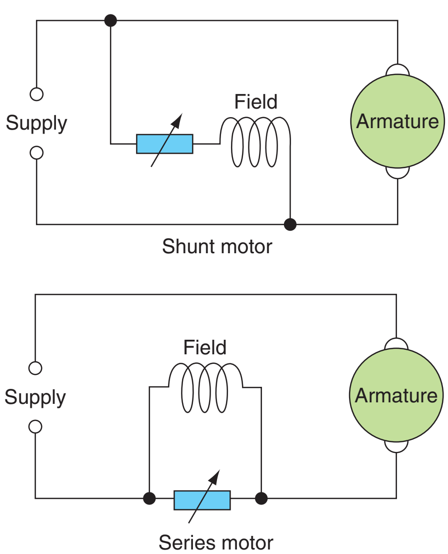


FIGURE 6.6
Speed control of a d.c. motor.

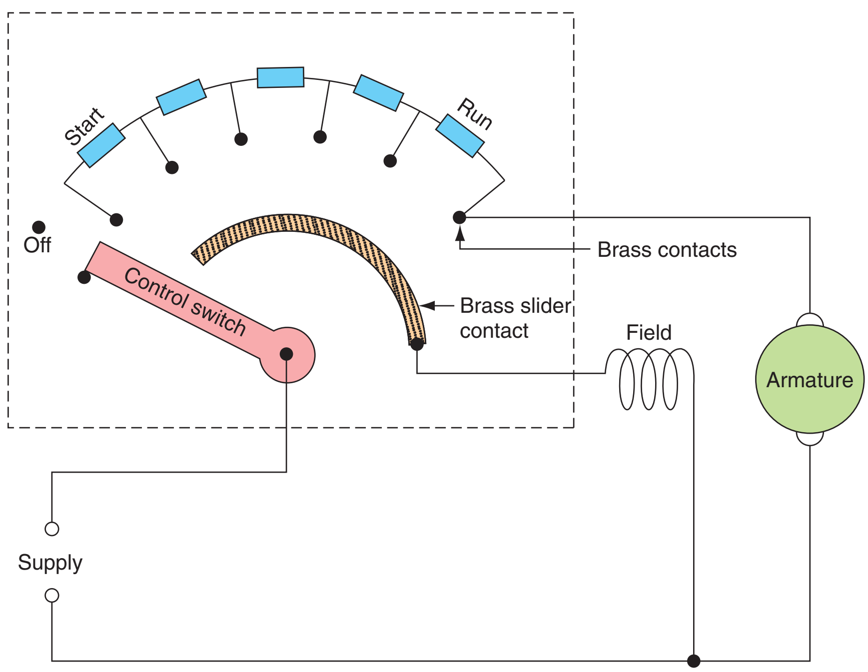


FIGURE 6.7
A d.c. motor starting.

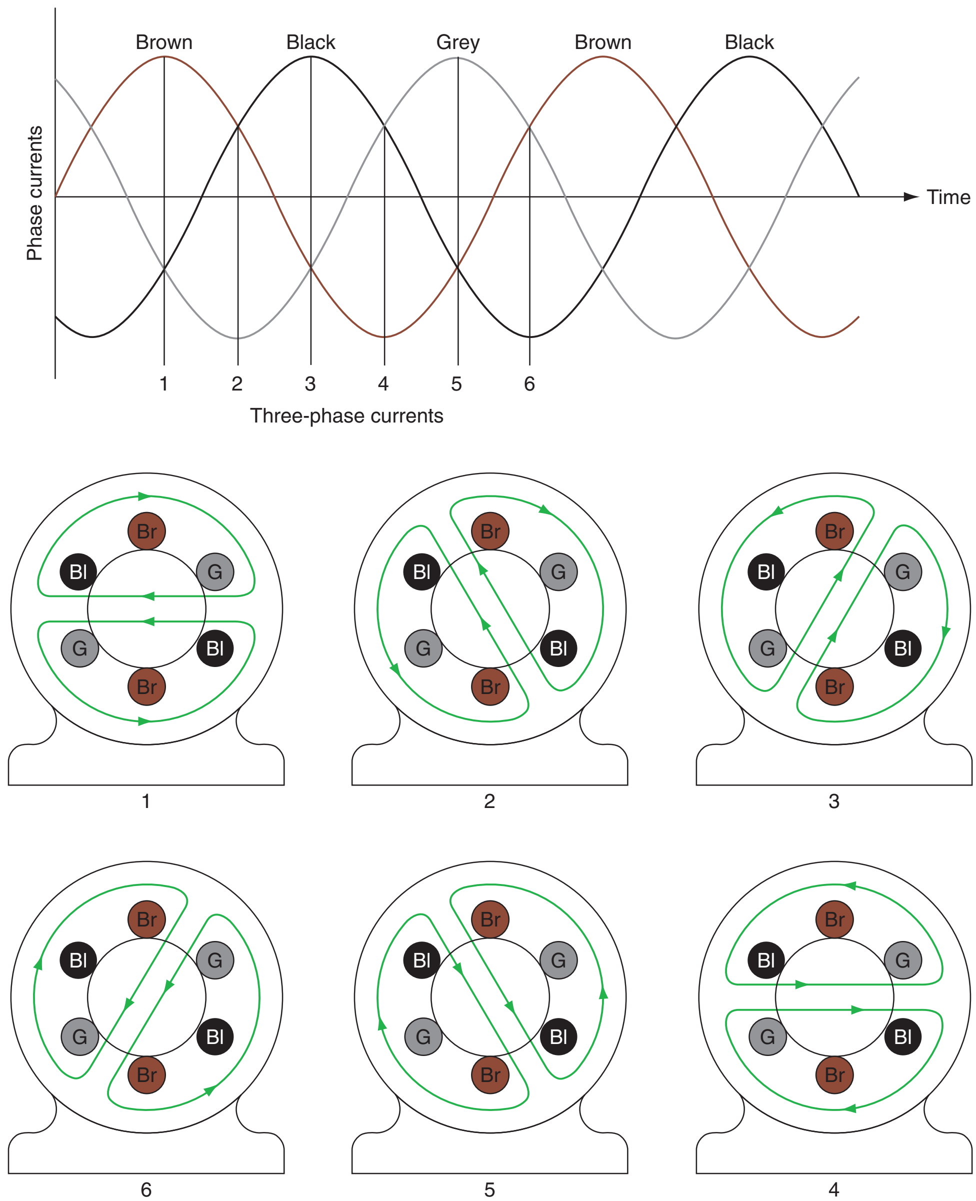


FIGURE 6.8
Distribution of magnetic flux due to three-phase currents.

the various intervals of time 1–6 shown in Fig. 6.8. The three-phase supply establishes a rotating magnetic flux which rotates at the same speed as the supply frequency. This is called synchronous speed, denoted as n_S:

$$n_s = \frac{f}{P} \text{ or } N_S = \frac{60f}{P}$$

where:

n_S is measured in revolutions per second,

N_S is measured in revolutions per minute,

f is the supply frequency measured in hertz,

P is the number of pole pairs.

Example

Calculate the synchronous speed of a four-pole machine connected to a 50 Hz mains supply.

We have

$$n_S = \frac{f}{P}(\text{rps})$$

A four-pole machine has two pairs of poles:

$$\therefore n_S = \frac{50\ \text{Hz}}{2} = 25\ \text{rps}$$

$$\text{or } N_S = \frac{60 \times 50\ \text{Hz}}{2} = 1500\ \text{rpm}$$

This rotating magnetic field is used for practical effect in the induction motor.

THREE-PHASE INDUCTION MOTOR

When a three-phase supply is connected to insulated coils set into slots in the inner surface of the stator or stationary part of an induction motor as shown in Fig. 6.9(a), a rotating magnetic flux is produced. The rotating magnetic flux cuts the conductors of the rotor and induces an emf in the rotor conductors by Faraday's law, which states that when a conductor cuts or is cut by a magnetic field, an emf is induced in that conductor, the magnitude of which is proportional to the *rate* at which the conductor cuts or is cut by the magnetic flux. This induced emf causes rotor currents to flow and establish a magnetic flux which reacts with the stator flux and causes a force to be exerted on the rotor conductors, turning the rotor as shown in Fig. 6.9(b).

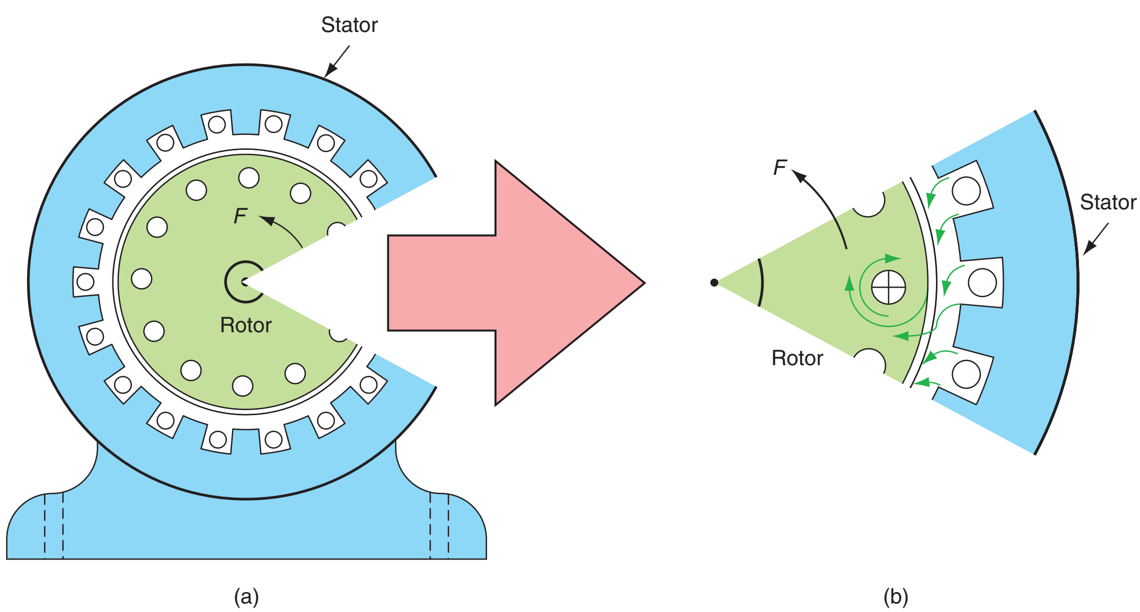


FIGURE 6.9
Segment taken out of an induction motor to show turning force: (a) construction of an induction motor; (b) production of torque by magnetic fields.

The turning force or torque experienced by the rotor is produced by inducing an emf into the rotor conductors due to the *relative* motion between the conductors and the rotating field. The torque produces rotation in the same direction as the rotating magnetic field. At switch-on, the rotor speed increases until it approaches the speed of the rotating magnetic flux, that is, the synchronous speed. The faster the rotor revolves the less will be the difference in speed between the rotor and the rotating magnetic field. By Faraday's laws, this will result in less induced emf, less rotor current and less torque on the rotor. The rotor can never run at synchronous speed because, if it did so, there would be no induced emf, no current and no torque. The induction motor is called an asynchronous motor. In practice, the rotor runs at between 2% and 5% below the synchronous speed so that a torque can be maintained on the rotor which overcomes the rotor losses and the applied load.

The difference between the rotor speed and synchronous speed is called slip; the per-unit slip, denoted *s*, is given by:

$$s = \frac{n_S - n}{n_S} = \frac{N_S - N}{N_S}$$

where

n_S = synchronous speed in revolutions per second

N_S = synchronous speed in revolutions per minute

n = rotor speed in revolutions per second

N = rotor speed in revolutions per minute.

The percentage slip is just the per-unit slip multiplied by 100.

Example

A two-pole induction motor runs at 2880 rpm when connected to the 50 Hz mains supply. Calculate the percentage slip.

The synchronous speed is given by:

$$N_S = \frac{60 \times f}{p}\,(\text{rpm})$$

$$\therefore N_S = \frac{60 \times 50\ \text{Hz}}{1} = 3000\ \text{rpm}$$

Thus the per-unit slip is:

$$s = \frac{N_S - N}{N_S}$$

$$\therefore s = \frac{3000\ \text{rpm} - 2880\ \text{rpm}}{3000\ \text{rpm}}$$

$$s = 0.04$$

So the percentage slip is 0.04 × 100 = 4%.

Definition

There are two types of *induction motor rotor* – the wound rotor and the cage rotor.

ROTOR CONSTRUCTION

There are two types of **induction motor rotor** – the wound rotor and the cage rotor. The cage rotor consists of a laminated cylinder of silicon steel with copper or aluminium bars slotted in holes around the circumference and short-circuited at each end of the cylinder as shown in Fig. 6.10. In small motors the rotor is cast in aluminium. Better starting and quieter running are achieved if the bars are slightly skewed. This type of rotor is extremely robust and since there are no external connections there is no need for slip-rings or brushes. A machine fitted with a cage rotor does suffer from a low starting torque and the machine must be chosen which has a higher starting torque than the load, as shown by curve (b) in Fig. 6.11. A machine with the characteristic shown by curve (a) in Fig. 6.11 would not start since the load torque is greater than the machine starting torque.

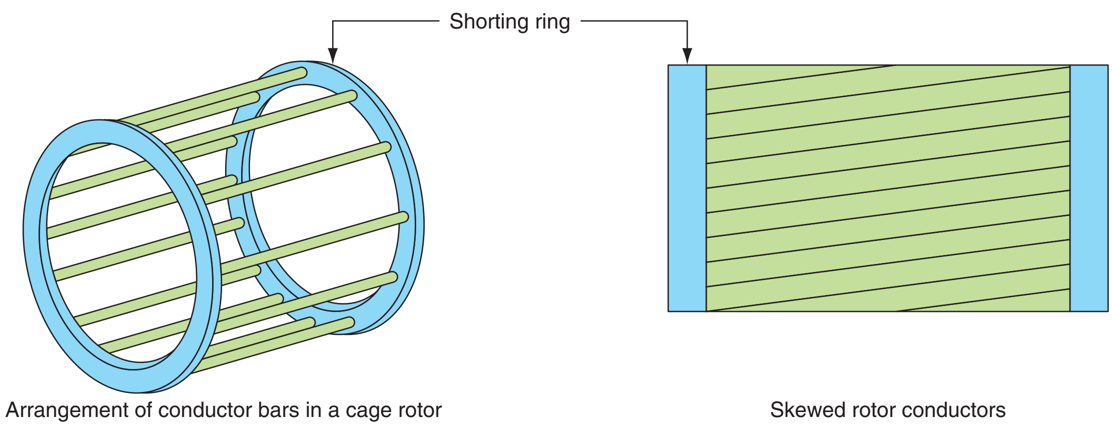


FIGURE 6.10
Construction of a cage rotor.

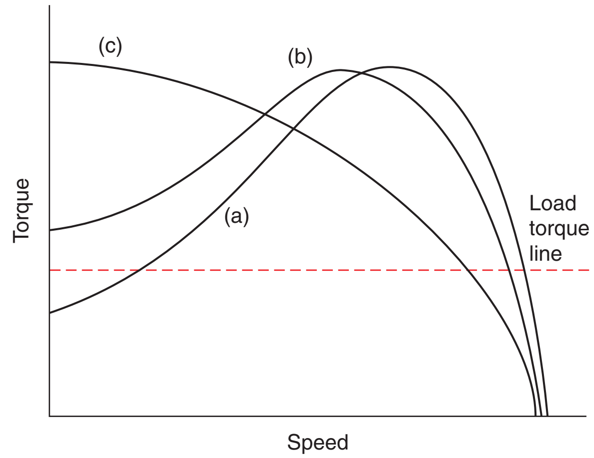


FIGURE 6.11
Various speed–torque characteristics for an induction motor.

Alternatively, the load may be connected after the motor has been run up to full speed, or extra resistance can be added to a wound rotor through slip-rings and brushes since this improves the starting torque, as shown by curve (c) in Fig. 6.11. The wound rotor consists of a laminated cylinder of silicon steel with copper coils embedded in slots around the circumference. The windings may be connected in star or delta and the end connections brought out to slip-rings mounted on the shaft. Connection by carbon brushes can then be made to an external resistance to improve starting, but once normal running speed is achieved the external resistance is short circuited. Therefore, the principle of operation for both types of rotor is the same.

The cage induction motor has a small starting torque and should be used with light loads or started with the load disconnected. The speed is almost constant at about 5% less than synchronous speed. Its applications are for constant speed machines such as fans and pumps. Reversal of rotation is achieved by reversing any two of the stator winding connections.

THREE-PHASE SYNCHRONOUS MOTOR

If the rotor of a three-phase induction motor is removed and replaced with a simple magnetic compass, the compass needle will rotate in the same direction as the rotating magnetic field set up by the stator winding. That is, the compass needle will rotate at synchronous speed. This is the basic principle of operation of the synchronous motor.

Key Fact

Cage rotor

A cage rotor induction motor

- requires very little maintenance,
- does not have carbon brushes,
- does not have a commutator,
- is almost indestructible,
- is used extensively in industry,
- is used for fans and pumps.

In a practical machine, the rotor is supplied through slip-rings with a d.c. supply which sets up an electromagnet having north and south poles.

When the supply is initially switched on, the rotor will experience a force, first in one direction and then in the other direction every cycle as the stator flux rotates around the rotor at synchronous speed. Therefore, the synchronous motor is not self-starting. However, if the rotor is rotated at or near synchronous speed, then the stator and rotor poles of opposite polarity will 'lock together' producing a turning force or torque which will cause the rotor to rotate at synchronous speed.

If the rotor is slowed down and it comes out of synchronism, then the rotor will stop because the torque will be zero. The synchronous motor can, therefore, only be run at synchronous speed, which for a 50 Hz supply will be 3000, 1500, 1000 or 750 rpm depending upon the number of poles, as discussed earlier in this chapter.

A practical synchronous machine can be brought up to synchronous speed by either running it initially as an induction motor or by driving it up to synchronous speed by another motor called a 'pony motor'. Once the rotor achieves synchronous speed the pony motor is disconnected and the load applied to the synchronous motor.

With such a complicated method of starting the synchronous motor, it is clearly not likely to find applications which require frequent stopping and starting. However, the advantage of a synchronous motor is that it runs at

Definition

A *single-phase a.c. supply* produces a pulsating magnetic field, not the rotating magnetic field produced by a three-phase supply. All a.c. motors require a rotating field to start. Therefore, single-phase a.c. motors have two windings which are electrically separated by about 90°. The two windings are known as the start and run windings.

Definition

Once rotation is established, the *pulsating field* in the run winding is sufficient to maintain rotation and the start winding is disconnected by a centrifugal switch which operates when the motor has reached about 80% of the full load speed.

a constant speed and operates at a leading power factor (p.f.). It can, therefore, be used to improve a bad p.f. while driving constant speed machines such as ventilation fans and pumping compressors.

Single-phase a.c. motors

A **single-phase a.c. supply** produces a pulsating magnetic field, not the rotating magnetic field produced by a three-phase supply. All a.c. motors require a rotating field to start. Therefore, single-phase a.c. motors have two windings which are electrically separated by about 90°.The two windings are known as the start and run windings. The magnetic fields produced by currents flowing through these out-of-phase windings create the rotating field and turning force required to start the motor. Once rotation is established, the **pulsating field** in the run winding is sufficient to maintain rotation and the start winding is disconnected by a centrifugal switch which operates when the motor has reached about 80% of the full load speed.

A cage rotor is used on single-phase a.c. motors, the turning force being produced in the way described previously for three-phase induction motors and shown in Fig. 6.9. Because both windings carry currents which are out-of-phase with each other, the motor is known as a 'split-phase' motor. The phase displacement between the currents in the windings is achieved in one of two ways:

- by connecting a capacitor in series with the start winding, as shown in Fig. 6.12(a), which gives a 90° phase difference between the currents in the start and run windings;
- by designing the start winding to have a high resistance and the run winding a high inductance, once again creating a 90° phase shift between the currents in each winding, as shown in Fig. 6.12(b).

When the motor is first switched on, the centrifugal switch is closed and the magnetic fields from the two coils produce the turning force required

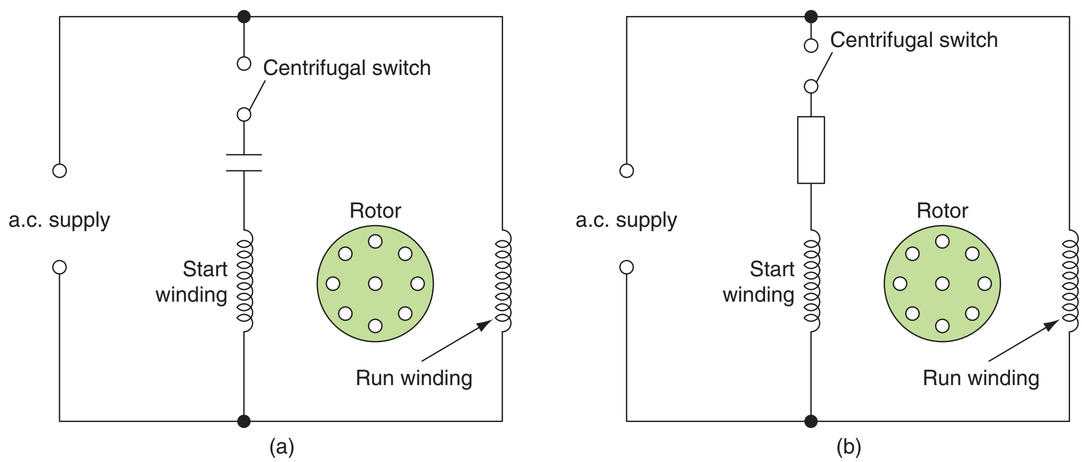


FIGURE 6.12
Circuit diagram of: (a) capacitor split-phase motors; (b) resistance split-phase motors.

to run the rotor up to full speed. When the motor reaches about 80% of full speed, the centrifugal switch clicks open and the machine continues to run on the magnetic flux created by the run winding only.

Split-phase motors are constant speed machines with a low starting torque and are used on light loads such as fans, pumps, refrigerators and washing machines. Reversal of rotation may be achieved by reversing the connections to the start or run windings, but not both.

SHADED POLE MOTORS

The shaded pole motor is a simple, robust single-phase motor, which is suitable for very small machines with a rating of less than about 50 W. Figure 6.13 shows a shaded pole motor. It has a cage rotor and the moving field is produced by enclosing one side of each stator pole in a solid copper or brass ring, called a shading ring, which displaces the magnetic field and creates an artificial phase shift.

Shaded pole motors are constant speed machines with a very low starting torque and are used on very light loads such as oven fans, record turntable motors and electric fan heaters. Reversal of rotation is theoretically possible by moving the shading rings to the opposite side of the stator pole face. However, in practice this is often not a simple process, but the motors are symmetrical and it is sometimes easier to reverse the rotor by removing the fixing bolts and reversing the whole motor.

There are more motors operating from single-phase supplies than all other types of motor added together. Most of them operate as very small motors in domestic and business machines where single-phase supplies are most common.

Definition

The purpose of the *motor starter* is not to start the machine, as the name implies, but to reduce heavy starting currents and provide overload and no-volt protection in accordance with the requirements of Regulations 552.

Motor starters

The magnetic flux generated in the stator of an induction motor rotates immediately the supply is switched on, and therefore the machine is self-starting. The purpose of the **motor starter** is not to start the machine, as the name implies, but to reduce heavy starting currents and provide overload and no-volt protection in accordance with the requirements of Regulations 552.

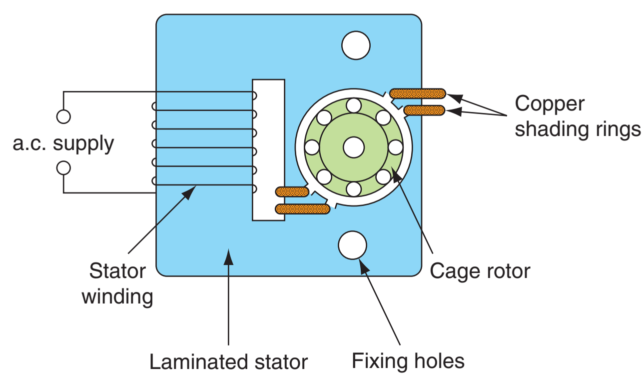


FIGURE 6.13
Shaded pole motor.

Thermal overload protection is usually provided by means of a bimetal strip bending under overload conditions and breaking the starter contactor coil circuit. This de-energizes the coil and switches off the motor under fault conditions such as overloading or single phasing. Once the motor has automatically switched off under overload conditions or because a remote stop/start button has been operated, it is an important safety feature that the motor cannot restart without the operator going through the normal start-up procedure. Therefore, no-volt protection is provided by incorporating the safety devices into the motor starter control circuit which energizes the contactor coil.

Electronic thermistors (thermal transistors) provide an alternative method of sensing if a motor is overheating (see Chapter 4 of this book). These tiny heat-sensing transistors, about the size of a matchstick head, are embedded in the motor windings to sense the internal temperature, and the thermistor either trips out the contactor coil as described above or operates an alarm.

All electric motors with a rating above 0.37 kW must be supplied from a suitable motor starter and we will now consider the more common types.

DIRECT ON LINE (D.O.L.) STARTERS

The d.o.l. starter switches the main supply directly on to the motor. Since motor starting currents can be seven or eight times greater than the running current, the d.o.l. starter is only used for small motors of less than about 5 kW rating.

When the start button is pressed current will flow from the brown line through the control circuit and contactor coil to the grey line which energizes the contactor coil and the contacts close, connecting the three-phase supply to the motor, as can be seen in Fig. 6.14. If the start button is released the control circuit is maintained by the hold on contact. If the

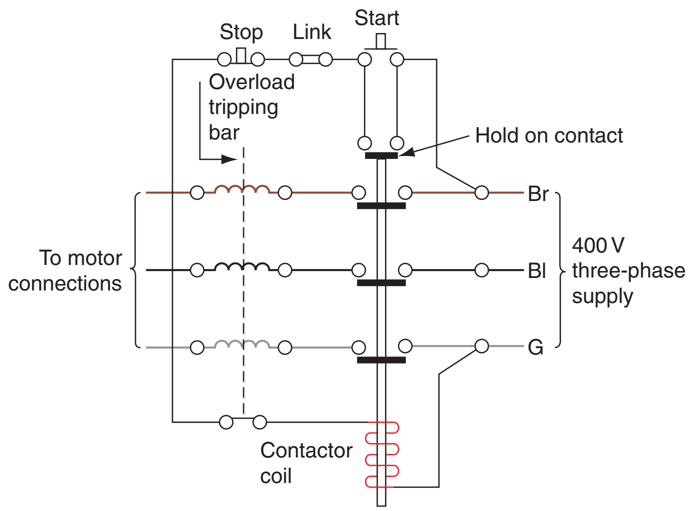


FIGURE 6.14
Three-phase d.o.l. starter.

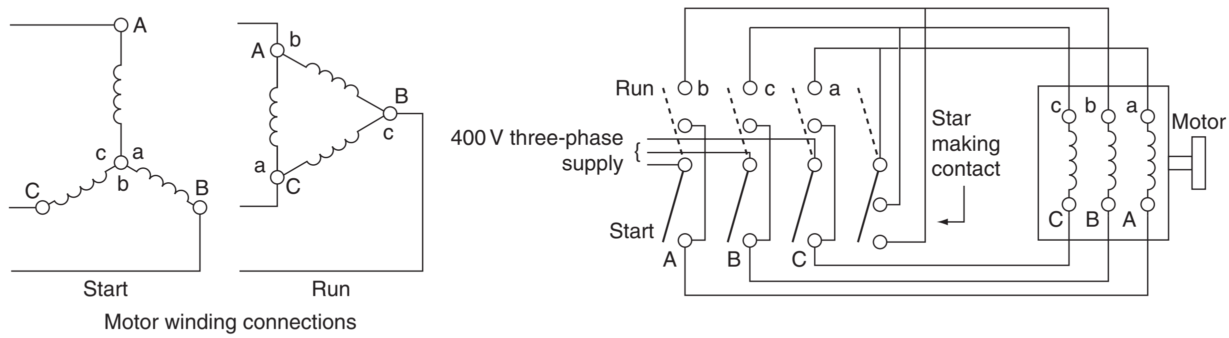


FIGURE 6.15
Star delta starter.

stop button is pressed or the overload coils operate, the control circuit is broken and the contractor drops out, breaking the supply to the load. Once the supply is interrupted the supply to the motor can only be reconnected by pressing the start button. Therefore this type of arrangement also provides no-volt protection.

When large industrial motors have to be started, a way of reducing the excessive starting currents must be found. One method is to connect the motor to a star delta starter.

STAR DELTA STARTERS

When three loads, such as the three windings of a motor, are connected in star, the line current has only one-third of the value it has when the same load is connected in delta. A starter which can connect the motor windings in star during the initial starting period and then switch to delta connection will reduce the problems of an excessive starting current. This arrangement is shown in Fig. 6.15, where the six connections to the three stator phase windings are brought out to the starter. For starting, the motor windings are star-connected at the a–b–c end of the winding by the star making contacts. This reduces the phase voltage to about 58% of the running voltage which reduces the current and the motor's torque. Once the motor is running a double-throw switch makes the changeover from star starting to delta running, thereby achieving a minimum starting current and maximum running torque. The starter will incorporate overload and no-volt protection, but these are not shown in Fig. 6.15 in the interests of showing more clearly the principle of operation.

AUTO-TRANSFORMER STARTER

An auto-transformer motor starter provides another method of reducing the starting current by reducing the voltage during the initial starting period. Since this also reduces the starting torque, the voltage is only reduced by a sufficient amount to reduce the starting current, being permanently connected to the tapping found to be most appropriate by the installing electrician. Switching the changeover switch to the start position connects the auto-transformer windings in series with the delta-connected motor starter winding. When sufficient speed has been achieved by the

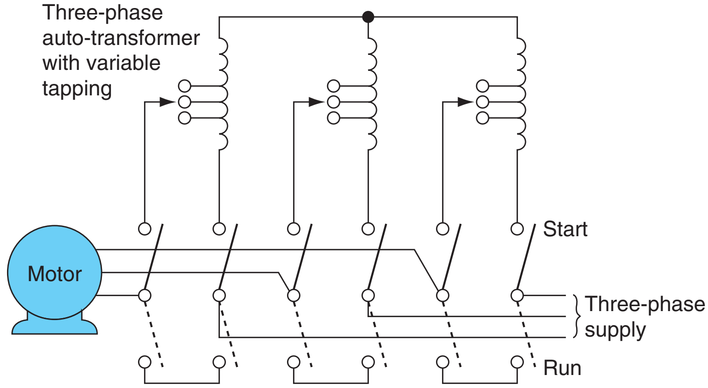


FIGURE 6.16
Auto-transformer starting.

motor the changeover switch is moved to the run connections which connect the three-phase supply directly on to the motor as shown in Fig. 6.16.

This starting method has the advantage of only requiring three connection conductors between the motor starter and the motor. The starter will incorporate overload and no-volt protection in addition to some method of preventing the motor being switched to the run position while the motor is stopped. These protective devices are not shown in Fig. 6.16 in order to show more clearly the principle of operation.

Key Fact

Shaded pole motors

- are very small motors,
- have a constant speed,
- use a cage rotor,
- are used in electric ovens, microwave ovens and fan heaters.

ROTOR RESISTANCE STARTER

When starting a machine on load a wound rotor induction motor must generally be used since this allows an external resistance to be connected to the rotor winding through slip-rings and brushes, which increases the starting torque as shown in Fig. 6.11 curve (c).

When the motor is first switched on the external rotor resistance is at a maximum. As the motor speed increases the resistance is reduced until at full speed the external resistance is completely cut out and the machine runs as a cage induction motor. The starter is provided with overload and no-volt protection and an interlock to prevent the machine being switched on with no rotor resistance connected, but these are not shown in Fig. 6.17 since the purpose of the diagram is to show the principle of operation.

Remote control of motors

When it is required to have stop/start control of a motor at a position other than the starter position, additional start buttons may be connected in parallel and additional stop buttons in series, as shown in Fig. 6.18 for the d.o.l. starter. This is the diagram shown in Fig. 6.14 with the link removed and a remote stop/start button connected. Additional stop and start facilities are often provided for the safety and convenience of the machine operator.

Installation of motors

Electric motors vibrate when running and should be connected to the electrical installation through a flexible connection. This may also make

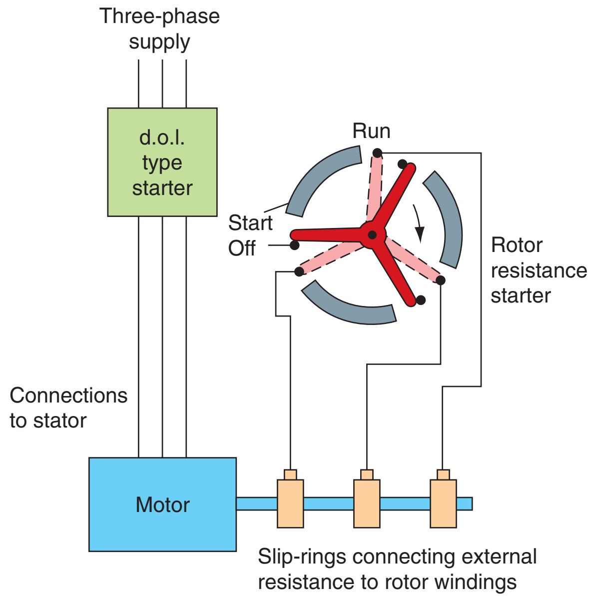


FIGURE 6.17
Rotor resistance starter for a wound rotor machine.

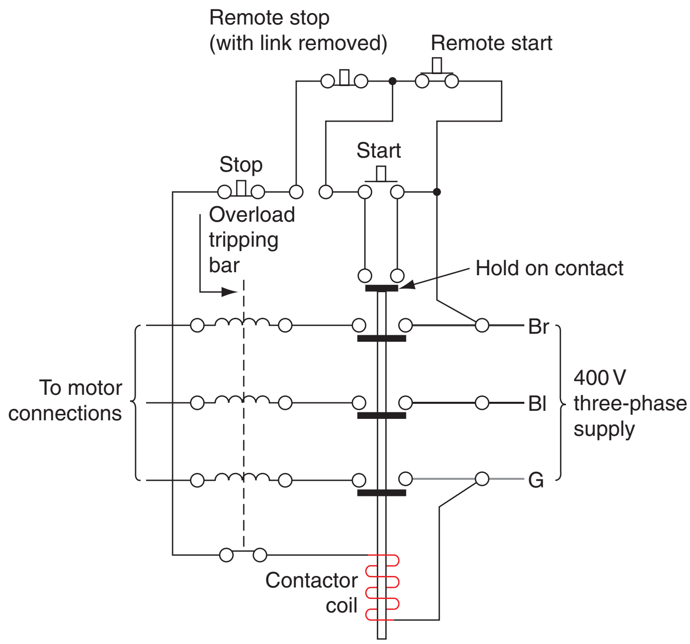


FIGURE 6.18
Remote stop/start connections to d.o.l. starter.

final adjustments of the motor position easier. Where the final connection is made with flexible conduit, the tube must not be relied upon to provide a continuous earth path and a separate circuit protective conductor (CPC) must be run either inside or outside the flexible conduit (Regulation 543.2.1).

All motors over 0.37 kW rating must be connected to the source of supply through a suitable starter which incorporates overload protection and a device which prevents dangerous restarting of the motor following a mains failure (Regulations 552.1.2 and 3).

The cables supplying the motor must be capable of carrying at least the full load current of the motor (Regulation 552.1.1) and a local means of isolation must be provided to facilitate safe mechanical maintenance (Regulations 537.2.1.2 and 537.3.1.1).

At the supply end, the motor circuit will be protected by a fuse or miniature circuit breaker (MCB). The supply protection must be capable of withstanding the motor starting current while providing adequate overcurrent protection. There must also be discrimination so that the overcurrent device in the motor starter operates first in the event of an excessive motor current.

Most motors are 'continuously rated'. This is the load at which the motor may be operated continuously without overheating.

Many standard motors have class A insulation which is suitable for operating in ambient temperatures up to about 55°C. If a class A motor is to be operated in a higher ambient temperature, the continuous rating may need to be reduced to prevent damage to the motor. The motor and its enclosure must be suitable for the installed conditions and must additionally prevent anyone coming into contact with the internal live or moving parts. Many different enclosures are used, depending upon the atmosphere in which the motor is situated. Clean air, damp conditions, dust particles in the atmosphere, chemical or explosive vapours will determine the type of motor enclosure. In high ambient temperatures it may be necessary to provide additional ventilation to keep the motor cool and prevent the lubricating oil thinning. The following motor enclosures are examples of those to be found in industry.

Safety First

Motors

- All electric motors over 0.37 kW must have a local means of isolation for safe mechanical maintenance.
- IEE Regulation 537.3.1.1

Screen protected enclosures prevent access to the internal live and moving parts by covering openings in the motor casing with metal screens of perforated metal or wire mesh. Air flow for cooling is not restricted and is usually assisted by a fan mounted internally on the machine shaft. This type of enclosure is shown in Fig. 6.19.

A duct ventilated enclosure is used when the air in the room in which the motor is situated is unsuitable for passing through the motor for cooling – for example, when the atmosphere contains dust particles or chemical vapour. In these cases the air is drawn from a clean air zone outside the room in which the machine is installed, as shown in Fig. 6.19.

A totally enclosed enclosure is one in which the air inside the machine casing has no connection with the air in the room in which it is installed, but it is not necessarily airtight. A fan on the motor shaft inside the casing circulates the air through the windings and cooling is by conduction through the motor casing. To increase the surface area and assist cooling, the casing is surrounded by fins, and an externally mounted fan can increase the flow of air over these fins. This type of enclosure is shown in Fig. 6.19.

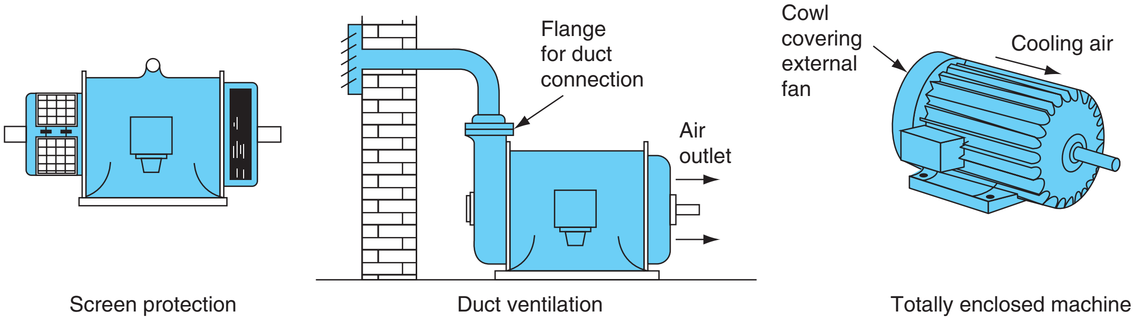


FIGURE 6.19
Motor enclosures.

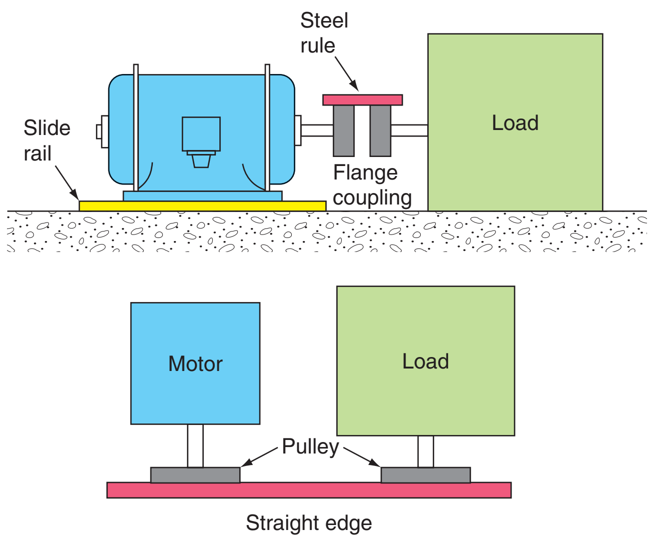


FIGURE 6.20
Pulley and flange coupling arrangement.

A flameproof enclosure requires that further modifications be made to the totally enclosed casing to prevent inflammable gases coming into contact with sparks or arcing inside the motor. To ensure that the motor meets the stringent regulations for flameproof enclosures the shaft is usually enclosed in special bearings and the motor connections contained by a wide flange junction box.

When a motor is connected to a load, either by direct coupling or by a vee belt, it is important that the shafts or pulleys are exactly in line. This is usually best achieved by placing a straight edge or steel rule across the flange coupling of a direct drive or across the flat faces of a pair of pulleys, as shown in Fig. 6.20. Since pulley belts stretch in use it is also important to have some means of adjusting the tension of the vee belt. This is usually achieved by mounting the motor on a pair of slide rails as shown in Fig. 6.21. Adjustment is carried out by loosening the motor fixing bolts, screwing in the adjusting bolts which push the motor back, and when the correct belt tension has been achieved the motor fixing bolts are tightened.

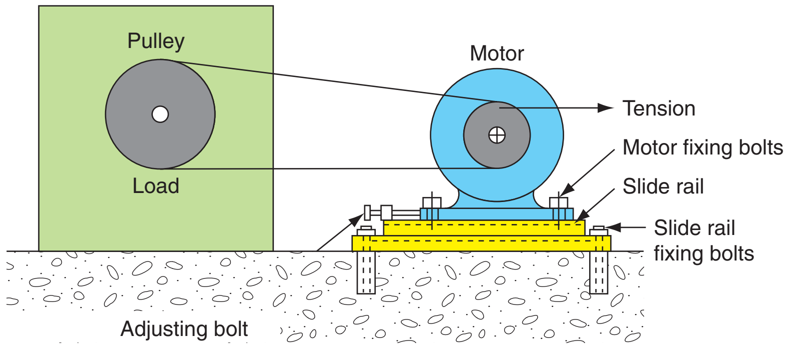


FIGURE 6.21
Vee belt adjustment of slide rail mounted motor.

Motor maintenance

All rotating machines are subject to wear, simply because they rotate. Motor fans which provide cooling also pull dust particles from the surrounding air into the motor enclosure. Bearings dry out, drive belts stretch and lubricating oils and greases require replacement at regular intervals. Industrial electric motors are often operated in a hot, dirty, dusty or corrosive environment for many years. If they are to give good and reliable service they must be suitable for the task and the conditions in which they must operate. Maintenance at regular intervals is required, in the same way that a motor car is regularly serviced.

Definition

The solid construction of the *cage rotor* used in many a.c. machines makes them almost indestructible.

The solid construction of the **cage rotor** used in many a.c. machines makes them almost indestructible, and, since there are no external connections to the rotor, the need for slip-rings and brushes is eliminated. These characteristics give cage rotor a.c. machines maximum reliability with the minimum of maintenance and make the induction motor the most widely used in industry. Often the only maintenance required with an a.c. machine is to lubricate in accordance with the manufacturer's recommendations.

However, where high torque and variable speed characteristics are required d.c. machines are often used. These require a little more maintenance than a.c. machines because the carbon brushes, rubbing on the commutator, wear down and require replacing. New brushes must be of the correct grade and may require 'bedding in' or shaping with a piece of fine abrasive cloth to the curve of the commutator.

The commutator itself should be kept clean and any irregularities smoothed out with abrasive cloth. As the commutator wears, the mica insulation between the segments must be cut back with an undercutting tool or a hacksaw blade to keep the commutator surface smooth. If the commutator has become badly worn, and a groove is evident, the armature will need to be removed from the motor, and the commutator turned in a lathe.

Motors vibrate when operating and as a result fixing bolts and connections should be checked as part of the maintenance operation. Where a motor drives a load via a pulley belt, the motor should be adjusted on the slider rails until there is about 10 mm of play in the belt.

Planning maintenance work with forethought and keeping records of work done with dates can have the following advantages:

- The maintenance is carried out when it is most convenient.
- Regular simple maintenance often results in less emergency maintenance.
- Regular servicing and adjustment maintain the plant and machines at peak efficiency.

The result of planned maintenance is often that fewer breakdowns occur, which result in loss of production time. Therefore, a planned maintenance programme must be a sensible consideration for any commercial operator.

Power-factor correction

Most electrical installations have a low p.f. because loads such as motors, transformers and discharge lighting circuits are inductive in nature and cause the current to lag behind the voltage. A capacitor has the opposite effect to an inductor, causing the current to lead the voltage. Therefore, by adding capacitance to an inductive circuit the bad p.f. can be corrected. The load current I_L is made up of an in-phase component I and a quadrature component I_Q. The p.f. can be corrected to unity when the capacitor current I_C is equal and opposite to the quadrature or reactive current I_Q of the inductive load. The quadrature or reactive current is responsible for setting up the magnetic field in an inductive circuit. Figure 6.22 shows the p.f. corrected to unity, that is when $I_Q = I_C$.

A low p.f. is considered a disadvantage because a given load takes more current at a low p.f. than it does at a high p.f. In Chapter 7 we calculated that a 1.84 kW load at unity p.f. took 8 A, but at a bad p.f. of 0.4 a current of 20 A was required to supply the same load.

The supply authorities discourage industrial consumers from operating at a bad p.f. because:

- larger cables and switchgear are necessary to supply a given load;
- larger currents give rise to greater copper losses in transmission cables and transformers;
- larger currents give rise to greater voltage drops in cables;

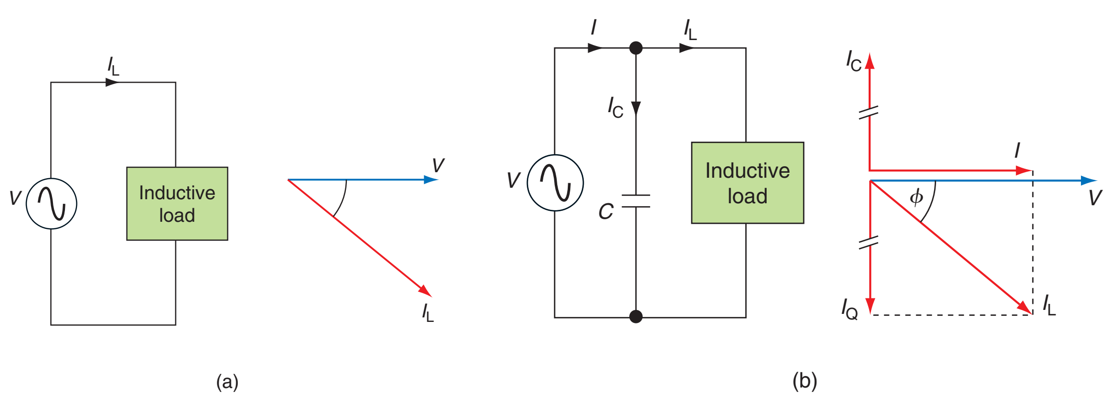


FIGURE 6.22

Power-factor correction of inductive load: (a) circuit and phasor diagram for an inductive load with low p.f.; (b) circuit and phasor diagram for (a) with capacitor correcting p.f. to unity.

- larger cables may be required on the consumer's side of the electrical installation to carry the larger currents demanded by a load operating with a bad p.f.

Bad p.f.s are corrected by connecting a capacitor either across the individual piece of equipment or across the main busbars of the installation. When individual capacitors are used they are usually of the paper dielectric type of construction (see Fig. 4.23 in Chapter 4). This is the type of capacitor used for p.f. correction in a fluorescent luminaire. When large banks of capacitors are required to correct the p.f. of a whole installation, paper dielectric capacitors are immersed in an oil tank in a similar type construction to a transformer, and connected on to the main busbars of the electrical installation by suitably insulated and mechanically protected cables.

The current to be carried by the capacitor for p.f. correction and the value of the capacitor may be calculated as shown by the following example.

Example

An 8 kW load with a p.f. of 0.7 is connected across a 400 V, 50 Hz supply. Calculate:

(a) the current taken by this load,
(b) the capacitor current required to raise the p.f. to unity,
(c) the capacitance of the capacitor required to raise the p.f. to unity.

$$\text{For (a), since } P = VI\cos\phi\ (W)$$

$$I = \frac{P}{V\cos\phi}\ (\text{A})$$

$$\therefore I = \frac{8000\,\text{W}}{400\,\text{V} \times 0.7} = 28.57\ (\text{A})$$

This current lags the voltage by an angle of 45.6° (since $\cos^{-1} 0.7 = 45.6°$) and can therefore be drawn to scale as shown in Fig. 6.23 and represented by line AB.

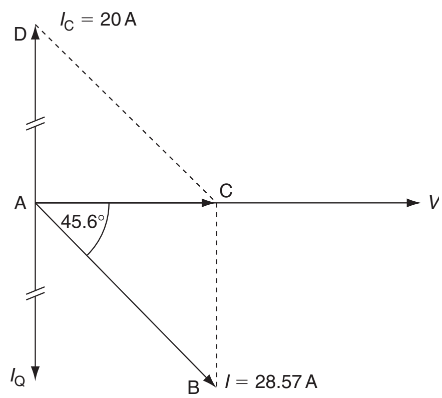


FIGURE 6.23
Phasor diagram.

For (b) at unity p.f. the current will be in phase with the voltage, represented by line AC in Fig. 6.23. To raise the load current to this value will require a capacitor current I_c which is equal and opposite to the value of the quadrature or reactive component I_Q. The value of I_Q is measured from the phasor diagram and found to be 20 A which is the value of the capacitor current required to raise the p.f. to unity and shown by line AD in Fig. 6.23.

For (c), since:

$$I_C = \frac{V}{X_C}\ (\text{A}) \quad \text{and} \quad X_C = \frac{V}{I_C}\ (\Omega)$$

$$\therefore X_C = \frac{400\,\text{V}}{20\,\text{A}} = 20\,\Omega$$

Since:

$$X_C = \frac{I}{2\pi fC}\ (\Omega) \quad \text{and} \quad C = \frac{I}{2\pi fX_C}\ (\text{F})$$

$$\therefore C = \frac{I}{2 \times \pi \times 50\,\text{Hz} \times 20\,\Omega} = 159\ \mu\text{F}$$

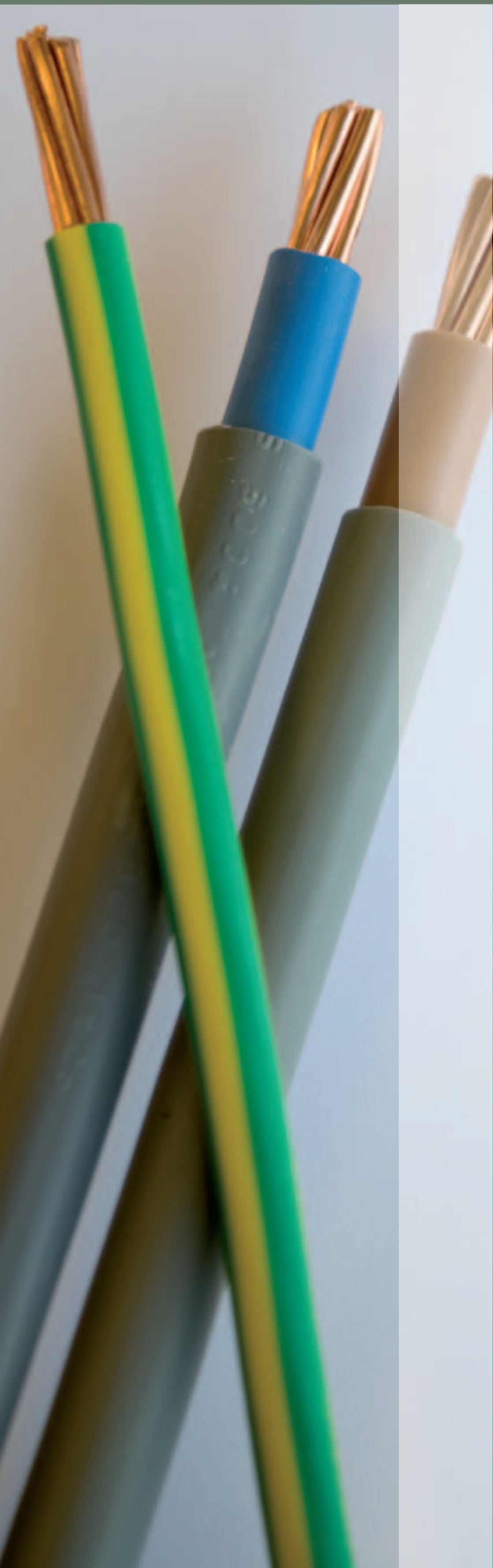
A 159 μF capacitor connected in parallel with the 8 kW load would correct the p.f. to unity.

Check your Understanding

When you have completed these questions, check out the answers at the back of the book.
Note: more than one multiple choice answer may be correct.

1. The series motor finds many applications such as:
    a. constant speed steel rolling mills
    b. electric hand drills
    c. electric trains and trams
    d. vacuum cleaners.
2. The compound motor finds applications such as:
    a. constant speed steel rolling mills
    b. electric hand drills
    c. electric trains and trams
    d. vacuum cleaners.
3. The advantage of a d.c. machine is:
    a. it is easy to control the speed
    b. it runs at an almost constant speed
    c. it requires little maintenance
    d. it is practically indestructible.
4. The advantage of a cage rotor induction motor is:
    a. it is easy to control the speed
    b. it runs at an almost constant speed
    c. it requires little maintenance
    d. it is practically indestructible.
5. A cage rotor induction motor finds applications operating:
    a. electric oven fans and fan heaters
    b. pumps and fans in industry
    c. refrigerators and washing machines
    d. trains and trams.
6. A split-phase a.c. motor finds applications operating:
    a. electric oven fans and fan heaters
    b. pumps and fans in industry
    c. refrigerators and washing machines
    d. trains and trams.

7. A shaded pole motor finds applications operating:
    a. electric oven fans and fan heaters
    b. pumps and fans in industry
    c. refrigerators and washing machines
    d. trains and trams.
8. The purpose of the motor starter connected to an electric motor is:
    a. to start the motor
    b. to reduce high starting currents
    c. to provide overload protection
    d. to provide no-volt protection.
9. A capacitor connected in parallel with an electric motor provides:
    a. improved starting
    b. motor speed control
    c. power-factor correction
    d. safe mechanical maintenance.
10. Use bullet points and a sketch to describe how a three-phase a.c. supply connected to the stator winding of an induction motor causes the rotor shaft to turn around. (You might want to look at Fig. 6.9.)
11. Use a simple sketch to explain how a turning force is exerted upon the armature winding of a d.c. motor. (You might want to look at Fig. 6.1.)
12. Very briefly describe how a three-phase supply produces a rotating magnetic flux in an induction motor.
13. Use a labelled sketch to describe the construction of a cage rotor.
14. Why is a cage rotor practically indestructible?
15. Why does a wound rotor or armature winding require maintenance of the commutator and carbon brushes.
16. Briefly describe how a centrifugal switch works.
17. Briefly describe why a centrifugal switch is required in a single-phase a.c. motor.



18. List three types of single-phase a.c. motors and give one application for each type.

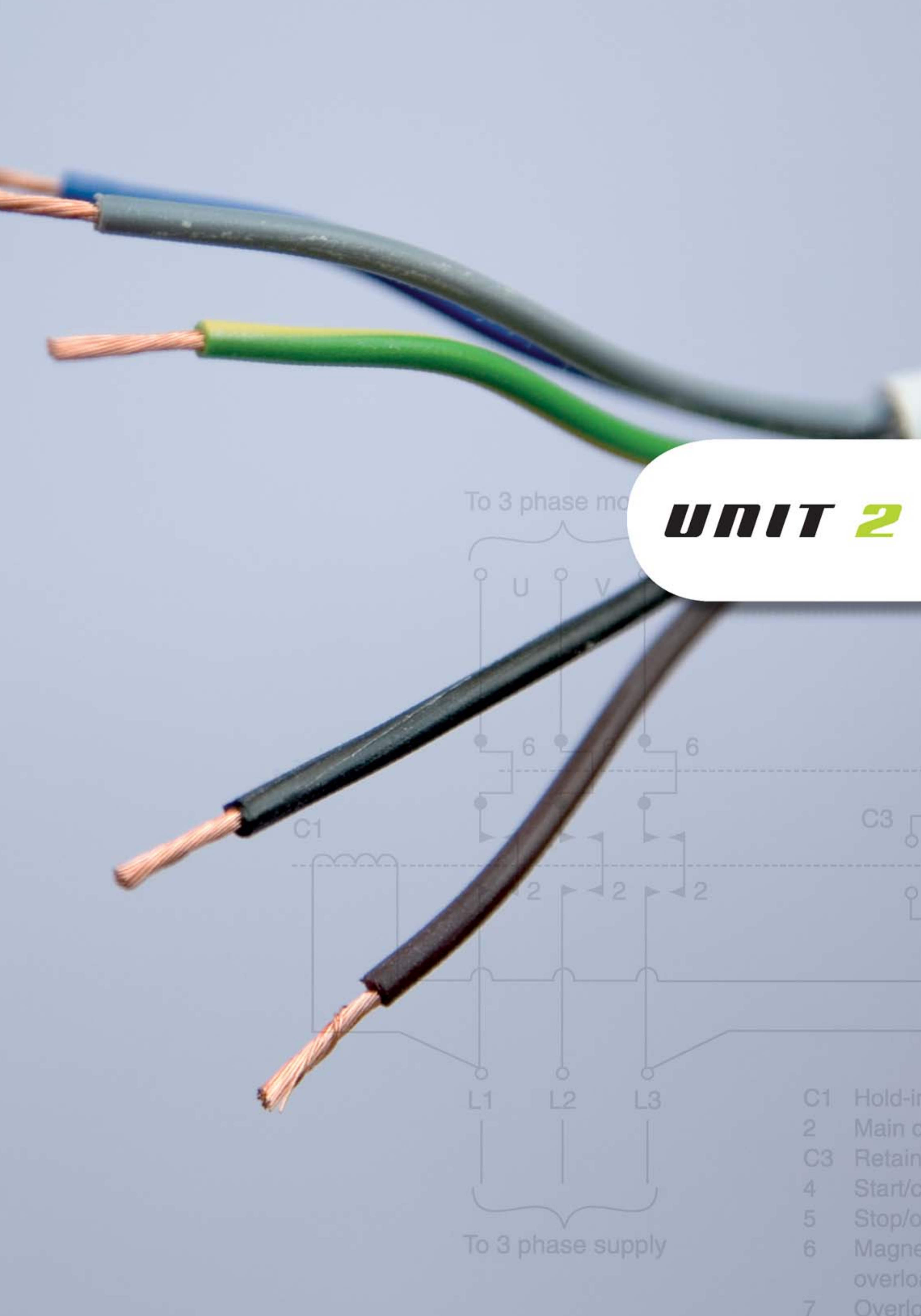
19. List three things that a motor starter does.

20. Which electric motors require a motor starter?

21. Section 552 of the IEE Regulations – Rotating Machines – list five Regulations in this section. Very briefly state the requirements of each Regulation.

22. Why is p.f. improvement necessary for motor circuits?

UNIT 2



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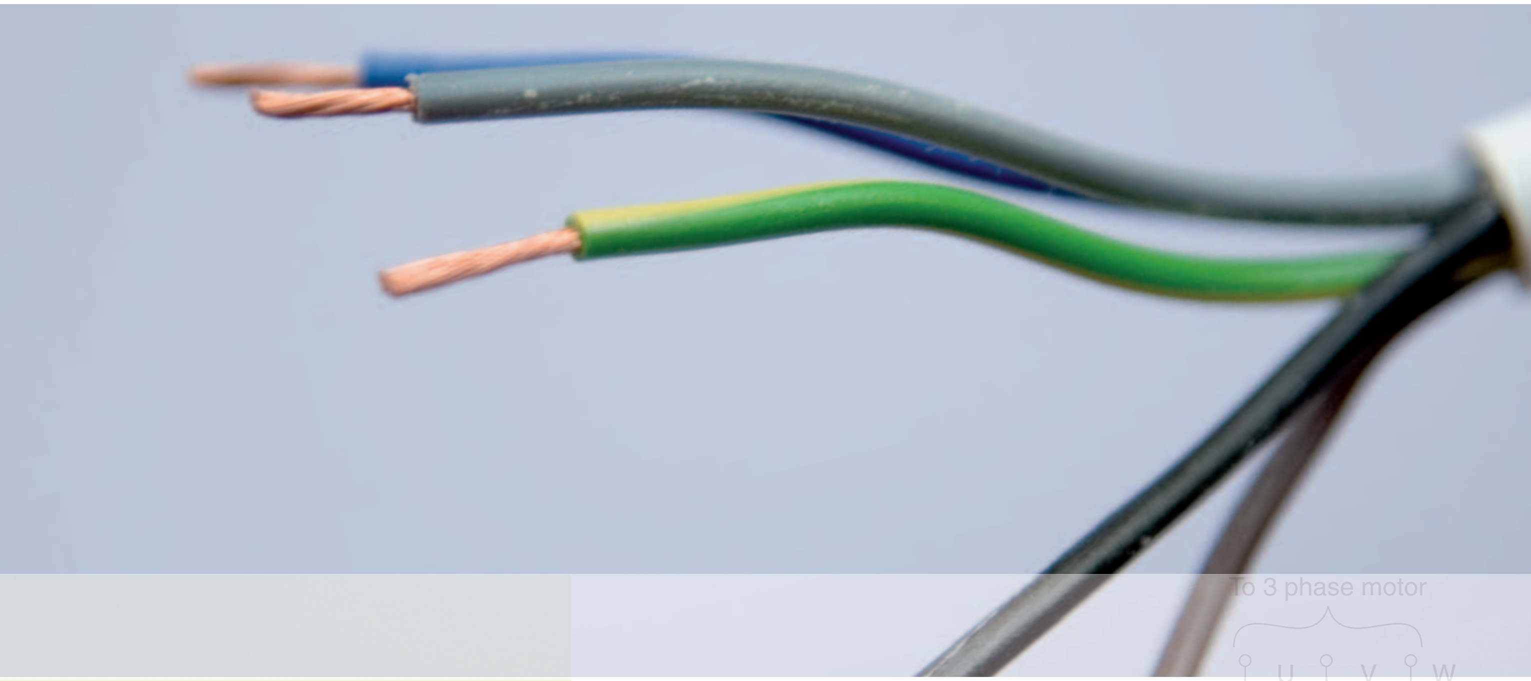
CH 7

Safe, effective and efficient working practices



Unit 2 – Installation (buildings and structures): inspection, testing and commissioning – Outcome 1

Underpinning knowledge: when you have completed this chapter you should be able to:

- describe the procedures or activities necessary to make an area safe before work commences
- describe four installation work activities
- identify the parties involved in installation activities and their relationships
- state the management systems used to monitor contract progress
- state the systems, equipment and procedures which create a safe electrical installation
- describe the supply system earthing arrangements
- describe an installation overcurrent protection equipment
- state the factors affecting the selection of conductors

Those involved with installation activities

An electrician working for an electrical contracting company works as a part of the broader construction industry. This is a multi-million-pound industry carrying out all types of building work, from basic housing to hotels, factories, schools, shops, offices and airports. The construction industry is one of the UK's biggest employers, and carries out contracts to the value of about 10% of the UK's gross national product.

Although a major employer, the construction industry is also very fragmented. Firms vary widely in size, from the local builder employing two or three people to the big national companies employing thousands. Of the total workforce of the construction industry, 92% are employed in small firms of less than 25 people.

The yearly turnover of the construction industry is about £35 billion. Of this total sum, about 60% is spent on new building projects and the remaining 40% on maintenance, renovation or restoration of mostly housing.

In all these various construction projects the electrotechnical industries play an important role, supplying essential electrical services to meet the needs of those who will use the completed building.

The building team

The construction of a new building is a complex process which requires a team of professionals working together to produce the desired results. We can call this team of professionals the building team, and their interrelationship can be expressed as in Fig. 7.1.

The client is the person or group of people with the actual need for the building, such as a new house, office or factory. The client is responsible for financing all the work and, therefore, in effect, employs the entire building team.

The architect is the client's agent and is considered to be the leader of the building team. The architect must interpret the client's requirements and produce working drawings. During the building process the architect will supervise all aspects of the work until the building is handed over to the client.

The quantity surveyor measures the quantities of labour and material necessary to complete the building work from drawings supplied by the architect.

Specialist engineers advise the architect during the design stage. They will prepare drawings and calculations on specialist areas of work.

The clerk of works is the architect's 'on-site' representative. He or she will make sure that the contractors carry out the work in accordance with the drawings and other contract documents. They can also agree general matters directly with the building contractor as the architect's representative.

The local authority will ensure that the proposed building conforms to the relevant planning and building legislation.

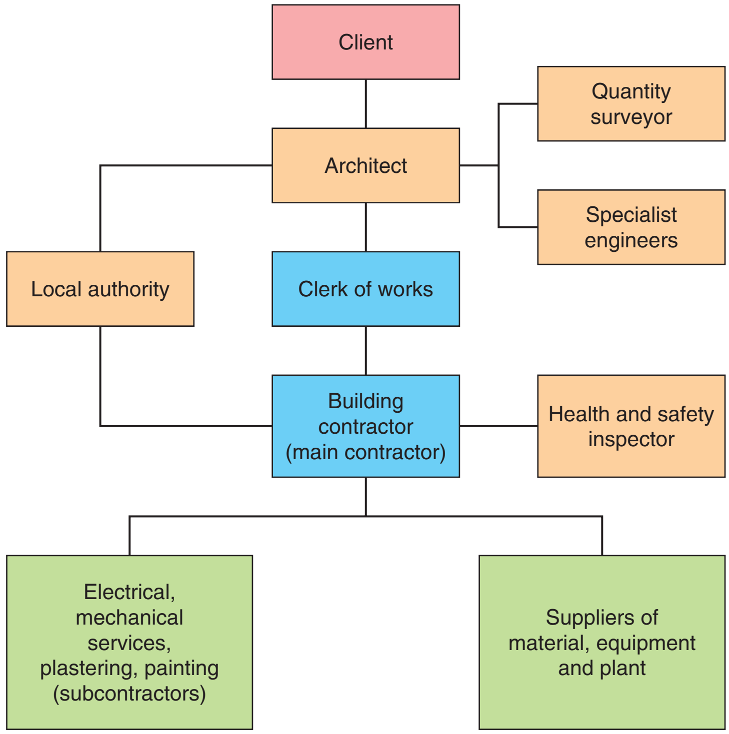


FIGURE 7.1
The building team.

The health and safety inspectors will ensure that the government's legislation concerning health and safety is fully implemented by the building contractor.

The building contractor will enter into a contract with the client to carry out the construction work in accordance with contract documents. The building contractor is usually the main contractor and he or she, in turn, may engage sub-contractors to carry out specialist services such as electrical installation, mechanical services, plastering and painting.

The electrical team

The electrical contractor is the sub-contractor responsible for the installation of electrical equipment within the building.

Electrical installation activities include:

- installing electrical equipment and systems into new sites or locations;
- installing electrical equipment and systems into buildings that are being refurbished because of change of use;
- installing electrical equipment and systems into buildings that are being extended or updated;
- replacement, repairs and maintenance of existing electrical equipment and systems.

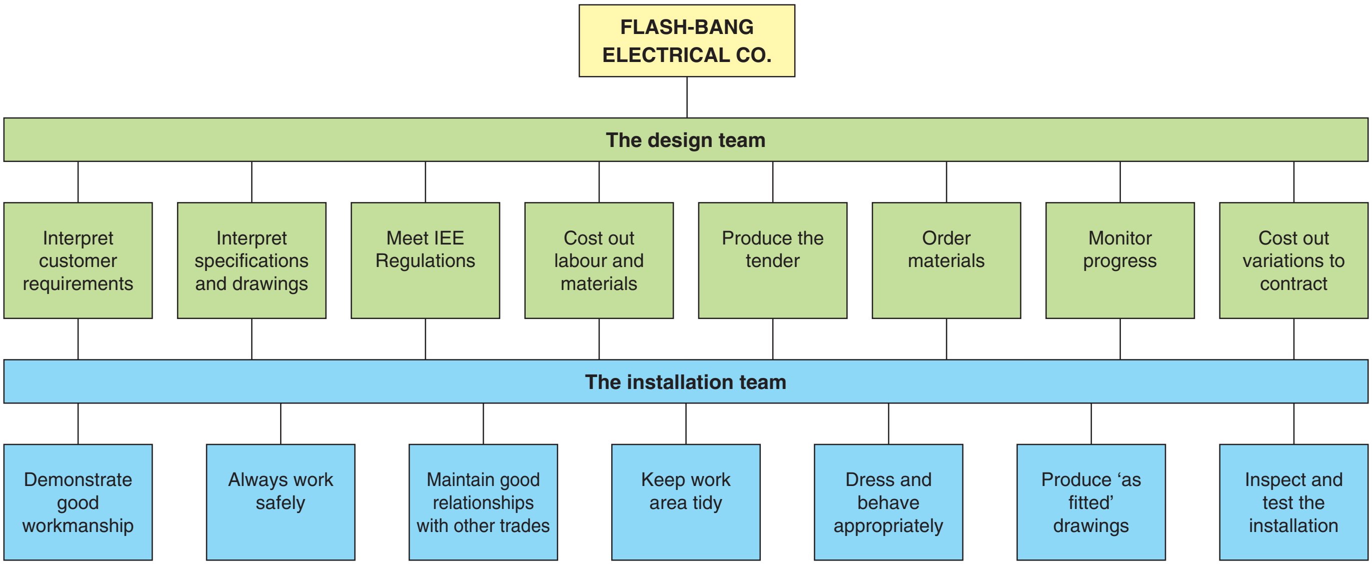


FIGURE 7.2
The electrical team.

Try This

My Team

Sketch a block diagram, similar to those shown in Figs 7.1 and 7.2, that represents the team in which you work.

An electrical contracting firm is made up of a group of individuals with varying duties and responsibilities. There is often no clear distinction between the duties of the individuals, and the responsibilities carried by an employee will vary from one employer to another. If the firm is to be successful, the individuals must work together to meet the requirements of their customers. Good customer relationships are important for the success of the firm and the continuing employment of the employee.

The customer or his representatives will probably see more of the electrician and the electrical trainee than the managing director of the firm and, therefore, the image presented by them is very important. They should always be polite and seen to be capable and in command of the situation. This gives a customer confidence in the firm's ability to meet his or her needs. The electrician and his trainee should be appropriately dressed for the job in hand, which probably means an overall of some kind. Footwear is also important, but sometimes a difficult consideration for a journeyman electrician. For example, if working in a factory, the safety regulations may insist that protective footwear be worn, but rubber boots may be most appropriate for a building site. However, neither of these would be the most suitable footwear for an electrician fixing a new light fitting in the home of the managing director!

The electrical installation in a building is often carried out alongside other trades. It makes sound sense to help other trades where possible and to develop good working relationships with other employees.

The employer has the responsibility of finding sufficient work for his employees, paying government taxes and meeting the requirements of the Health and Safety at Work Act described in Chapter 1. The rates of pay and conditions for electricians and trainees are determined by negotiation between the Joint Industry Board and the AMICUS Union, which will also represent their members in any disputes. Electricians are usually paid at a rate agreed for their grade as an electrician, approved electrician or technician electrician; movements through the grades are determined by a combination of academic achievement and practical experience.

The electrical team will consist of a group of professionals and their interrelationship can be expressed as shown in Fig. 7.2.

Designing an electrical installation

Definition

The *designer* of any electrical installation is the person who interprets the electrical requirements of the customer within the regulations.

The designer of an electrical installation must ensure that the design meets the requirements of the IEE Wiring Regulations for electrical installations and any other regulations which may be relevant to a particular installation. The designer may be a professional technician or engineer whose job is to design electrical installations for a large contracting firm. In a smaller firm, the designer may also be the electrician who will carry out the installation to the customer's requirements. The **designer** of any electrical installation is the person who interprets the electrical requirements of the customer within the regulations, identifies the appropriate types of installation, the most suitable methods of protection and control and the size of cables to be used.

A large electrical installation may require many meetings with the customer and his professional representatives in order to identify a specification of what is required. The designer can then identify the general characteristics of the electrical installation and its compatibility with other services and equipment, as indicated in Part 3 of the Regulations. The protection and safety of the installation, and of those who will use it, must be considered, with due regard to Part 4 of the Regulations. An assessment of the frequency and quality of the maintenance to be expected will give an indication of the type of installation which is most appropriate.

Definition

The size and quantity of all the materials, cables, control equipment and accessories can then be determined. This is called a '*bill of quantities*'.

The size and quantity of all the materials, cables, control equipment and accessories can then be determined. This is called a '**bill of quantities**'.

It is a common practice to ask a number of electrical contractors to tender or submit a price for work specified by the bill of quantities. The contractor must cost all the materials, assess the labour cost required to install the materials and add on profit and overhead costs in order to arrive at a final estimate for the work. The contractor tendering the lowest cost is usually, but not always, awarded the contract.

To complete the contract in the specified time the electrical contractor must use the management skills required by any business to ensure that men and materials are on site as and when they are required. If alterations or modifications are made to the electrical installation as the work proceeds which are outside the original specification, then a **variation order** must be issued so that the electrical contractor can be paid for the additional work.

The specification for the chosen wiring system will be largely determined by the building construction and the activities to be carried out in the completed building.

An industrial building, for example, will require an electrical installation which incorporates flexibility and mechanical protection. This can be achieved by a conduit, tray or trunking installation.

In a block of purpose-built flats, all the electrical connections must be accessible from one flat without intruding upon the surrounding flats. A loop-in conduit system, in which the only connections are at the light switch and outlet positions, would meet this requirement.

For a domestic electrical installation an appropriate lighting scheme and multiple socket outlets for the connection of domestic appliances, all at a reasonable cost, are important factors which can usually be met by a PVC insulated and sheathed wiring system.

The final choice of a wiring system must rest with those designing the installation and those ordering the work, but whatever system is employed, good workmanship by competent persons is essential for compliance with the regulations (IEE Regulation 134.1.1). The necessary skills can be acquired by an electrical trainee who has the correct attitude and dedication to his craft.

Legal contracts

Before work commences, some form of legal contract should be agreed between the two parties, that is, those providing the work (e.g. the subcontracting electrical company) and those asking for the work to be carried out (e.g. the main building company).

A contract is a formal document which sets out the terms of agreement between the two parties. A standard form of building contract typically contains four sections:

1. *The articles of agreement* – this names the parties, the proposed building and the date of the contract period.
2. *The contractual conditions* – this states the rights and obligations of the parties concerned, for example, whether there will be interim payments for work completed, or a penalty if work is not completed on time.
3. *The appendix* – this contains details of costings, for example, the rate to be paid for extras as daywork, who will be responsible for defects, how much of the contract tender will be retained upon completion and for how long.
4. *The supplementary agreement* – this allows the electrical contractor to recoup any value-added tax paid on materials at interim periods.

In signing the contract, the electrical contractor has agreed to carry out the work to the appropriate standards in the time stated and for the agreed cost. The other party, say the main building contractor, is agreeing to pay the price stated for that work upon completion of the installation.

If a dispute arises the contract provides written evidence of what was agreed and will form the basis for a solution.

For smaller electrical jobs, a verbal contract may be agreed, but if a dispute arises there is no written evidence of what was agreed and it then becomes a matter of one person's word against another's.

Effective and efficient management systems

Smaller electrical contracting firms will know where their employees are working and what they are doing from day to day because of the level of personal contact between the employer, employee and customer.

As a firm expands and becomes engaged on larger contracts, it becomes less likely that there is anyone in the firm with a complete knowledge of the firm's operations, and there arises an urgent need for sensible management and planning skills so that men and materials are on site when they are required and a healthy profit margin is maintained.

When the electrical contractor is told that he has been successful in tendering for a particular contract he is committed to carrying out the necessary work within the contract period. He must therefore consider:

- by what date the job must be finished;
- when the job must be started if the completion date is not to be delayed;
- how many men will be required to complete the contract;
- when certain materials will need to be ordered;
- when the supply authorities must be notified that a supply will be required;
- if it is necessary to obtain authorization from a statutory body for any work to commence.

In thinking ahead and planning the best method of completing the contract, the individual activities or jobs must be identified and consideration given to how the various jobs are interrelated. To help in this process a number of management techniques are available. In this chapter we will consider only two: bar charts and network analysis. The very preparation of a bar chart or network analysis forces the contractor to think deeply, carefully and logically about the particular contract, and it is therefore a very useful aid to the successful completion of the work.

Definition

There are many different types of bar chart used by companies but the *object of any bar chart* is to establish the sequence and timing of the various activities involved in the contract as a whole.

BAR CHARTS

There are many different types of bar chart used by companies but the object of any bar chart is to establish the sequence and timing of the various activities involved in the contract as a whole. They are a visual aid in the process of communication. In order to be useful they must be clearly understood by the people involved in the management of a contract. The chart is constructed on a rectangular basis, as shown in Fig. 7.3.

All the individual jobs or activities which make up the contract are identified and listed separately down the vertical axis on the left-hand side, and time flows from left to right along the horizontal axis. The unit of time can be chosen to suit the length of the particular contract, but for most practical purposes either days or weeks are used.

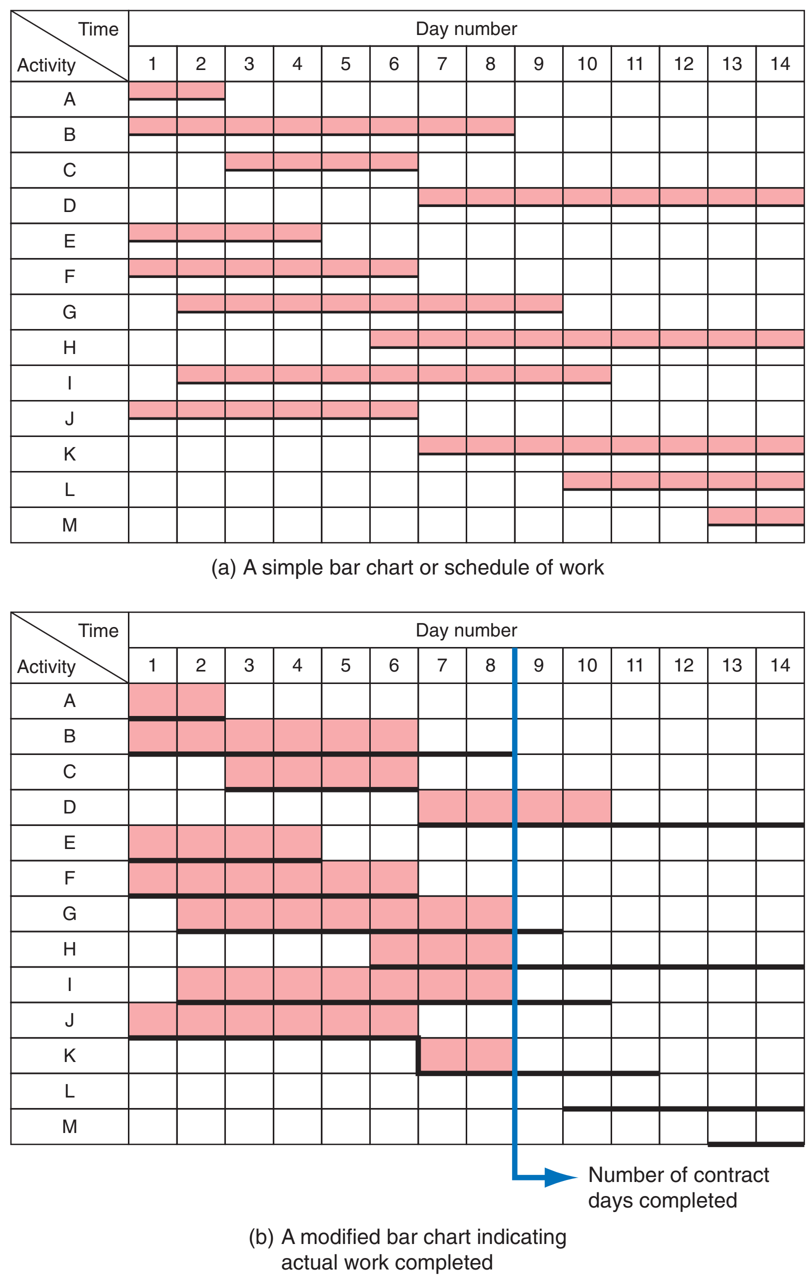


FIGURE 7.3
Bar charts: (a) a simple bar chart or schedule of work; (b) a modified bar chart indicating actual work completed.

The simple bar chart shown in Fig. 7.3(a) shows a particular activity A which is estimated to last 2 days, while activity B lasts 8 days. Activity C lasts 4 days and should be started on day 3. The remaining activities can be interpreted in the same way.

With the aid of colours, codes, symbols and a little imagination, much additional information can be included on this basic chart. For example, the actual work completed can be indicated by shading above the activity line as shown in Fig. 7.3(b) with a vertical line indicating the number of contract days completed; the activities which are on time, ahead of or behind time can easily be identified. Activity B in Fig. 7.3(b) is 2 days behind schedule, while activity D is 2 days ahead of schedule. All other activities are on time. Some activities must be completed before others can start. For example, all conduit work must be completely erected before the cables are drawn in. This is shown in Fig. 7.3(b) by activities J and K. The short vertical line between the two activities indicates that activity J must be completed before K can commence.

Useful and informative as the bar chart is, there is one aspect of the contract which it cannot display. It cannot indicate clearly the interdependence of the various activities upon each other, and it is unable to identify those activities which must strictly adhere to the time schedule if the overall contract is to be completed on time, and those activities in which some flexibility is acceptable. To overcome this limitation, in 1959 the Central Electricity Generating Board (CEGB) developed the critical path network diagram which we will now consider.

NETWORK ANALYSIS

Definition

A *network diagram* can be used to co-ordinate all the interrelated activities of the most complex project.

In large or complex contracts there are a large number of separate jobs or activities to be performed. Some can be completed at the same time, while others cannot be started until others are completed. A **network diagram** can be used to co-ordinate all the interrelated activities of the most complex project in such a way that all sequential relationships between the various activities, and the restraints imposed by one job on another, are allowed for. It also provides a method of calculating the time required to complete an individual activity and will identify those activities which are the key to meeting the completion date, called the critical path. Before considering the method of constructing a network diagram, let us define some of the terms and conventions we shall be using.

Definition

Critical path is the path taken from the start event to the end event which takes the longest time.

Critical path

Critical path is the path taken from the start event to the end event which takes the longest time. This path denotes the time required for completion of the whole contract.

Definition

Float time, slack time or time in hand is the time remaining to complete the contract after completion of a particular activity.

Float time

Float time, slack time or time in hand is the time remaining to complete the contract after completion of a particular activity.

$$\text{Float time} = \text{Critical path time} - \text{Activity time}$$

The total float time for any activity is the total leeway available for all activities in the particular path of activities in which it appears. If the float time is used up by one of the early activities in the path, there will be no float left for the remaining activities and they will become critical.

Definition

Activities are represented by an arrow, the tail of which indicates the commencement, and the head the completion of the activity.

ACTIVITIES

Activities are represented by an arrow, the tail of which indicates the commencement, and the head the completion of the activity. The length and direction of the arrows have no significance: they are not vectors or phasors. Activities require time, manpower and facilities. They lead up to or emerge from events.

Definition

Dummy activities are represented by an arrow with a dashed line.

DUMMY ACTIVITIES

Dummy activities are represented by an arrow with a dashed line. They signify a logical link only, require no time and denote no specific action or work.

Definition

An *event* is a point in time, a milestone or stage in the contract when the preceding activities are finished.

EVENT

An **event** is a point in time, a milestone or stage in the contract when the preceding activities are finished. Each activity begins and ends in an event. An event has no time duration and is represented by a circle which sometimes includes an identifying number or letter.

Time may be recorded to a horizontal scale or shown on the activity arrows. For example, the activity from event A to B takes 9 hours in the network diagram shown in Fig. 7.4.

Example 1

Identify the three possible paths from the start event A to the finish event F for the contract shown by the network diagram in Fig. 7.4. Identify the critical path and the float time in each path.

The three possible paths are:

1. event A–B–D–F
2. event A–C–D–F
3. event A–C–E–F.

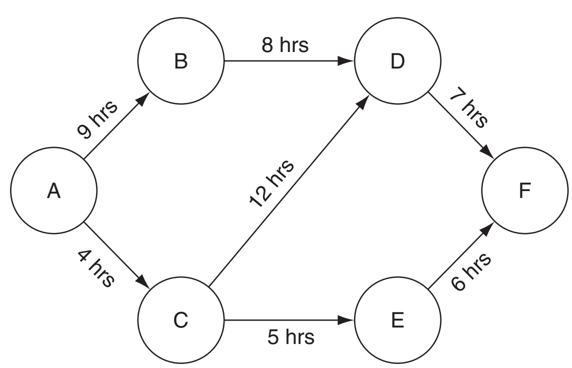


FIGURE 7.4
A network diagram for Example 1.

The times taken to complete these activities are:

1. path A–B–D–F = 9 + 8 + 7 = 24 hours
2. path A–C–D–F = 4 + 12 + 7 = 23 hours
3. path A–C–E–F = 4 + 5 + 6 = 15 hours.

The longest time from the start event to the finish event is 24 hours, and therefore the critical path is A–B–D–F.

The float time is given by:

$$\text{Float time} = \text{Critical path} - \text{Activity time}$$

For path 1, A–B–D–F,

$$\text{Float time} = 24 \text{ hours} - 24 \text{ hours} = 0 \text{ hours}$$

There can be no float time in any of the activities which form a part of the critical path since a delay on any of these activities would delay completion of the contract. On the other two paths some delay could occur without affecting the overall contract time. For path 2, A–C–D–F,

$$\text{Float time} = 24 \text{ hours} - 23 \text{ hours} = 1 \text{ hour}$$

For path 3, A–C–E–F,

$$\text{Float time} = 24 \text{ hours} - 15 \text{ hours} = 9 \text{ hours}$$

Example 2

Identify the time taken to complete each activity in the network diagram shown in Fig. 7.5. Identify the three possible paths from the start event A to the final event G and state which path is the critical path.

The time taken to complete each activity using the horizontal scale is:

activity A–B = 2 days
activity A–C = 3 days
activity A–D = 5 days
activity B–E = 5 days
activity C–F = 5 days
activity E–G = 3 days
activity D–G = 0 days
activity F–G = 0 days

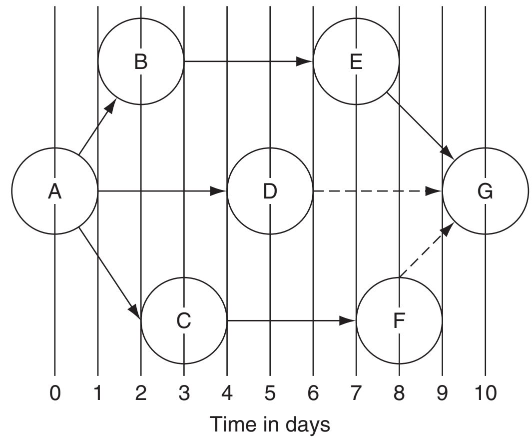


FIGURE 7.5
A network diagram for Example 2.

Activities D–G and F–G are dummy activities which take no time to complete but indicate a logical link only. This means that in this case once the activities preceding events D and F have been completed, the contract will not be held up by work associated with these particular paths and they will progress naturally to the finish event.

The three possible paths are:

1. A–B–E–G
2. A–D–G
3. A–C–F–G.

The times taken to complete the activities in each of the three paths are:

path 1, A–B–E–G = 2 + 5 + 3 = 10 days
path 2, A–D–G = 5 + 0 = 5 days
path 3, A–C–F–G = 3 + 5 + 0 = 8 days.

The critical path is path 1, A–B–E–G.

CONSTRUCTING A NETWORK

The first step in constructing a network diagram is to identify and draw up a list of all the individual jobs, or activities, which require time for their completion and which must be completed to advance the contract from start to completion.

The next step is to build up the arrow network showing schematically the precise relationship of the various activities between the start and end event. The designer of the network must ask these questions:

1. Which activities must be completed before others can commence? These activities are then drawn in a similar way to a series circuit but with event circles instead of resistor symbols.
2. Which activities can proceed at the same time? These can be drawn in a similar way to parallel circuits but with event circles instead of resistor symbols.

Commencing with the start event at the left-hand side of a sheet of paper, the arrows representing the various activities are built up step by step until the final event is reached. A number of attempts may be necessary to achieve a well-balanced and symmetrical network diagram showing the best possible flow of work and information, but this time is well spent when it produces a diagram which can be easily understood by those involved in the management of the particular contract.

Example 3

A particular electrical contract is made up of activities A–F as described below:

A = an activity taking 2 weeks commencing in week 1
B = an activity taking 3 weeks commencing in week 1
C = an activity taking 3 weeks commencing in week 4
D = an activity taking 4 weeks commencing in week 7
E = an activity taking 6 weeks commencing in week 3
F = an activity taking 4 weeks commencing in week 1.

Certain constraints are placed on some activities because of the availability of men and materials and because some work must be completed before other work can commence as follows:

Activity C can only commence when B is completed.
Activity D can only commence when C is completed.
Activity E can only commence when A is completed.
Activity F does not restrict any other activity.

(a) Produce a simple bar chart to display the activities of this particular contract.
(b) Produce a network diagram of the programme and describe each event.
(c) Identify the critical path and the total contract time.
(d) State the maximum delay which would be possible on activity E without delaying the completion of the contract.
(e) State the float time in activity F.

(a) A simple bar chart for this contract is shown in Fig. 7.6(a).
(b) The network diagram is shown in Fig. 7.6(b). The events may be described as follows:
Event 1 = the commencement of the contract.
Event 2 = the completion of activity A and the commencement of activity E.
Event 3 = the completion of activity B and the commencement of activity C.
Event 4 = the completion of activity F.
Event 5 = the completion of activity E.
Event 6 = the completion of activity C.
Event 7 = the completion of activity D and the whole contract.

(c) There are three possible paths:
1 via events 1–2–5–7
2 via events 1–4–7
3 via events 1–3–6–7.

The time taken for each path is:

path 1 = 2 weeks + 6 weeks = 8 weeks
path 2 = 4 weeks = 4 weeks
path 3 = 3 weeks + 3 weeks + 4 weeks = 10 weeks.

The critical path is therefore path 3, via events 1–3–6–7, and the total contract time is 10 weeks.

(d) We have that:

Float time = Critical path time − Activity time

Activity E is on path 1 via events 1–2–5–7 having a total activity time of 8 weeks.

Float time = 10 weeks − 8 weeks = 2 weeks.

Activity E could be delayed for a maximum of 2 weeks without delaying the completion date of the whole contract.

(e) Activity F is on path 2 via events 1–4–7 having a total activity time of 4 weeks.

Float time = 10 weeks − 4 weeks = 6 weeks.

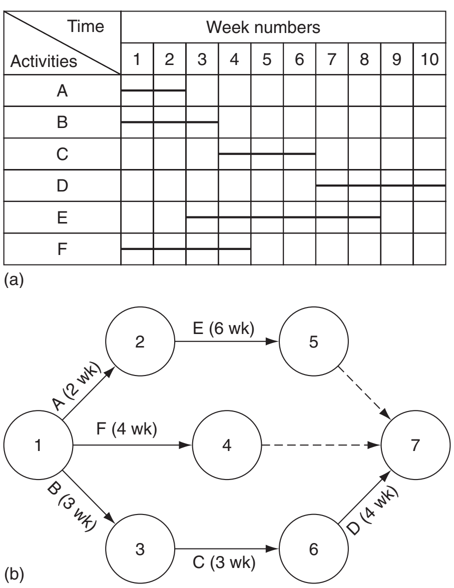


FIGURE 7.6
(a) Bar chart and (b) network diagram for Example 3.

On-site communications

Good communication is about transferring information from one person to another. Electricians and other professionals in the construction trades communicate with each other and the general public by means of drawings, sketches and symbols in addition to what we say and do.

DRAWINGS AND DIAGRAMS

Many different types of electrical drawing and diagram can be identified: layout, schematic, block, wiring and circuit diagrams. The type of diagram to be used in any particular application is the one which most clearly communicates the desired information.

LAYOUT DRAWINGS OR SITE PLAN

Definition

These are scale drawings based upon the architect's site plan of the building and show the positions of the electrical equipment which is to be installed.

These are scale drawings based upon the architect's site plan of the building and show the positions of the electrical equipment which is to be installed. The electrical equipment is identified by a graphical symbol.

The standard symbols used by the electrical contracting industry are those recommended by the British Standard BS EN 60617, *Graphical Symbols for Electrical Power, Telecommunications and Electronic Diagrams*. Some of the more common electrical installation symbols are given in Fig. 7.7.

The site plan or layout drawing will be drawn to a scale, smaller than the actual size of the building, so to find the actual measurements you must measure the distance on the drawing and then multiply by the scale.

For example, if the site plan is drawn to a scale of 1:100, then 10 mm on the site plan represents 1 m measured in the building.

A layout drawing is shown in Fig. 7.8 of a small domestic extension. It can be seen that the mains intake position, probably a consumer's unit, is situated in the store room which also contains one light controlled by a switch at the door. The bathroom contains one lighting point controlled by a one-way switch at the door. The kitchen has two doors and a switch is installed at each door to control the fluorescent luminaire. There are also three double sockets situated around the kitchen. The sitting room has a two-way switch at each door controlling the centre lighting point. Two wall lights with built in switches are to be wired, one at each side of the window. Two double sockets and one switched socket are also to be installed in the sitting room. The bedroom has two lighting points controlled independently by two one-way switches at the door.

The wiring diagrams and installation procedures for all these circuits can be found in Chapter 14 of *Basic Electrical Installation Work,* 5th Edition.

AS-FITTED DRAWINGS

Definition

When the installation is completed a set of drawings should be produced which indicate the final positions of all the electrical equipment.

When the installation is completed a set of drawings should be produced which indicate the final positions of all the electrical equipment. As the building and electrical installation progresses, it is sometimes necessary to modify the positions of equipment indicated on the layout drawing because,

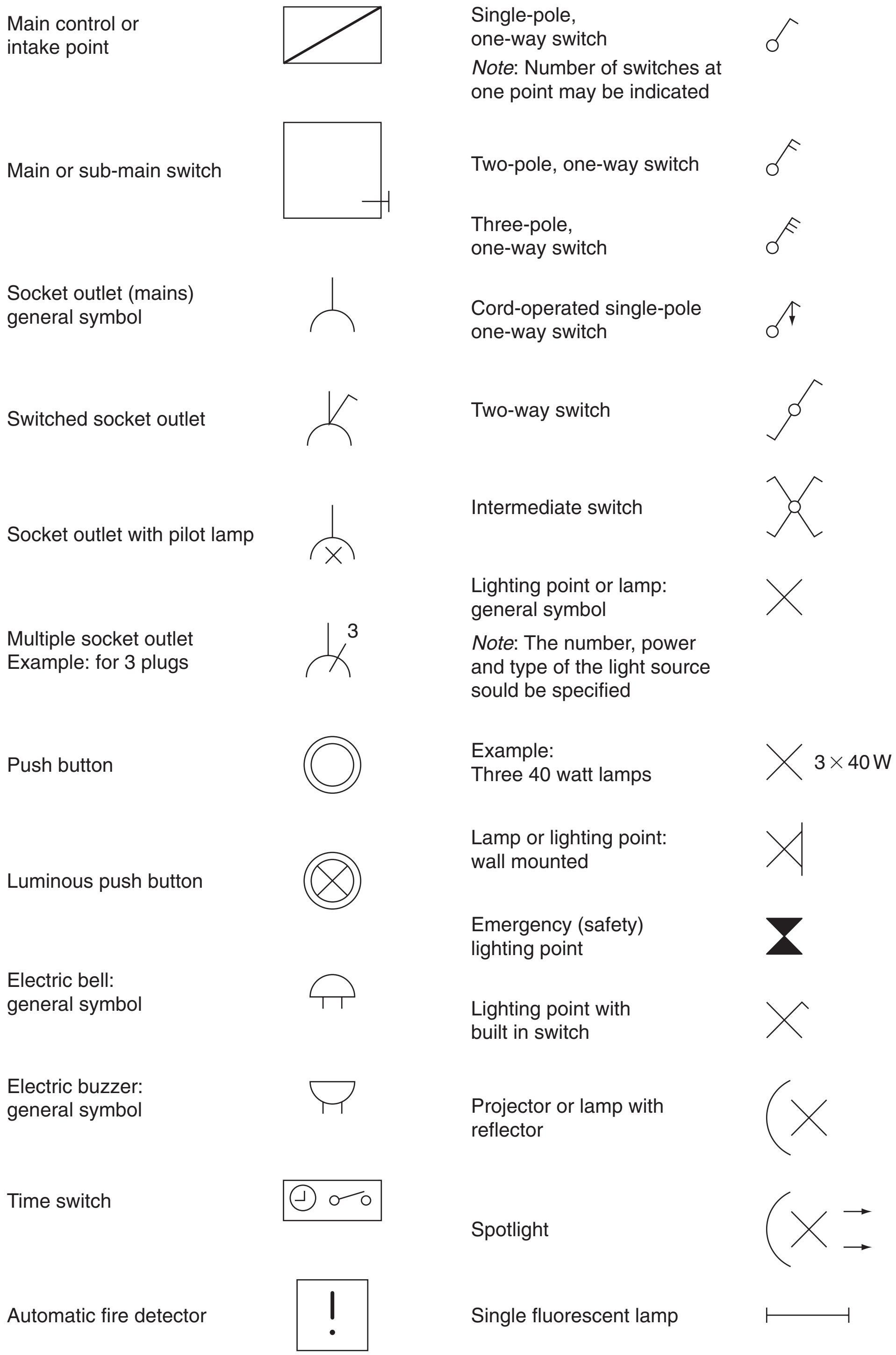


FIGURE 7.7
Some BS EN 60617 installation symbols.

for example, the position of a doorway has been changed. The layout drawings indicate the original intentions for the positions of equipment, while the 'as-fitted' drawing indicates the actual positions of equipment upon completion of the job.

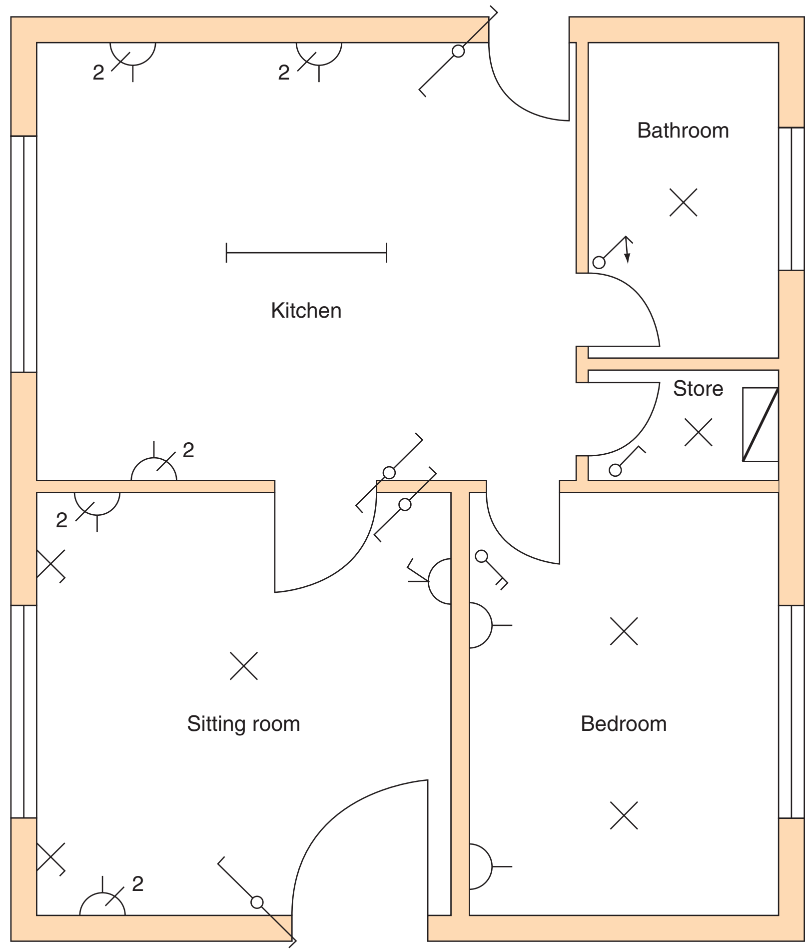


FIGURE 7.8
Layout drawing or site plan for electrical installation.

DETAIL DRAWINGS AND ASSEMBLY DRAWINGS

Definition

These are additional drawings produced by the architect to clarify some point of detail.

These are additional drawings produced by the architect to clarify some point of detail. For example, a drawing might be produced to give a fuller description of the suspended ceiling arrangements.

SCHEMATIC DIAGRAMS

Definition

A *schematic diagram* is a diagram in outline of, for example, a motor starter circuit.

A **schematic diagram** is a diagram in outline of, for example, a motor starter circuit. It uses graphical symbols to indicate the interrelationship of the electrical elements in a circuit. These help us to understand the working operation of the circuit.

An electrical schematic diagram looks very much like a circuit diagram. A mechanical schematic diagram gives a more complex description of the individual elements in the system, indicating, for example, acceleration, velocity, position, force sensing and viscous damping.

BLOCK DIAGRAMS

Definition

A *block diagram* is a very simple diagram in which the various items or pieces of equipment are represented by a square or rectangular box.

A **block diagram** is a very simple diagram in which the various items or pieces of equipment are represented by a square or rectangular box. The purpose of the block diagram is to show how the components of the circuit relate to each other and therefore the individual circuit connections are not shown.

Definition

A *wiring diagram* or connection diagram shows the detailed connections between components or items of equipment.

WIRING DIAGRAMS

A **wiring diagram** or connection diagram shows the detailed connections between components or items of equipment. They do not indicate how a piece of equipment or circuit works. The purpose of a wiring diagram is to help someone with the actual wiring of the circuit. Figure 7.9 shows the wiring diagram for a two-way lighting circuit.

Try This

Drawing

The next time you are on site:

- ask your supervisor to show you the site plans,
- ask him to show you how the scale works.

Definition

A *circuit diagram* shows most clearly how a circuit works.

CIRCUIT DIAGRAMS

A **circuit diagram** shows most clearly how a circuit works. All the essential parts and connections are represented by their graphical symbols. The purpose of a circuit diagram is to help our understanding of the circuit. It will be laid out as clearly as possible, without regard to the physical layout of the actual components, and therefore it may not indicate the most convenient way to wire the circuit. Chapter 3 and Figs 3.1–3.6 cover this topic in more detail in *Basic Electrical Installation Work* 5th Edition.

TELEPHONE COMMUNICATIONS

Telephones today play one of the most important roles in enabling people to communicate with each other. You are never alone when you have a

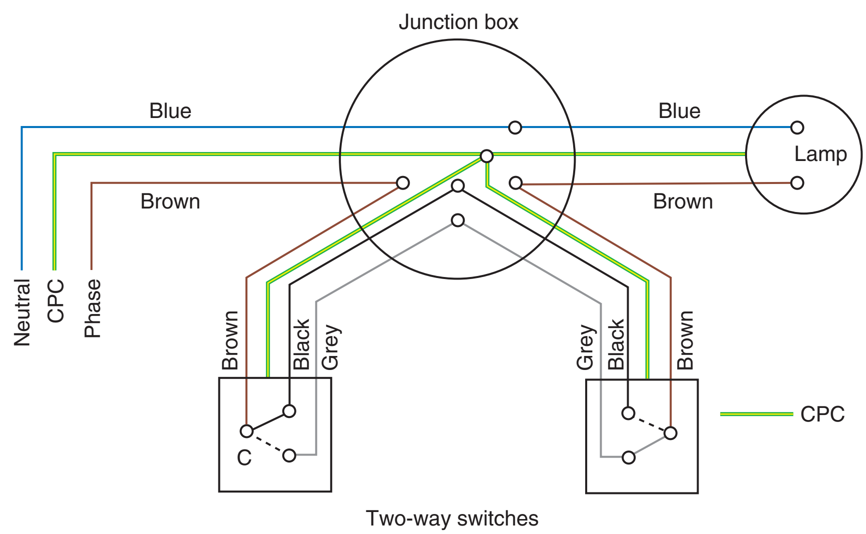


FIGURE 7.9
Wiring diagram of two-way switch control.

telephone. If there is a problem, you can ring your supervisor or foreman for help. The advantage of a telephone message over a written message is its speed; the disadvantage is that no record is kept of an agreement made over the telephone. Therefore, business agreements made on the telephone are often followed up by written confirmation.

When *taking* a telephone call, remember that you cannot be seen and, therefore, gestures and facial expressions will not help to make you understood. Always be polite and helpful when answering your company's telephone – you are your company's most important representative at that moment. Speak clearly and loud enough to be heard without shouting, sound cheerful and write down messages if asked. Always read back what you have written down to make sure that you are passing on what the caller intended.

Many companies now use standard telephone message pads such as that shown in Fig. 7.10 because they prompt people to collect all the relevant information. In this case John Gall wants Dave Twem to pick up the Megger from Jim on Saturday and take it to the Bispham site on Monday. The person taking the call and relaying the message is Dave Low.

FIGURE 7.10
Typical standard telephone message pad.

When *making* a telephone call, make sure you know what you want to say or ask. Make notes so that you have times, dates and any other relevant information ready before you make the call.

WRITTEN MESSAGES

Definition

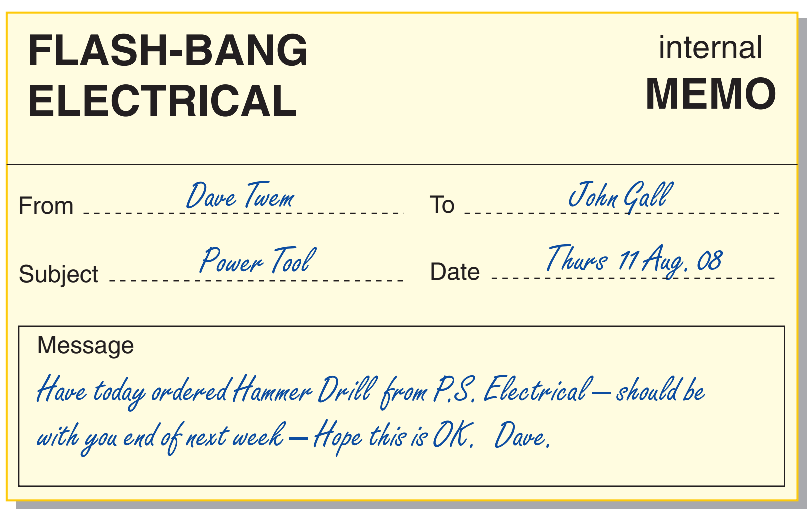
A lot of communications between and within larger organizations take place by completing standard forms or sending internal memos.

A lot of communications between and within larger organizations take place by completing standard forms or sending internal memos. Written messages have the advantage of being 'auditable'. An auditor can follow the paperwork trail to see, for example, who was responsible for ordering certain materials.

When completing standard forms, follow the instructions given and ensure that your writing is legible. Do not leave blank spaces on the form, always specifying 'not applicable' or 'N/A' whenever necessary. Sign or give your name and the date as asked for on the form. Finally, read through the form again to make sure you have answered all the relevant sections correctly.

Internal memos are forms of written communication used within an organization; they are not normally used for communicating with customers or suppliers. Figure 7.11 shows the layout of a typical standard memo form used by Dave Twem to notify John Gall that he has ordered the hammer drill.

Letters provide a permanent record of communications between organizations and individuals. They may be handwritten, but formal business letters give a better impression of the organization if they are type-written. A letter should be written using simple concise language, and the tone of the letter should always be polite even if it is one of the complaints. Always include the date of the correspondence. The greeting on a formal letter should be 'Dear Sir/Madam' and concluded with 'Yours faithfully'. A less formal greeting would be 'Dear Mr Smith' and concluded 'Yours sincerely'. Your name and status should be typed below your signature.



FLASH-BANG ELECTRICAL

internal MEMO

From Dave Twem

To John Gall

Subject Power Tool

Date Thurs 11 Aug. 08

Message

Have today ordered Hammer Drill from P.S. Electrical – should be with you end of next week – Hope this is OK. Dave.

FIGURE 7.11

Typical standard memo form.

DELIVERY NOTES

When materials are delivered to site, the person receiving the goods is required to sign the driver's 'delivery note'. This record is used to confirm that goods have been delivered by the supplier, who will then send out an invoice requesting payment, usually at the end of the month.

The person receiving the goods must carefully check that all the items stated on the delivery note have been delivered in good condition. Any missing or damaged items must be clearly indicated on the **delivery note** before signing, because, by signing the delivery note the person is saying 'yes, these items were delivered to me as my company's representative on that date and in good condition and I am now responsible for these goods'. Suppliers will replace materials damaged in transit provided that they are notified within a set time period, usually 3 days. The person receiving the goods should try to quickly determine their condition. Has the packaging been damaged, does the container 'sound' like it might contain broken items? It is best to check at the time of delivery if possible, or as soon as possible after delivery and within the notifiable period. Electrical goods delivered to site should be handled carefully and stored securely until they are installed. Copies of delivery notes are sent to head office so that payment can be made for the goods received.

Definition

By signing the *delivery note* the person is saying 'yes, these items were delivered to me as my company's representative on that date and in good condition and I am now responsible for these goods'.

TIME SHEETS

A **time sheet** is a standard form completed by each employee to inform the employer of the actual time spent working on a particular contract or site. This helps the employer to bill the hours of work to an individual job. It is usually a weekly document and includes the number of hours worked, the name of the job and any travelling expenses claimed. Office personnel require time sheets so that wages can be made up.

Definition

A *time sheet* is a standard form completed by each employee to inform the employer of the actual time spent working on a particular contract or site.

JOB SHEETS

A **job sheet** or **job card** such as that shown in Fig. 7.12 carries information about a job which needs to be done, usually a small job. It gives the name and address of the customer, contact telephone numbers, often a job reference number and a brief description of the work to be carried out. A typical job sheet work description might be:

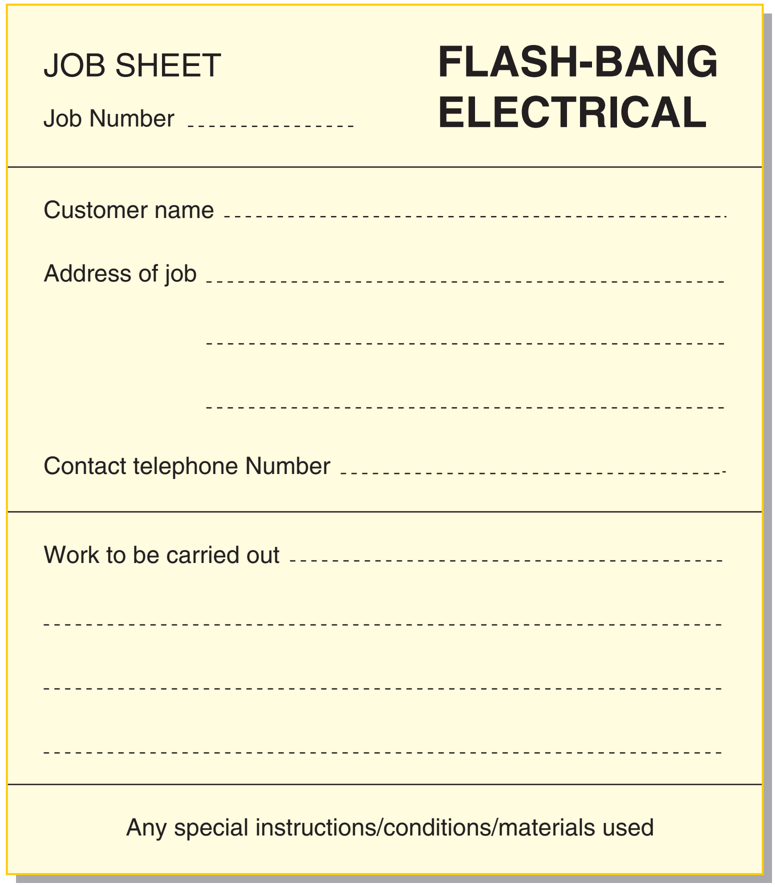
- Job 1: Upstairs lights not working.
- Job 2: Funny fishy smell from kettle socket in kitchen.

Definition

A *job sheet* or *job card* such as that shown in Fig. 7.12 carries information about a job which needs to be done, usually a small job.

An electrician might typically have a 'jobbing day' where he picks up a number of job sheets from the office and carries out the work specified.

Job 1, for example, might be the result of a blown fuse which is easily rectified, but the electrician must search a little further for the fault which caused the fuse to blow in the first place. The actual fault might, for example, be a decayed flex on a pendant drop which has become shorted out, blowing the fuse. The pendant drop would be re-flexed or replaced, along


JOB SHEET

Job Number ________________

FLASH-BANG ELECTRICAL

Customer name ________________

Address of job ________________

Contact telephone Number ________________

Work to be carried out ________________

Any special instructions/conditions/materials used

FIGURE 7.12
Typical time sheet.

with any others in poor condition. The installation would then be tested for correct operation and the customer given an account of what has been done to correct the fault. General information and assurances about the condition of the installation as a whole might be requested and given before setting off to job 2.

The kettle socket outlet at job 2 is probably getting warm and, therefore, giving off that ‘fishy’ bakelite smell because loose connections are causing the bakelite socket to burn locally. A visual inspection would confirm the diagnosis. A typical solution would be to replace the socket and repair any damage to the conductors inside the socket box. Check the kettle plug top for damage and loose connections. Make sure all connections are tight before reassuring the customer that all is well; then, off to the next job or back to the office.

The time spent on each job and the materials used are sometimes recorded on the job sheet, but alternatively a daywork sheet can be used. This will depend upon what is normal practice for the particular electrical company. This information can then be used to ‘bill’ the customer for work carried out.

Definition

Daywork is one way of recording *variations to a contract*, that is, work done which is outside the scope of the original contract. It is *extra* work.

DAYWORK SHEETS OR VARIATION ORDER

Daywork is one way of recording **variations to a contract**, that is, work done which is outside the scope of the original contract. It is *extra* work. If daywork is to be carried out, the site supervisor must first obtain a signature from the client's representative, for example, the architect, to **authorize the extra work**. A careful record must then be kept on the daywork sheets of all extra time and materials used so that the client can be billed for the extra work. A typical daywork sheet is shown in Fig. 7.13.

FLASH-BANG ELECTRICAL

VARIATION ORDER OR DAYWORK SHEET

Client name ....

Job number/REF. ....

Date	Labour	Start time	Finish time	Total hours	Office use

Materials quantity	Description	Office use

Site supervisor or Flash-Bang Electrical representative responsible for carrying out work ....

Signature of person approving work and status e.g.

Client ☐ Architect ☐ Q.S. ☐ Main contractor ☐ Clerk of works ☐

Signature ....

FIGURE 7.13
Typical daywork sheet or variation order.

REPORTS

On large jobs, the foreman or supervisor is often required to keep a report of the relevant events which happen on the site for example, how many people from your company are working on site each day, what goods were delivered, whether there were any breakages or accidents, and records of site meetings attended. Some firms have two separate documents, a site diary to record daily events and a weekly report which is a summary of the week's events extracted from the site diary. The site diary remains on site and the weekly report is sent to head office to keep managers informed of the work's progress.

PERSONAL COMMUNICATIONS

Remember that it is the customers who actually pay the wages of everyone employed in your company. You should always be polite and listen carefully to their wishes. They may be elderly or of a different religion or cultural background than you. In a domestic situation, the playing of loud music on a radio may not be approved of. Treat the property in which you are working with the utmost care. When working in houses, shops and offices use dust sheets to protect floor coverings and furnishings. Clean up periodically and make a special effort when the job is completed.

Dress appropriately: an unkempt or untidy appearance will encourage the customer to think that your work will be of poor quality.

The electrical installation in a building is often carried out alongside other trades. It makes good sense to help other trades where possible and to develop good working relationships with other employees. The customer will be most happy if the workers give an impression of working together as a team for the successful completion of the project.

Finally, remember that the customer will probably see more of the electrician and the electrical trainee than the managing director of your firm and, therefore, the image presented by you will be assumed to reflect the policy of the company. You are, therefore, your company's most important representative. Always give the impression of being capable and in command of the situation, because this gives customers confidence in the company's ability to meet their needs. However, if a problem does occur which is outside your previous experience and you do not feel confident to solve it successfully, then contact your supervisor for professional help and guidance. It is not unreasonable for a young member of the company's team to seek help and guidance from those employees with more experience. This approach would be preferred by most companies rather than having to meet the cost of an expensive blunder.

Construction site – safe working practice

In Chapter 1 we looked at some of the laws and regulations that affect our working environment. We looked at safety signs and personal protective equipment (PPE), and how to recognize and use different types of fire extinguishers. The structure of companies within the electrotechnical industry and the ways in which they communicate information by drawings, symbols and standard forms was discussed earlier in this chapter.

If your career in the electrotechnical industry is to be a long, happy and safe one, you must always wear appropriate PPE such as footwear, and head protection and behave responsibly and sensibly in order to maintain a safe working environment. Before starting work, make a safety assessment. What is going to be hazardous, will you require PPE, do you need any special access equipment.

Construction sites can be hazardous because of the temporary nature of the construction process. The surroundings and systems are always changing as the construction process moves to its completion date when everything is finally in place.

Safe methods of working must be demonstrated by everyone at every stage. 'Employees have a duty of care to protect their own health and safety and that of others who might be affected by their work activities'.

To make the work area safe before starting work and during work activities, it may be necessary to:

- use barriers or tapes to screen off potential hazards,
- place warning signs as appropriate,
- inform those who may be affected by any potential hazard,
- use a safe isolation procedure before working on live equipment or circuits,
- obtain any necessary 'permits to work' before work begins.

Try This

Communications

Make a list of all the different types of standard forms which your employer uses. Let me start the list for you with 'Time Sheets'.

Get into the habit of always working safely and being aware of the potential hazards around you when you are working.

Having chosen an appropriate wiring system which meets the intended use and structure of the building and satisfies the environmental conditions of the installation, you must install the system conductors, accessories and equipment in a safe and competent manner.

The structure of the building must be made good if it is damaged during the installation of the wiring system. For example, where conduits and trunking are run through walls and floors.

All connections in the wiring system must be both electrically and mechanically sound. All conductors must be chosen so that they will carry the design current under the installed conditions.

If the wiring system is damaged during installation it must be made good to prevent future corrosion. For example, where galvanized conduit trunking or tray is cut or damaged by pipe vices, it must be made good to prevent localized corrosion.

All tools must be used safely and sensibly. Cutting tools should be sharpened and screwdrivers ground to a sharp square end on a grindstone.

It is particularly important to check that the plug top and cables of hand held electrically powered tools and extension leads are in good condition. Damaged plug tops and cables must be repaired before you use them. All electrical power tools of 110 and 230V must be tested with a portable appliance tester (PAT) in accordance with the company's Health and Safety procedures, but probably at least once each year.

Tools and equipment that are left lying about in the workplace can become damaged or stolen and may also be the cause of people slipping, tripping or falling. Tidy up regularly and put power tools back in their boxes. You personally may have no control over the condition of the workplace in general, but keeping your own work area clean and tidy is the mark of a skilled and conscientious craftsman.

Finally, when the job is finished, clean up and dispose of all waste material responsibly as described in Chapter 8 of *Basic Electrical Installation Work*, 5th Edition under the heading Disposing of Waste.

Safe electrical installations

We know from earlier chapters in this book that using electricity is one of the causes of accidents in the workplace. Using electricity is a hazard because it has the potential, the possibility to cause harm. Therefore, the provision of protective devices in an electrical installation is fundamental to the whole concept of the safe use of electricity in buildings. The electrical installation as a whole must be protected against overload or short circuit and the people using the building must be protected against the risk of shock, fire or other risks arising from their own misuse of the installation or from a fault. The installation and maintenance of adequate and appropriate protective measures is a vital part of the safe use of electrical energy. I want to look at protection against an electric shock by both basic and fault protection, at protection by equipotential bonding and automatic disconnection of the supply, and protection against excess current.

Definition

Earth: The conductive mass of the earth whose electrical potential is taken as zero.

Definition

Earthing: The act of connecting the exposed conductive parts of an installation to the main protective earthing terminal of the installation.

Let us first define some of the words we will be using. Chapter 54 of the IEE Regulations describes the earthing arrangements for an electrical installation. It gives the following definitions:

Earth – the conductive mass of the earth whose electrical potential is taken as zero.

Earthing – the act of connecting the exposed conductive parts of an installation to the main protective earthing terminal of the installation.

Definition

Bonding conductor: A protective conductor providing equipotential bonding.

Definition

Bonding: The linking together of the exposed or extraneous metal parts of an electrical installation.

Definition

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

Definition

Exposed conductive parts: This is the metalwork of an electrical appliance or the trunking and conduit of an electrical system.

Definition

Extraneous conductive parts: This is the structural steelwork of a building and other service pipes such as gas, water, radiators and sinks.

Definition

Shock protection: Protection from electric shock is provided by basic protection and fault protection.

Definition

Basic protection: This is provided by the insulation of live parts in accordance with Section 416 of the IEE Regulations.

Bonding conductor – a protective conductor providing equipotential bonding.

Bonding – the linking together of the exposed or extraneous metal parts of an electrical installation.

Circuit protective conductor (CPC) – a protective conductor connecting exposed conductive parts of equipment to the main earthing terminal. This is the green and yellow insulated conductor in twin and earth cable.

Exposed conductive parts – this is the metalwork of an electrical appliance or the trunking and conduit of an electrical system which can be touched because they are not normally live, but which may become live under fault conditions.

Extraneous conductive parts – this is the structural steelwork of a building and other service pipes such as gas, water, radiators and sinks. They do not form a part of the electrical installation but may introduce a potential, generally earth potential, to the electrical installation.

Shock protection – protection from electric shock is provided by basic protection and fault protection.

Basic protection – this is provided by the insulation of live parts in accordance with Section 416 of the IEE Regulations.

Fault protection – this is provided by protective equipotential bonding and automatic disconnection of the supply (by a fuse or MCB) in accordance with IEE Regulations 411.3–6.

Protective equipotential bonding – this is equipotential bonding for the purpose of safety and shown in Figs 7.15–7.17.

Basic protection and fault protection

The human body's movements are controlled by the nervous system. Very tiny electrical signals travel between the central nervous system and the muscles, stimulating operation of the muscles, which enable us to walk, talk and run and remember that the heart is also a muscle.

If the body becomes part of a more powerful external circuit, such as the electrical mains, and current flows through it, the body's normal electrical operations are disrupted. The shock current causes unnatural operation of the muscles and the result may be that the person is unable to release the live conductor causing the shock, or the person may be thrown across the room. The current which flows through the body is determined by the resistance of the human body and the surface resistance of the skin on the hands and feet.

This leads to the consideration of exceptional precautions where people with wet skin or wet surfaces are involved, and the need for special consideration in bathroom installations.

Two types of contact will result in a person receiving an electric shock. Direct contact with live parts which involves touching a terminal or line

Definition

Fault protection: This is provided by protective equipotential bonding and automatic disconnection of the supply (by a fuse or MCB) in accordance with IEE Regulations 411.3–6.

Definition

Protective equipotential bonding: This is equipotential bonding for the purpose of safety.

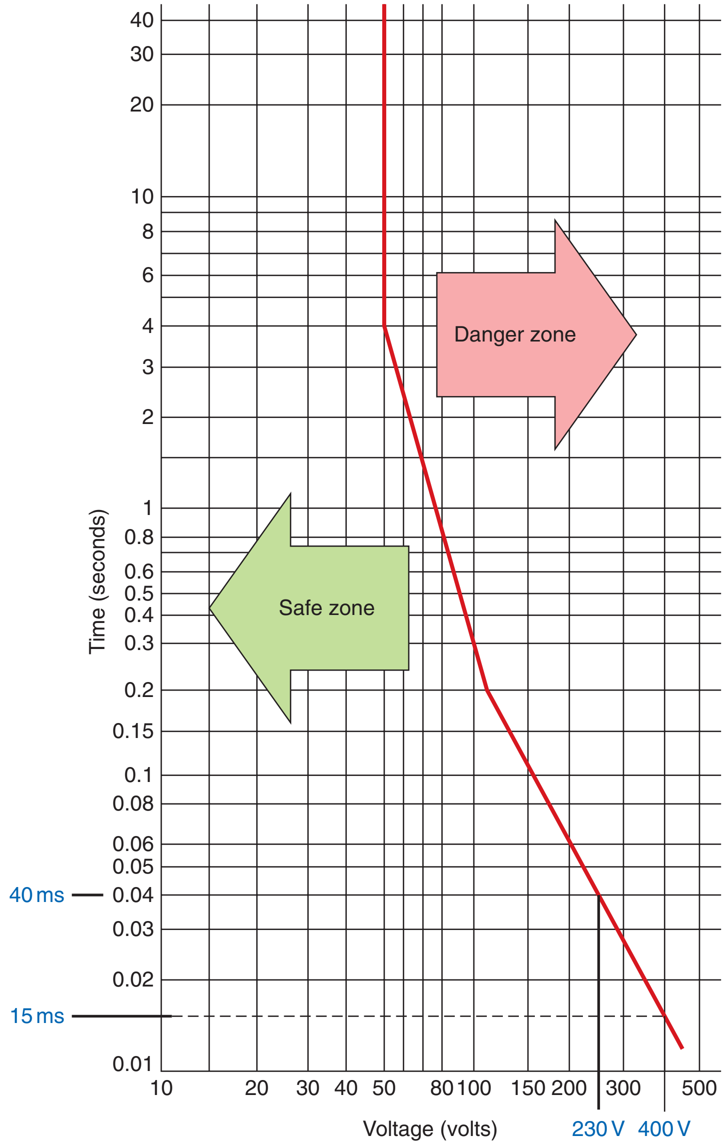


FIGURE 7.14
Touch voltage curve.

conductor that is actually live. The Regulations call this Basic Protection (131.2.1). Indirect contact results from contact with an exposed conductive part such as the metal structure of a piece of equipment that has become live as a result of a fault. The Regulations call this Fault Protection (131.2.2).

The touch voltage curve in Fig. 7.14 shows that a person in contact with 230V must be released from this danger in 40 ms if harmful effects are to be avoided. Similarly, a person in contact with 400V must be released in 15 ms to avoid being harmed.

In installations operating at normal mains voltage, the primary method of protections against direct contact is by insulation. All live parts are enclosed in insulating material such as rubber or plastic, which prevents contact with those parts. The insulating material must, of course, be suitable for the