13 Electrical installations

Learning objectives

Study of this chapter will enable the reader to:

1. understand how electricity is generated and distributed;
2. know the difference between single- and three-phase electricity;
3. distinguish line, neutral and earth conductors;
4. calculate the resistance of conductors;
5. understand the temperature effect of a current;
6. calculate current and power in electrical circuits;
7. know how to measure current and voltage;
8. use power factor;
9. calculate series and parallel circuit resistances;
10. find the current capacity of cables;
11. choose cable sizes;
12. calculate permissible cable lengths;
13. understand temporary electrical installations for construction sites;
14. calculate the total electrical loading in kilovolt-amperes and amperes for installation;
15. estimate the total cost of electricity likely to be consumed in an installation during normal use;
16. choose the correct fuse rating;
17. understand the operation of fuses and circuit-breakers;
18. know the distribution of electricity within buildings;
19. identify the use of isolating switches, distribution boards and meters;
20. understand earth bonding of services;
21. know the types of cable conduits and their applications;
22. understand the principles of ring circuits;
23. understand how electrical systems are tested;
24. be aware of telecommunications cables;
25. design lightning conductor systems;
26. identify the graphic symbols used on drawings.

Key terms and concepts

alternator 292; apparent power 296; balanced load 292; bonding 294; cable-sizing calculations 299; cables, trunking and conduits 307; capacitor 296; cartridge fuse 305; distribution board 307; electrical measurements 310; electric shock 304; fault current 305; fuses and circuit-breakers 304; graphic symbols 314; IEE Wiring Regulations 299; kilowatts (kW) and kilovolt-amperes (kVA) 296; lightning conductor systems 312; line current 292; line, neutral and earth conductor 293; methods of testing 310; miniature circuit-breaker 305; national grid 292; Ohm's law 295; power factor (*PF*) 296; real power 296; residual current device 305; ring circuit 308; series and parallel circuits 296; single- and three-phase 292; specific resistance 294; telecommunications 312; temperature coefficient of resistance 294; temporary electrical installations on sites 300; triple pole and neutral switch 308; voltage, current, power and resistance 295.

Introduction

The safe and economical use of electricity is of paramount importance to the building user and the world as it is the most highly refined form of energy available. Electricity production consumes up to three times its own energy value in fossil fuel, and electricity in its distributed form is potentially lethal.

In this chapter the handling methods and safety precautions for utilizing electricity are explained and a range of calculations, which can easily be performed by the services designer or constructor prior to employing specialist help, is introduced.

Electricity distribution

The electrical power-generating companies supply electrical power into the national 400 kV grid system of overhead bare wire conductors. This very high voltage is used to minimize the current carried by the cables over long distances. Step-down transformers reduce the voltage in steps down to 33 kV, when it can be supplied to industrial consumers and to other transformer stations on commercial and housing estates.

The electricity-generating alternator rotates at 50 Hz (3000 rev/mm) and has three coils in its stator. The output voltages and currents from each coil are identical but are spaced in time by one-third of a revolution, 120°. Each coil generates a sine wave or phase voltage that has the same heating effect as a 240 V continuous direct current supply. This is its root mean square (RMS) value. The RMS value of the three phases operating together is 415 V.

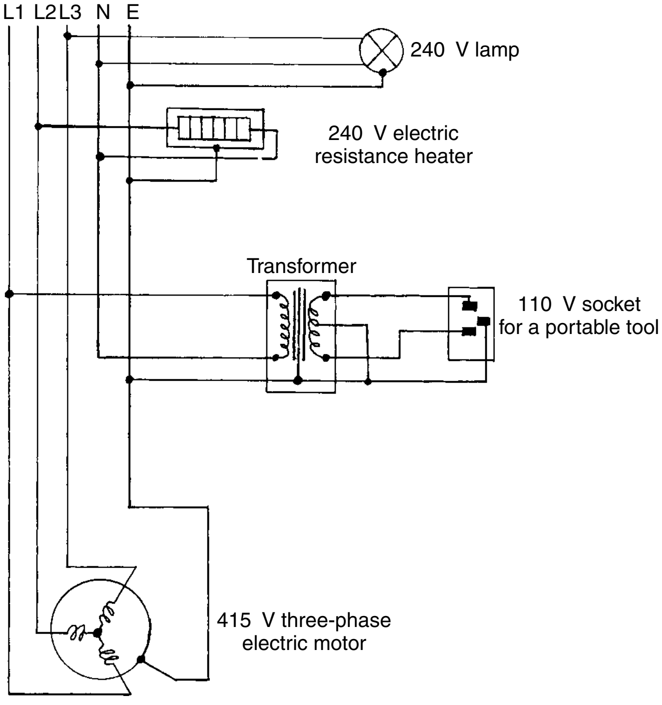
Figure 13.1 shows the connections to a three-wire three-phase 415 V, 50 Hz alternating current supply entering a non-domestic building. Various circuits of different voltages are supplied from the incoming mains. Equal amounts of power are fed into each phase, and so it is important that power consumption within a building is equally shared by each line. The neutral wire is a live conductor in that it is the return path to the alternator for the current which has been distributed.

Figure 13.2 shows a single-phase from one of the generator coils where the effective voltage is the RMS value:

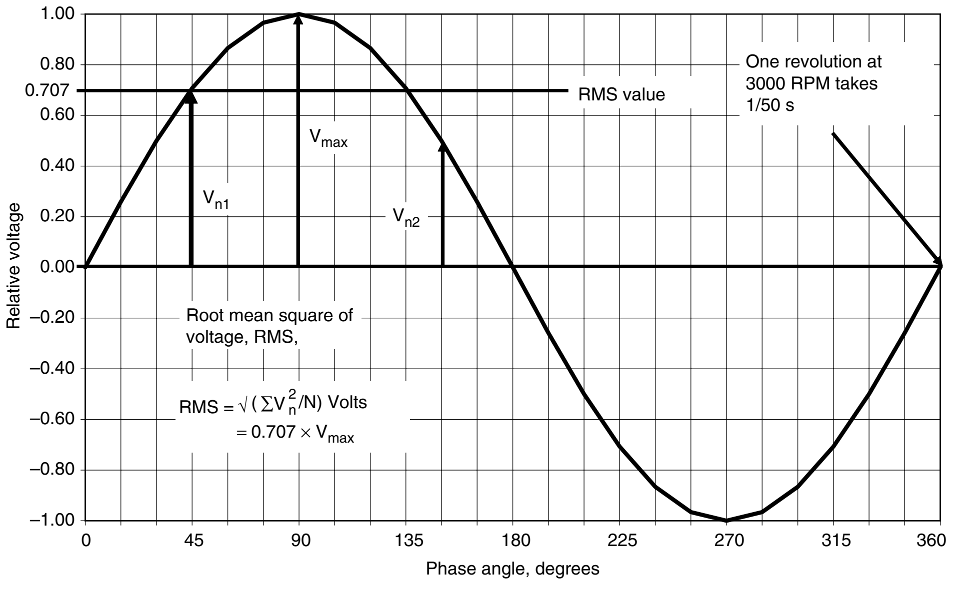
$$\text{RMS} = \sqrt{\frac{\sum V_n^2}{n}}$$

where V is the voltage at each of n measurements, say at 15° intervals.

A balanced load, such as a three-phase electrical motor driving an air-conditioning fan, water pump or lift motor, does not produce a current in the neutral wire. This is because an alternating



13.1 Wiring circuits from a three-phase 415 V incoming supply.



13.2 Single-phase RMS.

current flows alternately in the forward and backward directions along the line wire. The overall effect of three driving coils in the motor is a balance in the quantity and direction of the current taken from the line conductors. There is no net return current in the neutral wire from such a balanced load. Single-phase electrical loads, which are not in balance, produce a net current in the neutral conductor.

The casings of all electrical appliances are connected to earth by a protective conductor, the earth wire, connected to the earthed incoming service cable of the electricity supply authorities or an earth electrode in the ground outside the building. Gas and water service pipes are bonded to the earth by a protective conductor.

Circuit design

The resistance R ohms (Ω) of an electrical conductor depends on its specific resistance ρ Ωm, its length l m and its cross-sectional area A m^2. The specific resistance of annealed copper is 0.0172 μΩm (μ, micro stands for 10^{-6}) at 20°C.

$$R = \rho \frac{l}{A}\ \Omega$$

EXAMPLE 13.1

Calculate the electrical resistance per metre length at 20°C of a copper conductor of 2.5 mm^2 cross-sectional area.

$$R = \frac{0.0172}{10^6}\ \Omega\text{m} \times \frac{1\ \text{m}}{2.5\ \text{mm}^2} \times \frac{10^6\ \text{mm}^2}{1\ \text{m}^2}$$
$$= 0.0069\ \Omega$$

The resistance of a cable increases with increase in temperature and the temperature coefficient of resistance (α) of copper is 0.00428 Ω/Ω°C at 0°C. If the resistance of the conductor is R_0 at 0°C, then its resistance at another temperature R_t can be found from:

$$R_t = R_0\,(1 + \alpha t)\ \Omega$$

where t is the conductor temperature (°C).

EXAMPLE 13.2

Find the resistance of a 2.5 mm^2 copper conductor at 40°C.

R_0 is not known but the resistance of this conductor at 20°C was found in Example 13.1 and t can represent the increase in temperature above this value. A graph of resistance versus temperature would reveal a straight line of slope α.

$$
\begin{aligned}
R_{40} &= R_{20}\,(1 + \alpha \times 20)\ \Omega \\
&= 0.0069 \times (1 + 0.00428 \times 20)\ \Omega \\
&= 0.0075\ \Omega
\end{aligned}
$$

The relation between applied voltage, electric current and resistance is given by Ohm's law:

$$I \text{ amps} = \frac{V \text{ volts}}{R \text{ ohms}}$$

Figure 13.3 shows how an ammeter and a voltmeter are connected into a circuit to measure power consumption. The load may be an electrical resistance heater or tungsten filament lamp, in which case the power consumption in watts is found from:

$$\text{power in watts} = V \text{ volts} \times A \text{ amps} \times \cos \phi$$

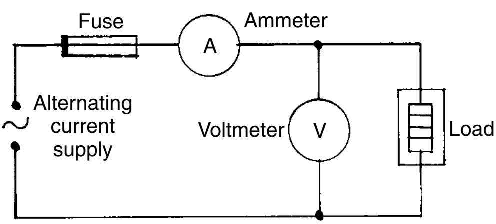
for single-phase and,

$$\text{power in watts} = V \text{ volts} \times A \text{ amps} \times \sqrt{3} \times \cos \phi$$

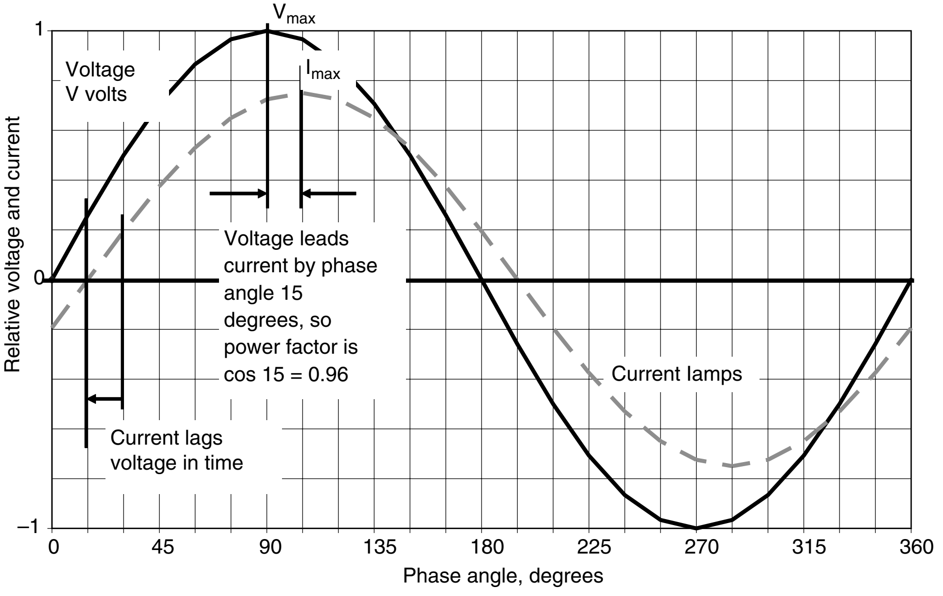
for three-phase, where cos ϕ is the power factor (zero to unity). An electrical resistance heater and tungsten lamps are purely resistive loads whose power factor, cos ϕ, is unity, 1.

Loads such as electric motors and fluorescent lamps have a property known as inductance, which causes the current to lag behind the voltage that is producing that current. This is due to an electromotive force (emf), that is, a voltage which opposes the incoming emf. The densely packed electromagnetic windings of a motor have a high inductance and thus the 50 Hz cyclic variation of voltage and current is opposed by the 'inertia' of the equipment. The opposing emf comes from the expanding and collapsing magnetic fields of the input power around the conductors.

The lag angle $\phi°$ between peak voltage and peak current means that the instantaneous available power is less than the product of the two peaks. Figure 13.4 shows voltage applied across a circuit creating a current that lags in real time; peak current occurs after the peak voltage.



13.3 Measurements of power consumption in an electrical circuit.



13.4 Phase angle lag.

Power factor is the term used to differentiate between useful output power in watts and the input instantaneous product of voltage and current to the load:

$$\text{power factor } PF = \frac{\text{useful power in watts}}{\text{input volts} \times \text{amps}} = \frac{\text{watts}}{\text{volt} \times \text{amps}}$$

$$= \frac{\text{real power (to do work)}}{\text{apparent power}}$$

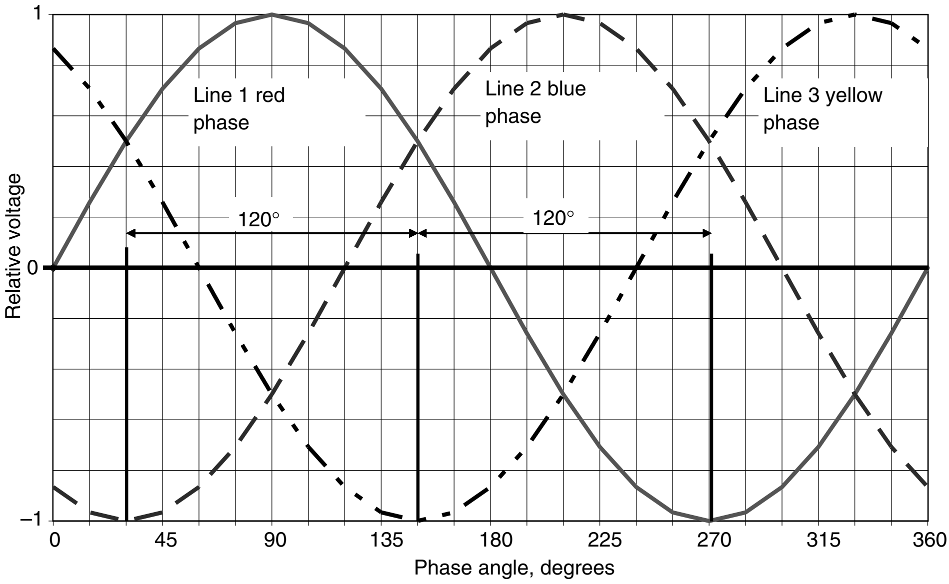
$$PF = \frac{\text{kW}}{\text{kVA}}$$

$$= \frac{\text{kilowatts}}{\text{kilovolt-amps}} = \frac{\text{kW real}}{\text{kVA (apparent)}}$$

Figure 13.5 shows all three phases as they occur in real time, separated by 120° phase angle. Because of the three voltage sine waves within each cycle, the overall power generated is higher and smoother than with only a single-phase motor. Capacitors have an electrical storage capability, which is used to overcome the effects of inductance. Power factors of electrical equipment are commonly 0.85 and these can be improved to 0.95 by the addition of power-factor-correcting capacitors.

Several loads to a circuit may be connected either in series or in parallel with each other. For series-connected resistances:

$$R = R_1 + R_2 + R_3 + \cdots$$



13.5 Three-phase.

For parallel-connected resistances:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

The resistance of electrical cables must be sufficiently low that the cables do not become significant sources of heat and run at temperatures that could be a fire hazard or damage their electrical insulation. Such heat generation would generally be wasted energy. The maximum voltage drop in a cable permitted in the Institution of Electrical Engineers (IEE) Wiring Regulations is 4% of the nominal supply voltage from the consumer's intake terminal to any point in the installation at full load current.

Cables that are grouped together, run in conduits or are covered with thermal insulation, say in a roof space, can operate at a temperature above the 30°C ambient condition assumed in the selection of their size and their electrical insulation. Where their temperature is likely to rise above this value, their current-carrying capacity is reduced by appropriate rating factors during design of the system. Care should be taken to allow natural cooling of all cable routes. The current-carrying capacity has to be 1.33 times the design current for cables partly surrounded by thermal insulation and twice the design current if they are wholly surrounded. This will generally mean an increase by one or two cable sizes.

EXAMPLE 13.3

Calculate the power consumption and resistance of a 240 V filament lamp if it has 1.5 A passing through it.

$$\begin{aligned}\text{power in watts} &= \text{volts} \times \text{amps}\\ &= 240\ \text{V} \times 1.5\ \text{A}\\ &= 360\ \text{W}\end{aligned}$$

From Ohm's law:

$$I = \frac{V}{R}$$

and so,

$$\begin{aligned}R &= \frac{V}{I}\\ &= \frac{240}{1.5}\\ &= 160\ \Omega\end{aligned}$$

EXAMPLE 13.4

PVC insulation on a conductor carrying 415 V has an electrical resistance to earth of 500 MΩ. What leakage current could flow through the PVC when the cable is laid on an earthed metal support? (1 MΩ = 10^6 Ω.)

The difference between line and earth is 240 V. From Ohm's law

$$\begin{aligned}I &= \frac{V}{R}\\ &= \frac{240\ \text{V}}{500 \times 10^6\ \Omega}\\ &= 0.48 \times 10^{-6}\ \text{A}\\ &= 0.48\ \mu\text{A}\end{aligned}$$

EXAMPLE 13.5

Compare the currents carried by an overhead line at 400 and 33 kV for the transmission of 10 MW of power for unity power factor, $\cos\phi = 1$.

For a three-phase system, using:

$$\text{watts} = \text{volts} \times \text{amps} \times \sqrt{3} \times \cos\phi$$

$$\text{current in amps} = \frac{\text{watts}}{\text{volts}} \times \frac{1}{\sqrt{3}} \times \frac{1}{\cos\phi}$$

For 400 kV:

$$\text{current} = \frac{10 \times 10^6\ \text{W}}{400 \times 10^3\ \text{V}} \times \frac{1}{\sqrt{3}} = 14.4\ \text{A}$$

For 33 kV:

$$\text{current} = \frac{10 \times 10^6\ \text{W}}{33 \times 10^3\ \text{V}} \times \frac{1}{\sqrt{3}} = 175\ \text{A}$$

This demonstrates the advantages of high-voltage transmission of electrical power as smaller cable sizes can be used for the long distances involved.

Cable capacity and voltage drop

The maximum current-carrying capacities and actual voltage drops according to the LEE Regulations for Electrical Installations (16th edn, 1991) for unenclosed copper cables which are twin-sheathed in PVC, clipped to the surface of the building, are given in Table 13.1. Flexible connections to appliances may use 0.5 mm^2 conductors for 3 A and 0.75 mm^2 conductors for 6 A loads. The maximum voltage drop allowed is 4% of the 240 V nominal supply (Jenkins, 1991).

EXAMPLE 13.6

Find the maximum lengths of 1, 1.5 and 2.5 mm^2 copper cable which can be used on a 240 V circuit to a 3 kW immersion heater.

$$\text{current} = \frac{3000\ \text{W}}{240\ \text{V}} = 12.5\ \text{A}$$

$$\text{allowed voltage drop} = \frac{4}{100} \times 240 = 9.6\ \text{V}$$

$$\text{maximum length or run} = \frac{\text{maximum voltage drop allowed mV}}{\text{load current A} \times \text{voltage drop mV/A m}}$$

Table 13.1 Electrical cable capacities.

Nominal cross-sectional area of conductor (mm^2)	*Maximum current rating (A)*	*Voltage drop in cable (mV/Am)*
1	15	44
1.5	19.5	29
2.5	27	18
4	36	11
6	46	7.3
10	63	4.4
16	85	2.8

For 1 mm^2 cable:

$$l = \frac{9.6 \times 10^3}{12.5 \times 44} \text{ m} = 17.5 \text{ m}$$

For 1.5 mm^2 cable:

$$l = \frac{9.6 \times 10^3}{12.5 \times 29} \text{ m} = 26.5 \text{ m}$$

For 2.5 mm^2 cable:

$$l = \frac{9.6 \times 10^3}{12.8 \times 18} \text{ m} = 42.7 \text{ m}$$

Construction site distribution

A list is made of all electrical equipment to be used on site in order to assess the maximum demand kilovolt-amperes and cable current rating required. An estimate of the cost of electricity for running the site may also be made.

EXAMPLE 13.7

A building site is to have the following electrical equipment available for use:

(a) tower crane, electric motors totalling 75 kW at 415 V;
(b) sump pump, 5 kW at 240 V;
(c) 60 tungsten lamps of 100 W each at 240 V;
(d) 12 flood lamps of 400 W each at 240 V;
(e) 20 hand tools of 400 W at 110 V.

1. Find the total kilovolt-amperes to be supplied to the site if the power factor of all rotary equipment is 0.8.
2. Find the electrical current rating for the incoming supply cable to the site.
3. Estimate the cost of electricity consumed on the site during a 12-month contract.

For rotating machinery:

$$\text{power, VA} = \frac{\text{useful power W}}{PF} = \frac{\text{W}}{0.8} \text{ and, kVA} = \frac{\text{kW}}{PF}$$

For single-phase current:

$$\text{line current} = \frac{\text{VA}}{\text{V}} \text{ A}$$
$$= \frac{\text{kVA}}{\text{kV}} \text{ A}$$

For three-phase current:

$$\text{line current} = \frac{\text{VA}}{\text{V} \times \sqrt{3}}\ \text{A}$$
$$= \frac{\text{kVA}}{\text{kV} \times \sqrt{3}}\ \text{A}$$

The results of the power calculations are given in Table 13.2.

The answers required are as follows.

1. The total input power kilovolt-amperes required for site is 120.8 kVA.
2. The incoming supply cable capacity at 415 volt, three-phase, 50 Hz required is:

$$\text{current} = \frac{120.8 \times 1000}{415 \times \sqrt{3}}$$
$$\text{current} = 168\ \text{A}$$

This is the input current to the site at the voltage of that cable. This is not the same as a total of the currents calculated in Table 13.2 as these larger numbers only appear at their reduced voltages in the relevant sub-circuits.

3. Assume that the crane, pump and tools are running for 25% of an 8-h working day, 5 days per week for 48 weeks, 20 of the tungsten lamps are for security lighting 16 h every night, and the remaining 40 tungsten lamps and the flood lamps are used for 3 h per day, 5 days per week for the winter period of 20 weeks. The crane, pump and tools are working for:

$$0.25 \times 8\ \frac{\text{h}}{\text{day}} \times 5\ \frac{\text{days}}{\text{week}} \times 48\ \text{weeks} = 480\ \text{h}$$

The security lamps are working for:

$$16\ \frac{\text{h}}{\text{day}} \times 7\ \frac{\text{days}}{\text{week}} \times 52\ \text{weeks} = 5840\ \text{h}$$

The other lamps are working for:

$$3\ \frac{\text{h}}{\text{day}} \times 5\ \frac{\text{days}}{\text{week}} \times 20\ \text{weeks} = 300\ \text{h}$$

Table 13.2 Building site plant schedule.

Equipment	*Power (kW)*	*Number*	*kW*	*kVA*	*V*	*A*
Tower crane	75	1	75	93.75	415	130.4
Sump pump	5	1	5	6.25	240	26
Lamps	0.1	60	6	6	240	25
Flood lamps	0.4	12	4.8	4.8	240	20
Hand tools	0.4	20	8	10	110	90.9
Total			98.8	120.8	n.a.	n.a.

Table 13.3 Building site energy use.

Equipment	*Power (kW)*	*Number*	*Time (h)*	*Energy (kWh)*
Tower crane	75	1	480	36 000
Sump pump	5	1	480	2400
Tungsten lamps, security	0.1	20	5824	11 648
Lamps	0.1	40	300	1200
Flood lamps	0.4	12	300	1440
Tools	0.4	20	480	3840
Total power used				56 528

The total energy used by the systems is found from,

kWh = number of appliances × kW per appliance × operation hours as shown in Table 13.3.

If electricity costs 8 p per unit (kWh) then the estimated cost for the 1-year contract will be:

$$\text{cost} = 8\frac{\text{P}}{\text{kWh}} \times 56\,528\ \text{kWh} \times \frac{\pounds 1}{100\ \text{p}}$$

$$= \pounds 4522$$

Site safety

Adequate safety in the use of electricity on site is essential and a legal obligation upon employers. The area electricity supply authority must be contacted before any site work, to establish the locations of overhead and underground power cables. Assume that all lines are live. Overhead lines are not insulated except at their suspension points. The Electricity At Work Regulations 1989 need to be consulted.

Roadways for site vehicles should be made underneath overhead cables by the erection of clearly marked goalposts, on each side of the cable route, through which traffic must pass. These goalposts form the entrance and exit from the danger area and are spaced at 1.25 jib lengths of the mobile crane to be used on site, or at a minimum of 6 m either side of the cables. Entry to the roadway other than through the goal posts is barred with wooden fencing or tensioned ropes with red and white bunting at high and low levels.

Underground cables that become exposed during excavations must remain untouched until the electricity authority has given advice. Safe working clearances will be ascertained at this time.

Hand lamps and tools are operated from a transformer at 110 V to reduce the damage caused by an electric shock. For work within tunnels, chimneys, tanks or drains, 25 V lamps, or battery lamps, are advised. Each portable appliance should be checked by the operator before use and also inspected and tested by a competent person at intervals not exceeding 7 days. Records of maintenance and safety checks should be kept.

A weatherproof cubicle is provided at the edge of the site by the main contractor for the electricity authority's temporary fuses and main switch. Site distribution cables are supported from hangers on an independent wire suspended between poles around the edge of the site, with spur branches to site accommodation and work areas. The minimum clear heights under cables should be 4.6 m in positions inaccessible to vehicles, 5.2 m in positions accessible to vehicles and 5.8 m across roads.

The site programme for the main contractor is as follows.

1. Arrange a pre-contract meeting between the executives responsible for the work.
2. List electrical requirements for all temporary plant.
3. Prepare layout drawings showing equipment siting and electrical loads, including site offices, stores, canteen, sanitary accommodation and illumination. Carefully site equipment to minimize interference with the construction work.
4. Apply to the electricity supply authority for a temporary supply to the site, stating maximum kilovolt-ampere demand and voltage and current requirements.
5. Provide the electrical distribution equipment: 415 V, three-phase, 50 Hz for fixed plant and movable plant fed by trailing cables; 240 V, single-phase, 50 Hz for site accommodation and site illumination; 110 V, single-phase, 50 Hz for portable lighting and tools; 50 or 25 V, single-phase, 50 Hz for portable lamps to be used in confined spaces and damp areas.
6. Once site accommodation is in place, ensure that a satisfactory semi-permanent electrical system is provided.
7. A competent electrician is to carry out all site work. His name, designation and location are to be prominently displayed on site, so that faults, accidents and alterations can be expedited. All plant and cables are regularly inspected and tested.
8. Display the electricity regulations placard and the first-aid instruction card.
9. Appraise the use of electrical equipment and distribution arrangements weekly to ensure that the most efficient use is made of the system. Idle equipment is returned to the supervised store.

Construction site electricity

Distribution equipment for site use is housed in weatherproof rugged steel boxes on skids. Built-in lifting lugs facilitate crane or manual transportation. The main items are as follows.

Supply incoming unit (SIU): a unit to house the electricity supply authority's incoming cable, service fuses, neutral link, current transformers and meters. Outgoing circuits of 100 A or more are controlled by triple pole and neutral (TPN) switches for three-phase and either cartridge fuses or residual current devices to break the circuits in the event of a current flowing to earth from a fault in a wire or item of plant.

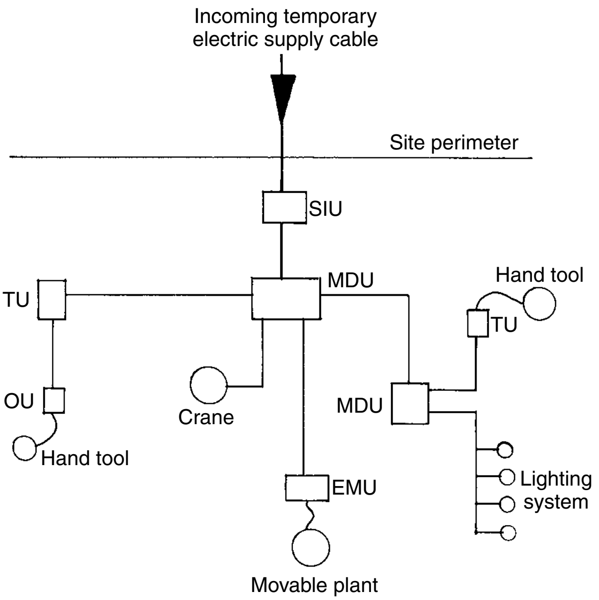
Main distribution unit (MDU): a cubicle, which may be bolted to the SIU, providing a number of single- and three-phase outlets through weatherproof plugs and sockets. Each outlet is protected by a residual current device.

Transformer unit (TU): a unit providing 110 V single- and three-phase supplies with 65 V between any line and earth for safety in the use of hand tools. It may be coupled to an SIU. Each outlet circuit is protected by a residual current device.

Outlet unit (OU): easily portable distribution box fed from an MDU or TU for final connection of sub-circuits to tools, lighting or motors. Each circuit is protected by a residual current device and clearly labelled with its voltage, phases and maximum current capacity.

Extension outlet unit (EOU): similar to an OU but fed from a 16 A supply and circuit protection is by a cartridge fuse. It may have up to four 16 A outlets on a cubicle metal box.

Earth monitor unit (EMU): flexible cables supplying electricity to movable plant; may incorporate a separate pilot conductor in addition to the protective conductor to earth. A small current passes through the portable plant and the EMU via the pilot and protective conductors. If the earth conductor is broken, the EMU current is interrupted and the circuit is automatically isolated at its circuit-breaker.



13.6 Distribution of electricity during site construction.

Semi-permanent installations are run in metal-sheathed or armoured flexible cable. The metal sheath is permanently earthed as is the earth wire. An over-sheath of PVC or an oil-resisting and flame-retardant compound is provided.

Connections from outlet units to hand-operated tools and lighting systems are made in tough rubber-sheathed (TRS) flexible cable. Walkways and ladders must be kept clear of cables and the cables must be kept 150 mm from piped services. Cables under site roadways are installed in a temporary service duct, such as drain pipework, at a depth of 600 mm and with markers at each end of the crossing. Figure 13.6 shows an arrangement of a site's electrical distribution.

Safety cut-outs

An electric shock is sustained when part of the human body establishes contact between a current-carrying conductor and earth. It is also likely from contact with two conductors of different phase. Voltages of less than 100 V have proved fatal under certain circumstances. The size of the current depends on the applied voltage and the body's resistance to earth.

Rubber shoes or flooring greatly increase the resistance of the shock circuit. Body resistance with damp skin is around 1100 Ω at 240 V; thus a current of 218 mA could flow. At 55 V, body resistance is 1600 Ω and this could produce 34 mA. A current of 1–3 mA is generally not dangerous and can just be perceived. At 10–15 mA acute discomfort and muscle spasm occurs, making release from the conductor difficult. A current of 25–50 mA causes severe muscle spasm and heart fibrillation, and will probably be fatal.

Prolonged exposure to a shock current causes burns from the heating effect of the supply. If electric shock occurs, switch off the supply without contacting any metal component. If necessary, begin resuscitation and summon qualified medical assistance immediately.

During normal operation, current flows from the 240 V (or other nominal value) line, through the appliance and along the neutral conductor back to the power station alternator. The nominal drop of voltage across the appliance is 240 V. Should either the line or the neutral conductors come into contact with a conducting material that is earthed, owing to a wiring fault, the current will choose the lower-resistance path to earth on its return journey to the earthed alternator. Immediately, a higher current will flow and the appliance has become a shock hazard.

The increased heating effect of the fault current can be used to melt a rewirable or cartridge fuse at the appliance, its fault current being 60% above the stated continuous rating. High rupturing capacity (HRC) cartridge fuses have silver elements in a ceramic tube, which is packed with granulated silica. They allow for the high starting currents required for electric motors. The correct fuse rating must be used for each appliance to avoid damage to cables and buildings from overheating through the use of too high a fuse capacity. Fuse ratings are quoted in Table 13.4 and are found from

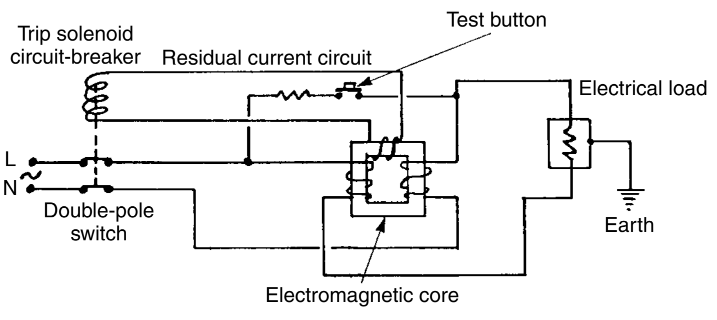
$$\text{fuse current rating} = 1.6 \times \frac{\text{appliance input VA}}{\text{circuit voltage}}$$

A faster-acting protection, with greater reliability, whose operation can be tested is provided by a miniature circuit-breaker (MCB), which opens switch contacts upon detection of an excess current. Circuit faults that cause a leakage to earth are detected by a residual current circuit-breaker (Fig. 13.7).

During normal operation, the line and neutral coils around the electromagnetic core generate equal and opposite magnetic fluxes, which cancel out. A current leakage to earth at the appliance reduces the current in the neutral conductor and a residual current is generated in the core by the line coil. This residual current generates an emf and current in the detector circuit, which in turn

Table 13.4 Fuse ratings for 240 V single-phase and unity power factor.

Power consumption (W)	*Fuse required (A)*
120	0.8
240	1.6
720	4.8
1200	8
3120	20.8
3600	24
7200	48



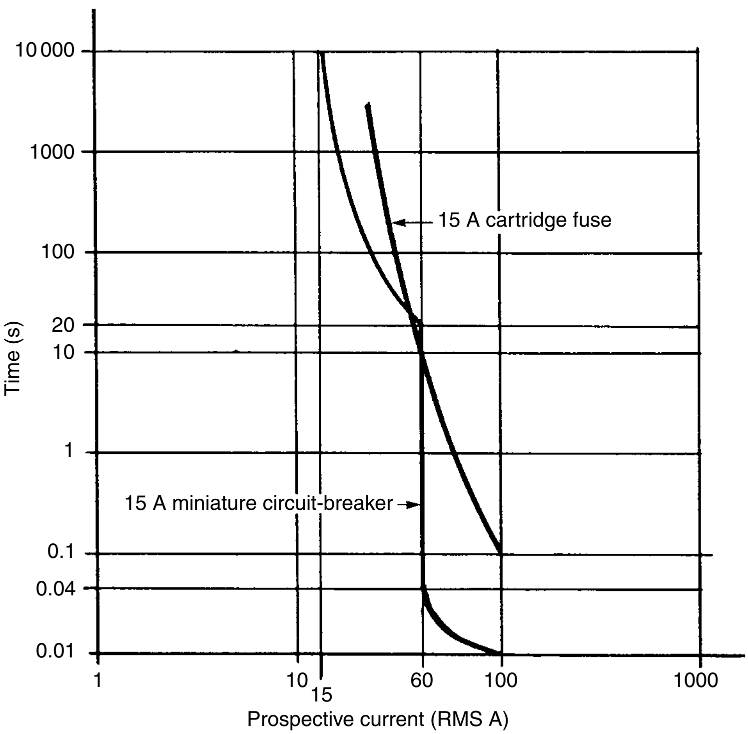
13.7 Residual current circuit-breaker.

energizes the trip solenoid, which opens the double-pole switch, or TPN switch in a three-phase circuit, and isolates the appliance.

Residual currents of 30 mA are set for sensitive applications and outdoor equipment. They are frequently used in addition to fuses. Pressing the test switch short-circuits the line coil and a residual current is generated in the core, tripping the residual current device for test purposes.

Fuses and circuit-breakers are selected for their time–current characteristics in relation to the risk that is being protected against. Figure 13.8 shows the performance curve for a cartridge fuse to British Standard 1361: 1971 type 1 having a 15 A continuous rating for domestic installations and a comparative miniature circuit-breaker (IEE Wiring Regulations for Electrical Installations, 16th edn, 1991). The horizontal and vertical scales of the graph are logarithmic. It can be seen that both devices will pass the design maximum 15 A current without opening the circuit. The cartridge fuse is designed to melt if a current of 46 A were to flow for a period of 5 s, or 97 A for 0.1 s. Other combinations of heating effect are in proportion. These points lie to the left of the fuse curve and do not cause it to break.

The MCB is designed to open the circuit when 60 A flows for between 0.1 and 5 s. A lower current value will take in excess of 20 s to open the contacts. A fault in the protected circuit that causes the current to rise above 60 A will open the MCB in less than 0.1 s. A miniature circuit-breaker and a residual current device (RCD) may be combined in one moulded casing to protect against excess current, short-circuit and a leakage to earth. The MCB has a bimetallic strip thermal and magnetic trip mechanism. The speed of operation of an RCD is typically 20 ms (Midland Electrical Manufacturing Company Limited).



13.8 Time–current characteristics of a cartridge fuse and a miniature circuit-breaker.

Electrical distribution within a building

The incoming cable, residual current device and meter are the property of the electricity supply authority. Underground cables are at a depth of 760 mm under roads, and enter the building through a large radius service duct of 100 mm internal diameter. A drainpipe can be used for this purpose, laid through the foundations and rising directly to the meter compartment. External meter compartments can be used. The meter should not be exposed to damp or hot conditions and the electricity supply authority's advice should be sought. Figure 13.9 shows a distribution system for a dwelling.

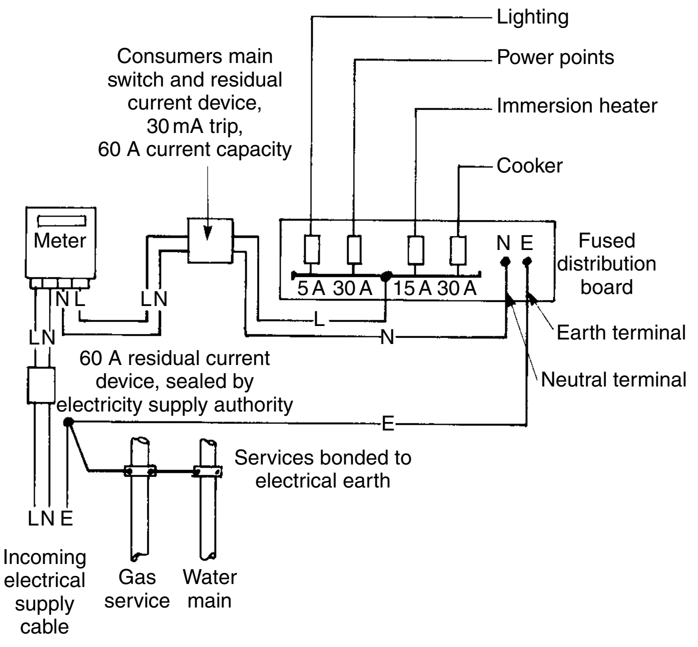
Each circuit has a fuse or circuit-breaker and the fused distribution board connects the neutral and earth protective conductors to the supply cable. Appliances have a cartridge fuse at their connecting plug. Three-phase distribution in a large building is shown in Fig. 13.10. Switches are used to enable separation of individual circuits as well as appliances. A fuse or circuit-breaker is always fitted on the live line so that the incoming current is disconnected.

Power socket outlets are fitted into a ring circuit as shown in Fig. 13.11. Care must be taken not to overload the circuit by connecting appliances whose total current consumption would exceed the 30 A limit, particularly in kitchens.

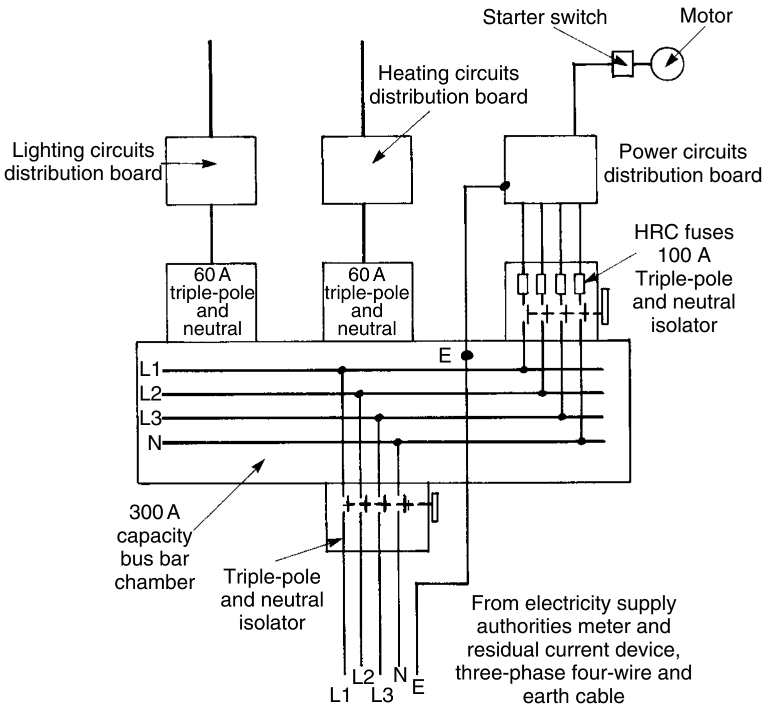
Types of cable used in distribution systems are as follows.

PVC-insulated and -sheathed

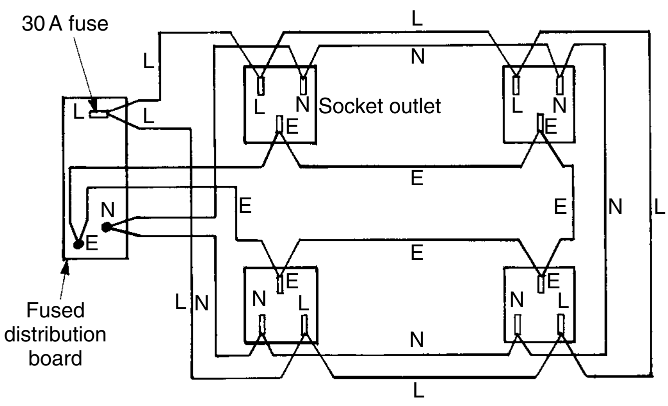
PVC-insulated and -sheathed cables consist of copper conductors of multi-stranded or solid wire having sizes from 1 to 16 mm^2 cross-sectional area. Single-, twin- or three-core cables, with or without earth wires, are used. They are among the cheapest cables available and can be pulled through conduits, trunking or holes bored in floor joists. Such holes are drilled 50 mm below the



13.9 Domestic electricity distribution.



13.10 Three-phase electricity distribution.



13.11 Ring main to socket outlets.

floorboards. Ambient temperature limits for the cable are 0–65°C and the cable must not exceed 70°C in use. Colour coding of the insulation ensures correct polarity at terminals. The earth, or protective conductor, is always green, neutral is always black and the line conductor is red on single-phase. Three-phase line conductors are one red, one yellow and one blue.

PVC is a flexible, non-hygroscopic, tough, durable, corrosion-resistant and chemically inert material, which is used for both electrical insulation and conduits. Installations are tested for earth leakage through their insulation at regular intervals and cables are replaced after about 20 years because of ageing of the PVC.

Mineral-insulated copper-sheathed

Solid copper conductors surrounded by compressed magnesium powder are factory-fitted inside a copper tube or sheath. A PVC over-sheath gives extra protection for cables that are to be buried in building materials. These cables are used for both internal and external wiring and withstand severe conditions, even continuing to operate during a fire. They can be operated continuously at temperatures of up to 250°C compared with only 70°C for PVC-covered cables.

The soft copper cable is supplied in rolls and is run continuously from the distribution board to the switch or power point. Screwed gland joints are designed to exclude dampness from the hygroscopic insulant. One sheath may encapsulate up to nineteen 1.5 mm^2 conductors. They are non-ageing and unlikely to require replacement during the building's period of service.

Particular applications are fire alarm systems, in petrol filling stations and within boiler plant rooms. The copper sheath is used as the earth protective conductor and also withstands severe abuse, flattening or twisting without short-circuiting the conductors. The cables can be bent by hand or machine, and conduit fittings are not needed. The overall diameters of mineral-insulated cables are much less than those of other types of comparably rated cable system. Only a thin plaster covering is needed if the cables are not to be surface mounted.

Armoured PVC-insulated, PVC-sheathed

Copper or aluminium conductors in PVC insulation, a PVC bedding, galvanized steel wire armour and a PVC sheath are used for heavy-current cables to large machinery and mobile plant on site. The cable can be run on the building surface, laid on the ground or put in a trench. Screwed gland nuts are used to bond the armour to the appliance casing.

Busbar

Bare copper or aluminium rectangular bar conductors are supported on insulators within a sheet metal duct or trunking. Vertical service shafts within buildings may have a rising busbar system with tap-off points at each floor level for the horizontal distribution of power with insulated cables. Small busbar distribution systems can be used in retail premises and within raised floors in office buildings. These provide flexibility in the siting of outlet boxes.

Overhead distribution in factories allows connections at any point along the busbar with plug-in boxes, allowing machinery to be moved at a later date. The trunking acts as the protective conductor. Three-phase 415 V supplies are distributed at current ratings of 100–600 A, branches being at 30, 60 or 100 A. An armoured PVC cable can supply the incoming end of the busbar. Where the system passes through a fire-resistant partition in the building, a fire barrier is fitted across the inside of the trunking.

Other cable insulants

Flexible external and special application cables are used as follows.

Butyl rubber: for up to 85°C continuous plus higher overload rating. Additional heat-resisting glass fibre wrapping increases the continuous temperature to 100°C. Flexible cord use.

Ethylene propylene rubber (EP rubber): an elastomer with similar properties to butyl rubber. Has improved resistance against the effects of water and long-term ageing. Retains its flexibility down to –70°C.

Silicone rubber: withstands –75°C and a wide variety of chemical and oxidizing agents, weak acids, salts and vegetable oils. It retains its insulation and elasticity at working temperatures of up to 150°C.

Polychloroprene (PCP): for general purpose heat-resisting, oil-resisting and flame-retardant (HOFR) use in the presence of oil and petrol.

Chlorosulphonated polyethylene (CSP): heavy duty use in aggressive atmospheres in laundries or in the presence of oil and petrol.

Conduit and trunking

Circular conduit systems are used to carry insulated cables and should last the service period of the building. The space occupied by the cable must not exceed 40% of the cross-sectional area of the inside of the conduit to allow for ventilation to remove the heat generated by cable resistance.

Materials used are light- or heavy-gauge steel, depending upon exposure to damp or explosive fumes. The external conduit will be galvanized. Lug grip connections are used for light-gauge pipework and screwed joints for heavy-gauge pipework. Pipe sizes are 16, 20, 25 and 32 mm. The conduits are used as the protective conductor.

PVC conduit, using solvent weld joints, is lighter and easier to handle and does not corrode but requires the cable to incorporate the protective conductor. Its upper temperature limit is 60°C.

Rectangular galvanized sheet steel or PVC trunking is used where large-cable carrying capacity is needed. These must not be filled to greater than 45% of their cross-sectional area with cables. Surface-mounted trunking can be incorporated into the interior decoration and up to three separate cable compartments are used for different services, including telecommunications, computer, power and lighting cables.

Trunking may be installed under raised timber flooring, within the concrete floor slab or screed, in a grid, branch duct or perimeter distribution arrangement. Outlets that are raised or flush with the floor are provided to suit either fixed or movable office layouts.

Testing

Inspection and testing of an electrical installation is carried out before it is put into service and at regular intervals during use. The main reasons for this are to ensure that its operation will be entirely safe, in accordance with the demands put upon it, and energy-efficient. The work entails the following tests.

Power measurement

The power consumed by a single of three-phase electrical system or item of plant, such as a refrigeration compressor, fan or pump motor, or a lighting or power sub-circuit, is measured with a portable instrument as shown in Fig. 13.12. Newly installed plant is checked for equal phase currents, voltage and power consumed during commissioning. The energy auditor measures these some years after installation, as commissioning data may no longer be relevant or plant may have been changed. The logger should also measure power factor so an assessment can be made of whether to install power factor capacitors to reduce incoming current. Each phase line conductor has one of the openable clamps fitted. Voltage difference across the circuit is measured

13.12 Electrical power measurement logger (reproduced by courtesy of Mobile Architecture and Built Environment Laboratory, Deakin University, Geelong).

with additional cables and attachment clips. Both useful power in kW and apparent power in kVA are measured. All work on live electrical wiring is only done by a registered electrician.

Verification of correct polarity

A visual inspection is carried out of all fuses and switches to check that they are fitted into a line conductor. The centre contact of each screw lamp holder is connected to the line conductor. Plugs and sockets must be correctly connected and wire rigidly held.

Tests of effective earthing

There are four separate tests:

Test of the protective conductor: A 40 V 50 Hz supply of up to 25 A is injected into the earth conductor. Its resistance is not to exceed 1 Ω. An impedance test meter is used.

Earth loop impedance test: A line-earth loop impedance test meter is attached to a 13 A three-pin plug. This is plugged into each power socket and the meter injects a current into the earth protective conductor. The current flows along the supply authority's cable sheath to the local transformer and back to the power socket along the line conductor.

Test of residual current devices: A test transformer providing 45 V is connected to a socket outlet. A short-circuit current is passed from the neutral to the protective conductor, causing the residual current device to trip instantaneously.

Measurement of consumer earth electrode resistance: Where this is used, a test electrode is put into the ground and a steady 50 Hz current is passed between the electrode and the consumer's earth electrode to determine its circuit resistance.

Insulation resistance tests

An insulation test meter is connected between the line and protective conductors. A 500 V direct current is applied to this circuit by the meter and an electrical resistance of 0.5 MΩ or more must be shown.

Test of ring circuit continuity

Each ring circuit is tested for resistance at the distribution board with an ohmmeter. Probes are connected to each side of the line conductor ring and a zero resistance proves a continuous circuit. The test is repeated on the neutral and protective conductor circuits and spur branches.

Tests on installations must be carried out in accordance with the IEE Wiring Regulations by a competent person, who should preferably be a professionally qualified electrical engineer having installation experience. IEE Completion and Inspection Certificates are issued by the engineer.

Telecommunications

Cables between the switchboard and socket for each telephone are accommodated within vertical and horizontal service ducts spaced 50 mm from alternating current cables to avoid speech interference. Alternatively, a partitioned chamber can be reserved throughout the cable trunking.

Lightning conductors

Rules are provided (BS Code of Practice 326: 1965) to determine whether a protection system is required. This depends on building construction, degree of isolation, height of the structure, topography, consequential effects and lightning prevalence. Recommendations on system types, including those for temporary structures, are given.

Copper and aluminium 10 mm rod, 25 mm × 3 mm strip, PVC-covered strip, copper strand and copper braid are used for conductors. The air terminal is sited above the highest point of the structure and a down conductor is bolted to the outside of the building so that side flashing between the lightning conductor and other metalwork will not occur.

Ground termination is with a series of earth rods driven to depths of up to 5 m, cast iron or copper plates 1 m square horizontally or vertically oriented 600 mm below ground, or a copper lattice of flat strips 3 m × 3 m at a depth of 600 mm. Where large floor areas containing earth rods are to be concreted, a precast concrete inspection pit is built over the rod location.

The electrical resistance to earth of the whole system is not to exceed 10 Ω (Butler, 1979a). Calculation of the ground earthing resistance R requires a knowledge of the earth type (BS Code of Practice 1013: 1965) and resistivity. Typical values of earth resistivity are 10 Ωm for clay, 50 Ωm for chalk, 100 Ωm for clay shale and 1000 Ω for slatey shales. The resistance of a rod electrode in earth is:

$$R = \frac{0.37\,\rho}{l} \log\left(\frac{4000\,l}{d}\right)\ \Omega$$

where l is the earth rod length (m), d is the earth rod diameter (mm) and ρ is the resistivity of the soil (Ωm). A number of rods are connected in parallel and spaced 3.5 m apart to provide the required resistance.

EXAMPLE 13.8

Design a lightning conductor system for a building 30 m high in an area where thunderstorms are expected. The ground has a high chalk content and rod electrodes 4 m long are to be used. The conductors are to be 25 mm × 3 mm copper strip. The specific resistance ρ of copper is 0.0172 μΩm.

length of conductor = air terminal + down conductor + ground lead

Take the length of the conductor as 40 m,

resistance of conductor $R = \rho \dfrac{l}{A} \Omega$

where A is the conductor cross-sectional area (m^2); hence:

$$R = 0.0172 \times 10^{-6}\ \Omega\text{m} \times \frac{40\ \text{m}}{(0.025 \times 0.003)\ \text{m}^2}$$
$$= 0.092\ \Omega$$

resistance R of earth electrode $= \dfrac{0.37\ \rho}{l} \log \left(\dfrac{4000\ l}{d} \right) \Omega$

where the earth resistivity ρ is 50 Ωm, the electrode length l is 4 m and the electrode diameter d is 10 mm; hence:

$$R = \frac{0.37 \times 50\ \Omega\text{m}}{4\ \text{m}} \times \log \left(\frac{4000 \times 4}{10} \right) \Omega$$
$$= 4.625 \times \log 1600$$
$$= 14.819\ \Omega$$

The resistance of one electrode in the ground plus the down conductor is greater than the 10 Ω allowed, and so we find the combined resistance of two electrodes connected in parallel:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{14.8} + \frac{1}{14.8} = 0.135$$
$$R = \frac{1}{0.135} = 7.4\ \Omega$$

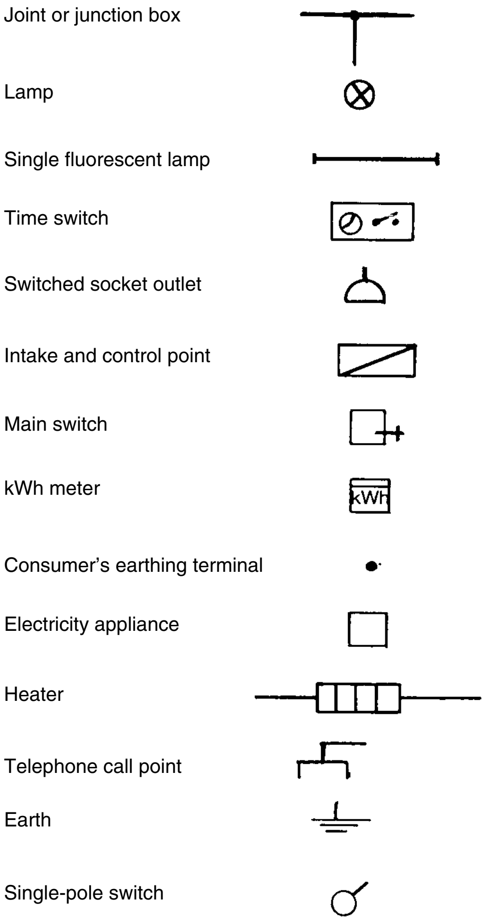
Two electrodes and the down conductor connected in series have a total resistance of:

$$R = (7.4 + 0.0092)\ \Omega = 7.4\ \Omega$$

This is less than the 10 Ω allowed and is satisfactory. The resistance of the lightning conductor is negligible in relation to that of the earth electrodes. The calculations have been made on the assumption that the lightning discharges in a direct current. Lightning energy can produce a current to earth of 20 000 A for a few milliseconds. It causes physical damage to building structures, starts fires in combustible materials and injury to people, sometimes fatal.

Graphical symbols for installation diagrams

Some of the symbols used on drawings of electrical installations are listed in Fig. 13.13 as in accordance with BS 3939: 1985, Guide for Graphical Symbols.



13.13 Drawing symbols for electrical installations.

Questions

1. Explain how electricity is generated and transmitted to the final user.
2. List the sources of energy used for the generation of electricity and state their immediate and long-term benefits.
3. Explain, with the aid of sketches, the meaning of the terms 'single-phase' and 'three-phase' electricity supplies and show how they are used within buildings.
4. What does 'balancing the phases' mean?
5. Calculate the electrical resistance per metre length at 20°C of a copper conductor of a 10 mm^2 cross-sectional area.
6. Find the electrical resistance of a copper conductor 1.5 mm^2 in cross-sectional area if its total length is 25 m and its temperature is 20°C.
7. A 28 m copper conductor 4 mm^2 in cross-sectional area is covered with thermal insulation, which causes the cable temperature to rise to 45°C. Calculate the percentage increase in electrical resistance compared with its value at a cable temperature of 20°C.
8. Sketch the methods of connection used for measurements of current, voltage drop and power consumption in an electrical resistance heater on an alternating current circuit.

9. State the function of power factor correction in alternating current circuits.
10. Calculate the apparent power, in kilovolt-amperes, of an electric motor which is connected to a 415 V AC three-phase supply and has a current flow of 17.5 A.
11. Calculate the resistance of a 3 kW immersion heater on a 240 V AC circuit.
12. What current, in milli-amperes, would flow to earth during an insulation resistance test when a 500 V DC emf is applied between the line and protective conductors and the resistance is found to be 1.75 MΩ?
13. Show by sample calculation why smaller cables can be used for long-distance power transmission when very high voltages are used.
14. A 33 kV supply to a factory carries 250 A per phase or line. Calculate the usable electrical power in the factory if the average power factor is 0.68.
15. Find the maximum length of 6 mm^2 cable that can be used if the maximum current-carrying capacity is to be utilized on a 240 V circuit.
16. A building site is to have the following electrical equipment in use each day:

    (a) concrete mixer, 5 kW, 4 h, 415 V;
    (b) sump pump, 1.5 kW, 6 h, 240 V;
    (c) 20 lamps, 150 W each, 4 h, 240 V;
    (d) 5 flood lamps, 300 W each, 4 h, 240 V;
    (e) 6 hand tools, 750 W each, 5 h, 110 V.

    The power factor of the machinery is 0.8. Site work takes place 5 days per week for 28 weeks. Electricity costs 6 p per unit. Find

    (i) the total kilovolt-amperes and the line current of the required temporary incoming supply system, and
    (ii) the cost of the electricity used on site during the contract.

17. Sketch and describe the safety precautions taken to avoid contact with both overhead and underground electricity cables during site construction work.
18. Sketch a suitable arrangement of temporary wiring, control and safety equipment on a site where the following items are employed: tower crane, sump pump, five flood lamps, security lighting and circuits on each of three floors for hand lamps and tools.
19. List the site programme for the main contractor in the installation and operation of temporary site electrical services.
20. Sketch and describe the characteristics of rewirable and cartridge fuses and residual current devices.
21. Show how an underground electrical service cable enters a building. Sketch the arrangement of electricity distribution within a typical residence.
22. List the cable and conduit systems used for electricity distribution and state their applications.
23. Briefly describe the methods of testing electrical installations.
24. State the requirements of telecommunications installations.
25. Sketch and describe a lightning conductor installation for a city centre office block.
26. Design a lightning conductor system for a 60 m high building on clay shale using 4.5 m earth rods. The down conductor is to be a copper rod 10 mm in diameter.
27. Why is power factor in electrical systems an issue for concern? More than one correct answer.

    1. It is not of any concern.
    2. Low-power factor means electrical energy is used inefficiently.
    3. High-power factor means electrical energy is wasted.

4. 100% power factor is not usually attainable at a justifiable cost.
5. Low-power factor means electrical supply system becomes oversized.

28. What is a low-power factor?

    1. Zero
    2. 0.95
    3. 0.85
    4. 1.0
    5. 0.8 and below.

29. Which is the correct formula for power factor?

    1. $PF = \frac{\text{kVA}}{\text{kVAh}}$
    2. $PF = \frac{\text{kVAh}}{\text{kWh}}$
    3. $PF = \frac{\text{kW}}{\text{kVA}}$
    4. $PF = \frac{\text{input energy}}{\text{kilovolt-ampere}}$
    5. $\text{kW} = \frac{\text{PF}}{\text{kVA}}$

30. How does a 30 mA residual current circuit-breaker work? More than one correct answer.

    1. Line and neutral conductors wrap around an electromagnetic core and no current flows through the core as magnetic flux from each wire cancels the other.
    2. Line and neutral conductors wrap around an electromagnetic core; current flows through the core due to magnetic flux from each wire.
    3. Line and neutral conductors wrap around an electromagnetic core; current flows through the core due to magnetic flux induced from line conductor.
    4. Line and neutral conductors wrap around an electromagnetic core; magnetic flux circulates harmlessly through the core due to the alternating current line and neutral conductors.
    5. Current leakage to earth from the protected appliance loses neutral current, causing imbalance between line and neutral magnetic fluxes in core; imbalance flux generates 30 mA in trip solenoid circuit breaker.

31. How can cartridge fuses cope with high starting currents at electric motors?

    1. They cannot.
    2. Only micro-circuit-breakers are used to protect motors driving compressors.
    3. High rupturing capacity cartridge fuses regularly pass 500% of normal running current.
    4. High rupturing capacity cartridge fuses have silver elements and packed with silica to allow high starting currents for a known duration.
    5. High rupturing capacity cartridge fuses have bimetallic elements and packed with carbon granules to allow high starting currents.

32. Which are correct about mineral-insulated copper-sheathed electrical cables? More than one correct answer.

    1. Fragile and easily damaged.
    2. Withstand most fires and remain operational.
    3. Supplied in hard copper fixed lengths, like plumbing pipes.
    4. Screwed gland joints exclude water from the hygroscopic insulant.
    5. Cannot be installed outdoors.

33. What is meant by busbar? More than one correct answer.

    1. Communications bus, C-bus, in a computer.
    2. Ethernet communications cabling system around a large network.
    3. PVC-insulated circular bar conductors at high level through an industrial manufacturing plant.
    4. Bare copper or aluminium bar conductors carried on insulators within sheet metal trunking.
    5. Up to 600 A three-phase vertical or horizontal distribution allowing off-takes along length.

34. What is the meaning of inverter drive?

    1. An electric motor installed in an inverted position.
    2. Three-phase electric motor.
    3. Three-phase motor running in single-phase.
    4. Digitally driven motor.
    5. Motor driven at variable alternating current frequencies.

35. Which is correct about electrical systems?

    1. Watts = volts × amps.
    2. Three-phase current = 3 × single-phase current.
    3. Watts and volt-amperes are always the same value.
    4. Current = voltage × resistance.
    5. Current measured in mega-ohms.

36. How is power consumed by an electrical item measured?

    1. Wattmeter cut into the line conductor.
    2. Voltmeter and current meter both cut into line conductor to the load.
    3. Ammeter connected into the line conductor to the load and a voltmeter connected in parallel with the load.
    4. Voltmeter connected into line conductor to the load and an ammeter connected in parallel with the load.
    5. Wattmeter connected in parallel with the load.

37. Which system of public electricity is provided to small- to medium-sized non-domestic buildings in the UK and Australia?

    1. 50 Hz, 240 V, AC.
    2. 210 V, single-phase, 55 Hz, alternating current.
    3. Two-phase, 60 Hz, 200 V.
    4. 440 V, three-phase, 60 Hz.
    5. AC, 50 Hz, three-phase, 415 V.

38. How is three-phase electricity created at a power station?

    1. Three single-phase alternators have interconnected output power circuits.
    2. Single-phase generators with rectifiers creating three-phases.
    3. Multiple transformers create three-phases.
    4. Each alternator has three stator coils so one revolution of the rotor generates three separate sine wave outputs.
    5. Three single-phase alternators each power one line voltage; each building takes all three lines to have three-phase power.

39. Which of these does a single-phase electricity current look like on an oscilloscope screen? (Hint, draw them.)

    1. Zero phase angle zero current, 90° phase angle maximum positive current, 180° phase angle zero current.
    2. Zero phase angle maximum positive current, 90° phase angle zero current, 180° phase angle maximum negative current.
    3. Zero phase angle 50% maximum positive current, 90° phase angle 100% positive current, 180° phase angle zero current.
    4. 135° phase angle zero current, 225° phase angle maximum negative current, 315° phase angle zero current.
    5. Zero phase angle zero maximum negative current, 90° phase angle zero current, 180° phase angle maximum positive current.

40. Which correctly describes the relationship between voltage and current in an alternating current system?

    1. Voltage and amperes are synchronized.
    2. Voltage peak occurs behind peak value of current.
    3. Current always follows voltage producing it by exactly one phase.
    4. Inefficient generators produce a current flow lagging voltage.
    5. Current always follows fractionally behind the voltage that produces flow of electricity.

41. What is the advantage of a three-phase system?

    1. Widely variable phase current meets variable demands.
    2. Continuously stable power supply.
    3. More easily generated.
    4. Can generate at any desired frequency.
    5. Quieter than single-phase.

42. How should the services in a building take power from a three-phase supply?

    1. Each phase serves a different part of the building.
    2. The mechanical services distribution board always takes all its power from the yellow phase.
    3. Single-phase circuits take current from each phase.
    4. Equal current taken from each phase.
    5. 240 V circuits for lighting and small power equipment each connect to all three phases.

43. Where are cartridge fuses or MCBs always installed?

    1. Live phase cable.
    2. Neutral wire.
    3. Earth conductor.
    4. External to the building.
    5. Within a fire-resistant switchboard.

44. Which is true about three-phase motors?

    1. Run hot.
    2. Need built-in cooling fan.
    3. Generate more noise than an equivalent single-phase motor.

4. Quieter than single-phase motors.
5. Provides more power output for same line current as a single-phase motor.

45. What opposes flow of electrical current into an electric motor?

    1. Resistance of the motor coils.
    2. Inductance.
    3. Temperature coefficient of resistance increases circuit electrical resistance.
    4. Mechanical feedback from forces on motor output shaft.
    5. Capacitance of motor control system.

46. How is electrical energy consumed by an item of plant, equipment or a whole building measured?

    1. Magnetic field-sensing data logger is strapped to the single or three-phase cable.
    2. Kilowatt meter measures instantaneous current flow and applied voltage.
    3. Integrating data logger multiplies output signal from a magnetic current transducer with voltage applied at the same time.
    4. Ammeter reading multiplied by voltmeter reading divided by the time in seconds of their duration is calculated and added to a running total of energy consumed.
    5. Integrating meter multiplies instantaneous current and voltage with the time duration and records kWh consumed.

47. What does self-induced electromotive force do to an electrical circuit?

    1. Nothing.
    2. Speeds up current flow.
    3. Opposes incoming current and causes it to lag behind voltage in real time.
    4. Opposes incoming current and causes it to appear leading the cyclic pattern of the driving voltage frequency.
    5. Supports the incoming current frequency and increases the current.

48. What does inductance do to an electrical system?

    1. Speeds up current.
    2. Multiplies available power by a percentage.
    3. Reduces current.
    4. Reduces available voltage.
    5. Causes current to lag behind applied voltage.

49. What is the time difference between voltage and current in an AC system called?

    1. Lead angle.
    2. Microsecond gap.
    3. Phase.
    4. Peak difference.
    5. Lag.

50. How is electrical power factor raised?

    1. Cannot be improved after equipment installation.
    2. Replace with more efficient specification motor.
    3. Install digitally controlled AC/DC rectifiers at mechanical switchboard.
    4. Install capacitor banks in parallel with each plant item.
    5. Renegotiate electrical supply contract.

51. Which is a typical time interval for a residual current device to open a 60 A circuit-breaker double-pole switch when a fault current occurs?

    1. 6 min.
    2. 1 min.
    3. 1 s.
    4. 20 ms.
    5. Less than 0.001 s.

52. What does RCD stand for?

    1. Residual circuit device.
    2. Residual current device.
    3. Resistance circuit design.
    4. Radio carbon dating.
    5. Ratio circuit device.

53. Which is the most common form of mortality from electric shock?

    1. Burns.
    2. Ventricular fibrillation.
    3. Muscle spasm.
    4. Pain.
    5. Bleeding.

54. Which is not a normal application for use of MICC wiring?

    1. Fire alarms systems.
    2. Public buildings such as theatres.
    3. Tunnels.
    4. Temporary buildings.
    5. Power stations and heavy industrial buildings.

55. Why are cables installed within fixed conduit?

    1. Hides ugly cables.
    2. Conduit is a permanent fixture of the building while cables require replacement when aged.
    3. Conduit becomes earth continuity conductor.
    4. Reduce heat emission from cables.
    5. Protects PCV cables from heat gain from environment.

56. Which is correct about electrical systems?

    1. Watts = volts × amps.
    2. Three-phase current = 3 × single-phase current.
    3. Watts and volt-amperes are always the same value.
    4. Current = voltage × resistance.
    5. Current measured in mega-ohms.