ELECTRICITY

Section 1 - Introduction

The presence of an electrical installation at, or close to, a fire presents an added risk to the firefighter. Although, if the electricity can be isolated, the extra hazard completely removed and extinguishment of the fire cam proceed, the extinguishing medium to be used depends on the material that is burning. It is no longer considered that electrical fires constitute a fire class' in themselves since any fire involving, or started by, electrical equipment must in fact be a fire of Class A, B, C or D. It is only when the current cannot be cut off that special extinguishing agents which are non-conductors of electricity will be required.

1. ELECTRICAL UNITS

Electricity when flowing 210n9 a wire (known as the *conductor)* is called a current and this is the measure of the number of electrons passing a particular point in the conductor. This rate of flow is measured in units called amperes (symbol A). Energy must be provided to cause the electrons to flow and this energy, which may be derived from a number of sources, is termed the applied voltage or electromotive force (emf). This is measured in volts (symbol V): the greater the applied voltage, the greater the current flowing.

An analogy can be drawn between electricity flowing in a circuit and water flowing through a pipe. In hydraulics, the pipe offers a resistance to the passage of water and this resistance is proportional to the diameter of the pipe. Similarly in electricity, the conductor offers a resistance to the passage of the electrons; the greater the size (diameter) of the conductor; the lower the resistance. The resistance of a conductor is measured in ohms

There is a direct relationship between voltage, current and resistance. For example, if a circuit has a resistance (R) of 1 ohm and a voltage (V) of 1 volt is applied at its end, a current (A) of 1 ampere will flow. This fundamental principle is known as *Ohms Law* which states: “the value of a current passing through a conductor is directly proportional to the potential difference between the ends of the conductor, and inversely proportional to the resistance of the conductor." This can be expressed mathematically as $R = V/A$.

2. THE RESISTANCE CF A CIRCUIT

The resistance of a circuit depends on a number of factors namely

- The length of the conductor. An increase in length results in an increase in resistance.
- The cross-sectional area of the conductor. The greater the cross-sectional area = the lower the resistance.
- The material of which the conductor is made. Some materials are better conductors than others (e.g silver is a better conductor than copper). Some materials offer such a high resistance (e.g. dry air) that virtually no current will flow.
- Temperature. For most materials, the hotter the material, the greater its resistance, although carbon is an exception and actually decreases in resistance when the temperature is raised.

It can be seen from Ohm's Law, that, the potential difference (V) becomes greater as the value of the resistance (R) increases, in order to maintain the same current (A) flowing. For example, a conductor having a resistance of 10 ohms may have a potential difference of 50 volts recorded across it. If the length of the conductor is doubled and the current flowing is retained at the same value, the potential difference will be 100 volts. It is because of this basic principle that the transmission of electricity is by extra high voltage, so that the size of the conductors can be kept to a minimum.

3. CONDUCTORS AND INSULATORS

Electricity is always endeavouring to find a path to earth, that is, to escape from its conductor and reach the ground or a conducting path that is connected to the ground. Some materials offer such a high resistance to the flow of electricity that the current cannot force its way along them; they are then said to act as insulators. Others that offer little resistance are said to be good conductors; copper and aluminium are two examples of good conductors and so are extensively used for electric cables. Water is also a good conductor, so a firefighter with wet clothing or holding a wet hose whom touches a live conductor will form an electrical path to earth and will receive a shock, which could be fatal.

Conductors must be insulated in order that they may carry the current to the point where it is to be utilised and to prevent the current flowing to earth. Although air is a good insulator under certain conditions and is the cheapest, some other form of insulation must generally be used except for overhead lines in the open county and for switchboard connections. Where bare conductors are used, they must be supported and at the points of support, arrangements must be made to prevent adjacent conductors from touching. Insulators of porcelain or glass, but sometimes of other insulating material, are employed.

In most positions however the use of bare wire is impossible and the conductor must be continually insulated For many years vulcanised rubber and oil-impregnated paper were the materials used for insulating cables, often with lead sheathing and wire-armouring for protection and to prevent the ingress of moisture. However most medium and low voltage. cables and all flexible conductors nowadays are insulated by PVC (Polyvinylchloride) or other plastics such as PCP (Polychloroprene) or CSP (chloro-sulphonated polyethylene). These plastics are extremely durable and whilst not strictly non-flammable, will only burn whilst a source of heat such as a naked flame is continuously applied

A mineral powder (generally magnesium oxide) within a copper sheathing is also used as an insulating medium for cables which are laid in hot places such as near furnaces or boilers. These cables are known as MICS (mineral-insulated copper-sheathed) or alternatively MICO (mineral-insulated copper-clad) cables and are also being used increasingly in general situations where extra protection is required.

Section II - Generation and Distribution

1. GENERATION

Electricity is generated as alternating current and distributed either as direct current or alternating current. Direct current flows from the positive to the negative terminal of the conductor, but with alternating current there is a rapid change (or alternation) in the direction of flow which occurs many times a second. The number of changes per second is called the frequency and is expressed as so many hertz (Hz) (cycles per second); this is standardised at 50Hz in this country.

A generator is a machine, which produces a difference in voltage between its terminals, the voltage difference being dependent on the design and speed of the generator; when the terminals of the generator are connected to an external circuit, an electric current flows through the circuit. Alternating current is generally used for transmission and distribution as the voltage can be increased or decreased according to requirements by means of apparatus called a *transformer,* and alternating current is particularly suitable for transmission over long distances *for* which very high voltages are required

This is because if the voltage is increased, the current is reduced and hence the equivalent resistance for any given length of conductor passing the same amount of power is less, so enabling smaller conductors to be used. Electricity distributed by supply undertakings is now almost entirely in the form of alternating current which can, if necessary, be converted (or rectified) into direct current for any specialised use.

(a) Alternators

Alternating current generators are called alternators, which in this country are generally driven by water turbines, although gas turbine diesel engine or steam turbines may be used for driving alternators. The public generating stations are linked together and to the main centres of consumption by a network of high voltage overhead conductors generally known as the 'grid'.

(b) Power stations

Power station alternators vary in size between 10,000 and 500,000 kilowatts (kW). The large modern power stations therefore comprise a turbine room in which are located the turbo alternators, the switch room and the control room. To reduce the fire hazard; each of these rooms is generally separated from the others by fire-resisting doors.

The type and construction of the building varies enormously, but modern power stations are generally fire-resisting and consist of a steel frame with brick or reinforced concrete panel walls. Some old power stations may have a certain amount of timber in the root but in the modern stations flammable materials are limited in the structure of the building. However, considerable quantities of insulating oil and other insulating materials used in the electrical equipment will be found, together with lubricating oil used on the turbines and generators. Most present day stations use hydrogen in a closed circuit for cooling the alternators. Some factories and commercial buildings, etc, may have small gas turbine or diesel driven alternators in places of varying suitability.

2. TRANSMISSION AND DISTRIBUTION LINES

(a) Systems

All power stations feed into the national grid system and the majority of power transmission is by overhead line

Although high voltages are used to transmit the large quantities of power from one part of the country to another; it is necessary to convert to lower voltages before the power can be used by consumers. This is done in several stages by means of transformers. Higher voltages are usually reduced to 132 kV, and from 132 kV a reduction is generally made to 33 kV, thence to 415/240 volts, usually through an intermediate stage of 11kv.

(b) Three-Phase system

Alternating current is normally generated by what is known as the three-phase system, that is, a system in which the current flowing is in three interdependent circuits, which are mutually displaced in phase by 120 electrical degrees. For high voltage transmission (11kV upwards) there are three conductors or lines between the generator and the voltage reducing transformer, but when the current is finally reduced below 11 kV to medium voltage, a common return conductor (neutral) is introduced. The voltage between the three-phase lines A, B and C is 415 volts but the voltage between each phase line and the neutral is$\sqrt{3}$ of the phase voltage i.e. 415/1.73=240 volts

These voltages are now the national standard declared voltages for normal consumer use (except for special higher voltage equipment)

(c) Safety procedures

The operation of overhead lines is subject to detailed safety regulations. These regulations precisely define who is a 'competent' person who is permitted to work on overhead lines and this authorisation may only relate to a specific part of the system, outside of which that person may not be considered 'competent'.

The basic principle of operation is that all current-carrying parts of the system are treated as 'live' until they are isolated from the rest of the system, proved to be 'dead' by approved instruments and efficiently earthed either at the points of isolation or at either side of the point of work. No work is allowed until a 'permit to work' has been issued and this permit clearly delineates the precautions that must be taken and the area within which work is permitted. These precautions are of the utmost importance when it is appreciated that:

- Many lines are automatically controlled and can be switched on under computer control;
- Many lines have automatic reclosers so that they are re-energised automatically after a fault;
- An isolated line parallel to a live line may, if not efficiently earthed, carry induced lethal voltages;
- Even single circuit isolated lines may be charged due to atmospheric effects and carry lethal voltages;

Authorised persons climbing live towers are subject to strict control rules, which prohibit working on the lower part of towers within specified distances of conductors.

(d) System control

Irrespective of the voltage involved, every part of the system is under control. Within the control network, access to other control points is usually direct and rapid via telephone or radio. Thus transmission and distribution networks are always under immediate control of 'competent' persons, but local lines at lower voltages may be under the control of local staff on telephone standby in their homes or offices.

It is important that fire brigade personnel should have quick access to the control system, and certain ex-directory telephone numbers are available at brigade controls for this purpose. These are, of course, only for use in a serious emergency and the normal publicised numbers should be used for routine matters.

3. SUBSTATIONS

Types

The point where electricity is transformed from one voltage to another is known as a substation and these can vary greatly in size and type. A rural outdoor substation for example may only occupy a space of about 1.8 x 1.8 metres whereas a 400 kV switching and transforming substation will cover several hectares and may be indoor or outdoor

- *PoIe-mounted substations.* A pole-mounted rural distribution substation does not usually exceed 11 kV, and has a transformer with open high voltage terminals and open or enclosed medium voltage terminals. The high voltage current may be fed to the transformer from overhead or underground cables, and the medium voltage local distribution may also be overhead or underground.
- *Outdoor distribution substation.* The high voltage side again does not usually exceed I 1kV, but may be up to 33 kV. This type of sub-station generally consists of a transformer with no accessible live parts, extra high voltage (EHV) switchgear with no accessible live parts and a locked MV distribution board.
- *Indoor distribution substation* This usually takes the form of a separate building or a room in a building at or below ground level. It will contain one or two transformers, EHV switchgear and MV distribution boards, generally with accessible live busbars. Voltages do not normally exceed 33kV.
- *Outdoor 'grid' substation* These substations vary from single transformer units fed by a single overhead transmission line to a multi-transformer unit with several transmission lines radiating from it. The larger sites may include a control building housing MV and sometimes EHV switch9ear. Voltages may be up to 400kV.

(b) Transformers

The more usual type of transformer consists of insulated copper conductors’ wound round iron cores, which may be immersed in oil in a tank. In the larger types *e.g.* those used for voltages down to 33kV, there are separate radiators for cooling the large quantities of oil. When the warm oil has risen to the top of the tank, it flows down the radiator and the cool oil is then returned to the bottom of the tank. Pumps are sometimes used to assist oil circulation and forced ventilation through the radiators may also be found. In these cases the pumps for oil and air circulation are automatically operated when the temperature of the winding reaches a predetermined level

Smaller transformers (11kV and below) have cooling tubes on the outside of the tank instead of radiators and rely on natural air circulation for cooling. The quantity of oil depends on the size of the transformer and may be as much as 45,500 litres in a large transformer.

Should a transformer sustain damage either through an internal electrical fault or some external cause, the oil may be released possibly at high temperature or even on fire. To prevent escaping oil flowing around other nearby transformers, many modern substations are constructed so that each unit is bunded in a separate compound, which is filled with shingle to a sufficient depth to take the full quantity of oil that could he released. Provision may also be made for draining away the oil from the compound through a flame trap. Many transformers are provided with a water spray, carbon dioxide or vaporising liquid extinguishing system which is automatically operated in case of fire.

(c) Switchgear and circuit breakers

High Voltage

When a switch is opened there is a tendency for the current to arc across the gap, and at high voltages the distance the current will jump is considerable. Consequently high voltage switches used for transformers and feeders are usually filled with oil to quench the arc when the switch is opened Some switches are automatic in operation; others are manual and are operated when it is necessary to open or close a circuit.

A circuit breaker is a special type of switch, which is normally designed to operate automatically to protect a circuit against overloads or faults. Those on high voltage circuits have their contacts immersed in a tank of oil and operate when the current reaches a predetermined level. A very high pressure is set up in the oil when the circuit breaker opens, and so the tank is robustly constructed. A gas vent is also provided to release the gas that is generated when the breaker operates.

Medium Voltage

The distribution side of a transformer that supplies medium voltage current to consumers is connected to a distribution hoard. This is a fuse board containing four busbars, one for each of the three phases and one for the neutral. The board is normally contained in a locked metal case if outdoors, but is open if inside a substation building.

The switching arrangement for isolating transformers from the distribution board is normally through isolating link switches, but sometimes a circuit breaker is connected between the transformer and busbars. Cartridge type fuses are generally inserted between the busbars and the distribution cables and used to isolate them

Feeder Cable Switch pear

The high voltage cables used to connect one substation to another are known as HV feeders and three types of switch may he employed.

- The automatic oil circuit breaker:
- An oil-immersed isolator (which is a manually operated oil-immersed switch),
- An air break isolator (which is a switch normally mounted outdoors on a pole or gantry and operated from ground level).

(d) Ventilation of substations

When substations are situated in buildings, ventilation is necessary as a considerable amount of heat is dissipated by transformers, particularly when working at full load. Where ventilation is provided, means should also exist for shutting off the ventilation in the event of fire although with modern switchgear and protection, the risk is not great. But as oil is used for cooling, there is the possibility that this may become ignited.

METHODS OF DISTRIBUTION

From the substation electric current is distributed to the consumer either by overhead lines or by underground cables. Sometimes the two methods are combined some cables running overhead and some underground.

Underground systems

The cables that run from the distribution boards in the substation are called distributors and until recently each cable generally carries four cores - one for each of the three phases and one for the neutral, although sometimes there is a fifth core for separate control of public street lighting. Underground cables are continuously insulated and armoured

(b) Overhead cables

Overhead cables are normally un-insulated unless there is a possibility of contact being made with them. The cables run from the distribution board in the substation to poles at the start of the distribution system. The phase cores and the neutral cables are connected to the overhead conductors at the top of the pole and consumers' services are tapped at the nearest pole to the premises concerned

(c) Service cables

From the street distributors, service cables are taken to supply each individual consumer and terminate at a main fuse or cut-out in the consumers premises. Apart from the main fuse and meter, the installation is generally the property of the consumer and therefore varies considerably in type and layout.

5. SHORT CIRCUITS

Whilst air and most other gases are good insulators, electric current can, if the insulation becomes faulty, leak between two conductors or between one conductor and earth. The amount of the leak depends on, among other things, the voltage, the condition of the insulating material and the distance between the conductors.

If therefore, a breakdown occurs in the insulation separating adjacent conductors or a conductor from the earth, what is known as a *short circuit* takes place. That is, the current instead of following its normal path finds a quicker return path. The electrical resistance in such a case may be negligible whereupon a heavy current will flow and will cause intense local heating combined with overloading of the cables, which may become dangerously overheated unless the circuit is broken.

Such a breakdown in the insulation may take place in many ways. Insulating material will deteriorate with age or from other causes and a condition may be reached where the insulating properties are insufficient to prevent a short circuit. The perishing of rubber is a good example of this, and is one of he main reasons why PVC has superseded rubber as an insulating medium.

Cables or wiring may be subjected to mechanical stress through vibration caused by external influences whilst damp is a frequent cause of the breakdown in insulating properties. Alternatively, excessive heat through external causes, such as steam pipes, industrial processes for which the system has not been designed, will also lead to rapid deterioration. Further, insulation is not infrequently destroyed by nails driven into walls and penetrating the wiring; workmen's picks or pneumatic drills striking cable ducts: abrasion and (although rarely) rodents.

As has been stated, if a breakdown of insulation occurs, excessive current will probably flow through the faulty and if the fuse or circuit breaker fails to operate, overheating will result.

For a fire to occur in such circumstances, it is only necessary that there should be combustible material in close proximity to the heated wire or to the hot spark. Fire can readily be started through a short circuit whether or not a cable is insulated. Likely places that are susceptible to damage by leaks and short circuits are below manhole or inspection covers containing cable boxes, in the base of street lighting standards and in pillars, which contain electrical equipment. Effective steps taken to prevent the entry of moisture will reduce or eliminate the risk.

6. PROTECTIVE DEVICES

When an electric current passes along a conductor it generates heat, the amount of which depends on the square of the amount of current flowing and on the resistance of the conductor. When a cable is installed the size is calculated according to the probable maximum current it will be called on to carry. If this maximum is exceeded, either because of excessive load placed on the circuit, or because of a short circuit, overheating will occur and the wire may reach a temperature sufficient to ignite the combustible insulation with which it is surrounded. To prevent this, an electric circuit is fitted with a fuse, or if the circuit is carrying a heavy current, with a mechanics device to break the circuit in the event of an overload.

The operation of a fuse in an electrical circuit is based on the principle that heat is generated when current flows through a conductor. The fuse is a short length of wire having a low melting point and forms part of the circuit, the size of the fuse wire being calculated for the normal expected load. If this is greatly exceeded, the passage of the current causes the temperature to rise and the fuse wire to melt, thus breaking the circuit. The current for which the fuse is set to melt is very much less than that which would allow a dangerous temperature rise in the rest of the circuit. The fuse thus acts as the weak link in a chain. This explains the danger of replacing fuse wire with incorrect substitutes or with fuses of a heavier capacity than those for which the circuit is designed.

In installations of greater power, the use of fuses is impracticable for technical reasons and automatic circuit breakers, which operate when the current rises to a dangerous level, are installed. Such circuit breakers are designed to open automatically if a fault occurs, or they can be opened manually if necessary, e.g. to test the mechanism. They can often be closed manually or automatically if they open due to a fault, to ascertain whether the overload was of a momentary nature only. Therefore, it should never be assumed that a circuit, especially a high voltage one, is dead when a circuit breaker has operated, if handling apparatus, particularly overhead lines. If a line has been brought down because of an accident and is lying on the ground it may not be making sufficient contact with the ground to operate the contact breaker. Furthermore, the contact breaker may be closed automatically several times after a period of time, to test whether the fault has cleared.

Section III - Internal Distribution

1. SINGLE PHASE TWC-WIRE AND EARTH SYSTEMS

(a) The Service point

Small consumers such as domestic householders are supplied with a single phase two-wire and earth system. In overhead supplies, the service lines terminate at insulators attached to the building; from these terminals short lengths of insulated cable are run inside the building. Underground service lines with insulated cables terminate in a sealing box chamber.

At the service point a cut-out is then provided. This consists of a fuse or perhaps a circuit breaker that protects the supply cables if severe overloading occurs. In domestic premises they are rated at 60 to 100 amps. In modern practice the neutral conductor is not fused and a solid bar link or other such connection is installed. This is because the neutral conductor, which is common to all three phases, is connected to the star point of the transformer at the station and is earthed there. Thus the neutral conductor is always near zero potential. It is now general practice to supply an earth terminal that is connected to the cable sheath and to the consumer's metal work; in some cases neutral and earth are combined.

Finally the service cable is connected to the meter, which records the units of electricity consumed. The service cable may be connected to more than one meter if different tariffs operate in a particular consumer's premises

(b) Internal Distribution After the Meter

A typical older small-consumer type of installation would consist of distribution and fuse boards and would comprise:

- *A main switch fuse* This is a single-phase double-pole switch with main fuses or phase fuse and neutral link Alternatively *a* main switch might comprise a single-phase double-pole switch without fuses or links
- *Intermediate fuse boards.* These will be installed as necessary according to the requirements of the consumer.
- *Final distribution fuse board* One or several of these may be installed as necessary. From these fuse boards pairs of wires (live and neutral) and usually an earth wire are led off as separate ways to form the individual sub-circuits. In modern installations these components would be united in one 'consumer unit' wired to the meters, and only the live conductors of the final sub-circuits are fused. Occasionally, old installations may be found with fused neutrals and similarly in older installations, it may be found that each socket outlet is fed independently with its own live and neutral wire from the final distribution fuse board.

In typical modern installations, the socket outlets are fed by ring circuits where each live conductor forms a loop, both ends of which are connected to the same fuseway at the distribution board.

Each socket may be fed from either side according to the load on the other branches.

2. THREE-PHASE FOUR-WIRE AND EARTH SYSTEM

If the load is not very great, as for example in a block of flats or in small commercial or industrial premises not using heavy or large power machinery, the supply may be tapped off a normal low voltage service cable which would terminate in the building as a service point.

Connection of the service cable is made in the same way as for a two-wire system with fuses or cut-outs inserted in all three line conductors. After the meter, the supply is fed through a three-phase main switch fuse into a busbar chamber, where circuits may be taken off the busbars to the final distribution fuse boards. The final sub-circuits may be fed off separate way from the distribution fuse boards as already detailed. Arrangements at this kind do not require a separate intake room provided there is no ready access to the busbar chamber

3. THREE-PHASE THREE-WIRE SYSTEM

(a) Intake equipment

This system would be for large users at premises where the power load is high. In a typical arrangement the power is supplied at 11 kV and the transformation to medium/tow voltage would take place in a substation installed on the premises. The equipment includes high-voltage oil-filled switchgear, a normal distribution transformer and the service point for a three-phase four-wire system The meter would be inserted on the medium or high voltage side of the transformer.

(b) Internal distribution

The three-phase four-wire and earth system (the neutral is added at the transformer) is now available for distribution on the premises according to whether it is required for lighting or heating (single-phase two-wire circuits) or power for electric motors, which may be three-phase three-wire circuits for which no neutral is required

A typical arrangement would consist of:

- *A main distribution board.* This is adjacent to the transformer and contains busbars of heavy section the incoming cables to the busbars being usually protected by suitable three-phase main control-switch fuses or by circuit breakers. Connected to the busbars would be sub-mains protected by switch fuses or by circuit breakers. These sub-mains will terminate in sub-distribution boards
- *Sub distribution boards.* A sub-switch room may be provided, but in many consumer premises, depending on the load and complexity of distribution, wail-mounted panels *may* be used. The equipment is similar to that in a main distribution board, but of smaller size. Connected to the busbars are circuits terminating normally in the final distribution boards
- *Final distribution boards.* This last stage distributes supplies to the final sub-circuits of apparatus, lighting and heating, etc.

4. PROTECTIOM AGAINST EARTH LEAKAGE

As has already been explained, electricity can only be safely used if the conductors or windings of apparatus which convey it are insulated, not only against contact with other conductors, but also against contact with any metal in which they are encased. Insulation may fail as a result of ageing, the ingress of moisture, mechanical damage, heat of corrosion, and precautions have to be taken to protect personnel and installations against the consequent dangers. These may be severe or fatal shock, or equipment overheating to a sufficient degree to constitute a fire risk.

(a) Earthing

Earthing is the safeguard normally applied against the consequences of contact between any current-carrying conductor and the casing containing it. The effect of earthing the casing of apparatus is to provide a return path to the earth point of the supply transformer. The total resistance of this return path should be low enough to pass sufficient current to blow the fuse or operate the circuit breaker in the event of a contact between conductors and metal casing, thus isolating the circuit.

(b) Earth-continuity conductor

The earth-continuity conductor consists of a special conductor (sometimes lad in with the insulated cores of the cable) connecting the earth terminals of all metal-cased appliances and of all socket outlets (and hence of any properly wired appliances plugged into the sockets) to the consumer's earthing terminal

In installations using metal conduit, ducts or trunking, or metal-sheathed and/or armoured cables, the earth-continuity conductor is sometimes formed wholly or partly by the metal cladding of such systems. It is then vital that all joints should be mechanically sound, electrically continuous and protected where necessary against corrosion.

(c) The earth-fault loop

The earth-fault loop (line to earth loop) starting and ending at the point of fault, comprises the following sections:

- The earth-continuity conductor from the point of fault onwards;
- The consumer's earthing terminal
- The metallic return path *(i.e.,* cable sheath and/or armouring of the supply cable, or the continuous earth-wire of an over-head line) where available, or through the ground as an alternative return path where no metallic return path is available
- The path through the earth neutral point of the transformer and the transformer winding;
- The line conductor back to the point of fault.

For the earthing to he effective, the total earth-loop impedance of an installation must be matched to the minimum fusing impedance of the protective gear in use to prevent a dangerous rise of voltage on the casings of electrical apparatus.

(d) Connections to earth

Six methods of providing an earthing connection for electrical circuits are as follows:

- *Water pipe earthing.* This method has become unreliable because of the extensive use of plastic piping, and is now forbidden as the sole means of earthing.
- *Local-mass earthing* (other than water mains pipe). Plates, rods, steel frames of buildings are sometimes used but in practice these rarely provide a low enough value of earth-loop impedance and may be subject to variation due to site and weather conditions, e.g. dampness or dryness of the soil, etc.
- *Cable sheath and/or armouring.* This is the most reliable system available and should be used whenever possible, unless the system of supply is as provided below (in protective multiple earthing).
- *Protective multiple earthing* In this system the earth-continuity conductor connecting all exposed metal work of the electrical installation is itself connected to the local supply neutral whether the supply system is overhead or underground. This system is extremely reliable and is being increasingly used throughout the country.
- *Voltage-operated earth-leakage circuit breaker* This system is often found not to have been installed properly in the first instance and/or to have been rendered ineffective in various ways afterwards. It is not easy to make it selective, and it may be subject to nuisance tripping through transient dampness; metallic shunts or parallel earth paths are the most frequent cause of ineffective operation. Its use is not advised except in very special circumstances
- *Differential current earth-leakage circuit breaker* This type of earth-leakage circuit breaker provides shock protection at least as good as by direct earthing methods; It is selective in operation and provides a greater protection in respect of fire risk The high-sensitivity type, operating at about 25 milliamp out-of-balance current, makes a fatal shock to earth almost impossible. Nuisance tripping should not he bad, and experience has shown that the so-called nuisance tripping is always fault tripping. The type operated on differential currents of 0.5 to 1 amp for up to 100 amp rating does not protect against shock; it can be used where the earth-loop impedance may be as high as 80 ohms for the 0.5 amp and 40 ohms for the 1 amp.

(e) Fires caused by earth faults

Fires can result from earth faults giving rise to local overheating, tracking or arcing, each of which can ignite insulating or combustible material in the vicinity. The following are some examples of circumstances where there is a high impedance, which prevents the protective gear from operating:

- Failure of insulation allowing an undesirable leakage to take place between a phase conductor and an earthing conductor or earthed metal work, e.g. persistent arcing between a conductor and conduit.
- Local overheating at a point of high resistance in the earth fault path itself, *e.g.* at loose or corroded

joints in the earth-continuity conductor.

Earth fault current, unable to dissipate due to high impedance in the earth fault loop, finding alternative paths to earth by tracking or arcing to adjacent metal work, e.g arcing between an earthed conductor (conduit) and a composite gas pipe. This could puncture the gas pipe and cause the escape and ignition of gas.

5. WIRING SYSTEMS FOR CONSUMER INSTALLATIONS

All wiring systems consist of conductors which are either bare or insulated and which are usually provided with some means of mechanical protection and fixing in the route the conductors take. The difference is mainly in the materials used

(a) Cables used for wiring

Cables used for wiring can be single or multi-cored. Single cables are now PVC insulated for general use, but vulcanised rubber insulation with tape and braid reinforcement may still be found in old premises. They are very tough and are used by the supply authority and for conduit wiring. Multi-cored cables have each core insulated separately and the whole encased in a pvc outer sheath Tough rubber sheathed cables may still be encountered; these resist most corrosive fumes but deteriorate under sunlight and the rubber is, of course, combustible. PVC-sheathed cables are almost non-flammable and are unaffected by most chemicals, petrol, oils and moisture. They are not quite as pliable or resistant to high temperature and pressure as vulcanised rubber, but other plastics are used in these circumstances

Lead-alloy sheathed cables are sometimes to be found, but are no longer used for new work. These are weatherproof and resist some acids, but are attacked by alkaline fumes and corrode in contact with oak under damp conditions.

Mineral-insulated copper-sheathed cables (MICS) are being increasingly used for general work although originally designed for use in extremely hot situations, and where intrinsic fire safety is essential. They consist of a number of conductors (1 to 7) embedded in highly compressed magnesium oxide insulation enclosing a continuous, solid drawn copper (or aluminium) sheath, and are resistant to damp, and mechanical damage.

Under the Regulations both power and lighting circuits require a separate earth-continuity conductor and this often takes the form of a bare wire inserted between the other two insulated conductors within the cable. In MICS the sheathing forms the earth-continuity conductor.

(b) Wiring systems and methods

The choice of a wiring system must take into account the conditions in which the circuits are to be installed, the appliance or apparatus they are designed to serve, and whether it is to be a surface or buried system. Most cables can be laid directly and permanently under plaster, but heavier installations employ metal conduit through which insulated single-core cables can be threaded. The cables can then be withdrawn and replaced if required or when re-wiring becomes necessary. The conduit can be laid in the walls and floor when the building is constructed.

Clip or saddle-fixed wiring is now used for many installations. The pvc-sheathed cable or MICS can be laid on the surface of walls or can be buried in the plaster, as the building is constructed.

Conduit-carried wiring is often found surface-fixed, especially if the wiring is done after the building has been constructed. Strong, durable, non-corroding, non-rusting plastic or fibre conduit may be used, in which case an earth-continuity conductor is needed. Surface-fixed conduit may be made of steel or aluminium and is supplied in heavy or right gauge. This conduit can be made watertight, but steel tends to corrode from condensation.

Aluminium conduit is resistant to corrosion, is light and does not need painting. The whole installation must be electrically and mechanically continuous and properly earthed. Screwed conduit is best and grip socket satisfactory, but tubes slipped together and not property locked are not electrically satisfactory.

Another system employs cable trunking, in which large section metal or plastic trunking is used instead of conduit to accommodate large numbers of cables of all types. This is usually a surface system so as to give easy access to cabling for rearrangement.

In many factories and workshops the plant layout is often subject to modification. It is essential therefore to have complete flexibility of the electrical installation and this is often met efficiently and economically by cable or busbar trunking systems. These are heavy section conductors in a steel trunking generally mounted overhead and tapped to serve a machine or other apparatus; a lead is taken from the fuse box (or tapping box) to each machine. The lines may be separate leads from the distribution point or arranged in rings fed from both ends

(c) Rising mains

In large blocks of flats and commercial buildings, the Power Authority or landlord sometimes installs rising mains consisting of bare or lightly insulated conductors. These are carried vertically through all floors up to roof level either totally enclosed in earthed metal casing or in a specially provided chase, channel, trunking or shaft fixed to insulators. They comprise three line and neutral busbars, which are tapped at each floor as required. An earth-continuity conductor is also provided. The opening in the floors through which the busbars pass should be efficiently sealed with non-combustible maternal for the full thickness of the floor, particularly as a precaution against fire

(d) Points of good practice

Switches Single-pole switches must always be inserted in the live conductor. If they are installed in the neutral they will successfully interrupt the flow, but will leave the major part of the circuit live to earth, with consequent hazard of electric shock.
Joints All joints should be in proper joint boxes or soldered, or made in such a way that they offer minimal resistance.
Temporary wiring. This should (as, of course, should all wiring) conform to the Electrical Wiring Regulations.
(iv) *Openings for cable passage.* The holes made for all wiring passing through floors and walls should he properly bushed with non-combustible materials.

(e) Flexible wiring

Electric circuits in premises normally terminate in a fixed electricity consuming device, such as a lamp, motor, heater, etc., or in a socket outlet or other device to which a flexible lead may be attached, the other end of which is connected to the current-consuming apparatus. They may be of various types of construction, depending on the use to which they are put.

The most common type of flex consists of two or three separate conductors, each with one or two layers of coloured rubber or pvc insulation, finished off with silk or cotton braided together, or with a pvc sheath. Modern twin-wire flexes often consist of two bare wires laid parallel and fused into a plastic sheath.

For many years the colour coding for electric flex in this country has been red for the live conductor black for the neutral and green for the earth. Now however, all three-core flexes attached to domestic electrical appliances for wholesale must be coded in the following colours: *brown* for the live conductor, *blue* for the neutral and *green and yellow for* the earth.

Where not subject to handling or heat, flexible leads will give reasonably good service, the length of which will depend largely on atmospheric conditions. Owing to the close proximity of the two conductors$_1$ deterioration of the insulation will lead to short circuits, and many fires have been caused in the past due to old or worn flexes being retained in use

6. ELECTRIC LIGHTING

There are three main types of electric lighting in use, namely:

Incandescent lamps;
Vapour lamps;
Luminous discharge tubes

Another type of lighting, namely arc ramps, may still be encountered, but these are rapidly being replaced by modern types of lamp.

(a) Incandescent lamps

The incandescent lamp is the most generally used form of electric lighting. The current passes through a fine high-resistance wire filament, raising it to white heat. The filament is enclosed in a glass bulb, which is generally filled with an inert gas - the gas filled lamp. Operating voltages are standardised at 240 v~, but some areas may be found where the voltage differs from this.

(b) Vapour lamps

Another type of lamp is without a filament. Instead, a small quantity of mercury or sodium is contained in a gas-filled quartz tube enclosed in an evacuated glass bulb. When the current is turned on, the mercury is heated and vaporises and the current passing through the vapour causes it to glow. The colour of the light depends on the materials used; mercury gives a bluish-green light and sodium an orange-yellow light. Normal voltages can be employed for these lamps, but each must be fitted with a choke and a capacitor to limit the current passing. The choke and capacitor are usually integral with or close to the lamp-holder.

A modified form of mercury vapour lamp is the fluorescent tube, which has come into wide use for lighting purposes. In it, ultra-violet light emitted by the mercury vapour strikes a thin layer fluorescent material deposited on the inside of the tube and causes it to emit visible light.

(c) Luminous discharge tubes

When a high voltage current is passed through a tube containing certain gases at very low pressures, the gas becomes luminous and emits a colour, which depends on the gas in use. For example, neon gives a red right, carbon dioxide white and hydrogen green. Because the tubes can be bent into a variety of shapes, they are widely used for advertising purposes on the fronts of buildings and in shop windows. These tubes work at 3,000 volts or more, depending on the length of the tube, transformers being employed to step up the voltage to the required figure. The wiring therefore constitutes a serious hazard to firefighters, since it may run in many directions over the face of a building against which it may be necessary to pitch a ladder. The transformers, which are usually about 305 - 380 mm square, are mounted close to the discharge tubes and may be in considerable numbers, depending on the length of tubing to be lighted. Thus, the average sign for a theatre or cinema may require twenty or more such transformers

All such installations must be provided with a ‘fireman's switch', which is mounted on the fascia of the building out of reach of the public but accessible to the fire brigade. This switch isolates the current from the transformers and renders the whole of the installation dead. Before pitching a ladder against a building on which luminous discharge signs are fitted, this switch should be opened with a ceiling hook by pushing it upwards.

(d) Arc lamps

Although arc lamps are not used very much nowadays, some may still be found. The arc lamp consists of two rods of high resistance carbon and the controlling mechanism. When a current is passed, the ends of the carbon are separated automatically and an arc is maintained, the glowing particles of which emit a brilliant light. If the supply is alternating current, a choke and a transformer are used to reduce the current.