

6.0 Electrical Installations

An *electrical installation* is a combination of electrical equipment installed to fulfill a specific purpose and having coordinated characteristics. In dealing with the electrical installation, it is necessary to ensure the safety of personnel as well as the protection of equipment from electrical faults.

The most common types of faults in domestic systems are (a) the short circuit faults (phase to neutral faults) - as a result of which large currents will flow and damage may occur to wires, insulators, switches, etc., due to over heating; and (b) insulation failure (fault between the phase conductor and non-current carrying metallic parts) of an electrical equipment - as a result of which high voltages may appear on the frames of equipment and may be dangerous to a person coming in contact with it.

Therefore, all electrical wiring systems and all electrical apparatus associated with wiring must be protected to:

- (a) prevent damage by fire or shock
- (b) maintain continuity of the supply
- (c) disconnect faulty apparatus from the remainder of the system
- (d) prevent damage to wiring and equipment
- (e) minimize the system interruptions under fault conditions.

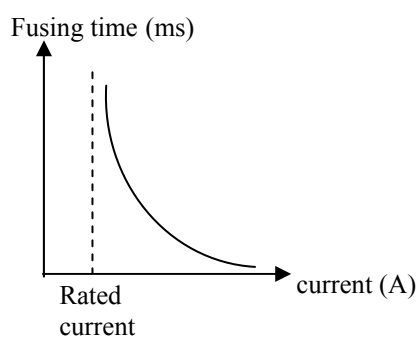
Protection must be provided against excess currents and earth leakage. Protective equipment must possess the following features:

- (a) Certainty and reliability of operation under fault conditions and non-operation under normal conditions.
- (b) Discrimination
- (c) Rapidity of operation
- (d) Simplicity, low initial and maintenance cost
- (e) Easy adjustment and testing.

The most popular methods of protection are

- (i) earthing or grounding of equipment
- (ii) use of fuses or circuit breakers (such as the Miniature Circuit Breaker – MCB)
- (iii) use of earth leakage and residual current circuit breakers.

6.1 Earthing or grounding of equipment refers to the connection of non-current carrying parts of electrical equipment to the earth to maintain earth potential. In domestic systems, the earthing circuit is usually earthed by connecting to metallic water pipes buried in ground. An effective earthing (grounding) system avoids having dangerous potentials on the equipment even during electrical faults and also ensures the proper operation of electrical protection equipment during fault conditions (this will be discussed under the operation of Earth Leakage and Residual Current Circuit Breakers).



Fuses: Fuses are the earliest means of protection against over-currents in circuits. Basically, the fuse consists of a short length of suitable material (often a thin wire). When the current flow is greater than the fusing current of the fuse, it will get hot and burn (melt), thus interrupting the fault current before damage could be caused. The size of the wire is designed to carry indefinitely the normal circuit current (rated current) and usually designed to fuse (melt/burn) at about 1.7 – 2 times the rated current carrying capacity. They have inverse time characteristics as shown in Figure 1. Accordingly, the operation of the fuse is faster when the fault current is larger.

In addition to operating for short circuits between the live and neutral, fuses are expected to operate under over-load conditions. Over-loading occurs when extra power is taken from the supply. The increased current due to over-loading will have an immediate effect on the cables; they will begin to heat up. If the over-loading is sustained the result could be an accelerated deterioration of the cable insulation and its eventual breakdown to cause an electrical fault. A heavy-sudden over-load for a very short period (e.g. such as in Motor starting) is not very serious since the over-load current flows for a short time and the rise in cable temperature is not very high.

6.2 Fuses

Terms commonly used with fuses

Fuse: a device for opening a circuit by means of a conductor designed to melt when an excessive current flows along it.

Fuse element: part of a fuse, which is designed to melt and thus open a circuit

Fuse link: part of a fuse, which comprises a fuse element and a cartridge (or other container) and is capable of being attached to the fuse contacts

Current rating: this is the maximum current, which the fuse will carry for an indefinite period without undue deterioration of the fuse element

Fusing current: this is the minimum current that will cause the fuse element to heat up melt or blow

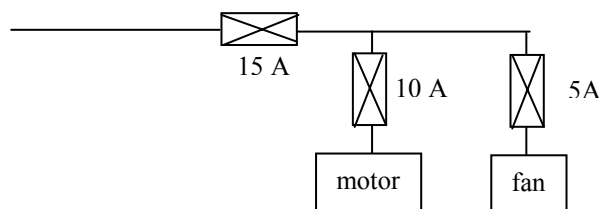
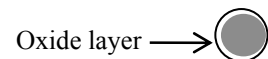
Fusing factor: this is the ratio of the fusing current to current rating

There are 3 general types of fuses.

- (a) re-wirable (semi-enclosed) fuse
- (b) cartridge fuse
- (c) high-rupturing capacity (HRC) fuse – a development of the cartridge fuse

6.2.1 Semi-enclosed (re-wirable) fuse is a simple device. It consists of a short length of wire, generally of tinned copper. The current at which the wire melts depends on the length of the wire and its cross sectional area ($R=\rho l/A$). Although the re-wirable fuse is cheap, involving only the fuse element, it has a number of disadvantages and limitations as listed below.

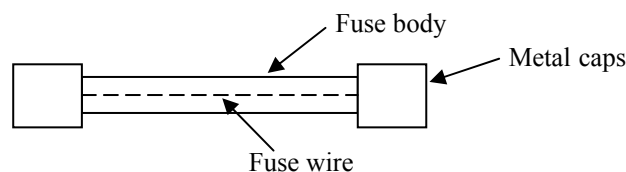
- Deterioration with time due to oxidation - may operate at lower currents than expected due to the reduction in cross sectional area and hence increase in resistance
- very easy for an inexperienced person to replace a blown fuse-element with a wire of incorrect size or type
- the time taken for the fuse to blow may be as long as several seconds during which time considerable electrical and physical damage may result to the circuit conductors and the equipment being protected.
- Calibration of re-wirable fuse can never be accurate



- unsuitable for circuits which require discriminative protection. i.e. it is possible in certain circuit conditions for the 15 A rated fuse element to start melting before the 10 A rated element completes fusing
- not capable of discriminating between a transient high current (such as motor starting current) and a continuous fault current. i.e. some times may burn during motor starting
- has an associated fire risk
- when the fault current is particularly high, though the fuse works, an arc may still be maintained by the circuit voltage (through air and metallic vapour)

Due to the above reasons, the semi-enclosed or re-wirable fuses are not regarded as a suitable means of protection against over currents and are now not recommended.

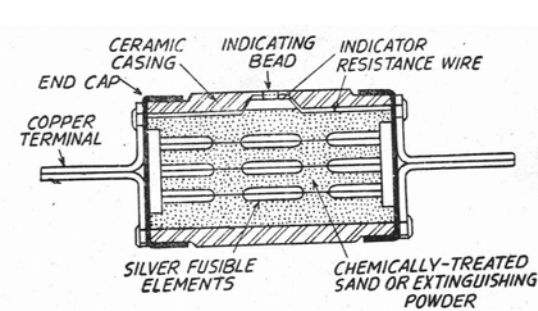
6.2.2 Fully enclosed (cartridge) fuse was developed to overcome the disadvantages of the re-wirable type of fuse.



In its simplest form, the fuse wire is enclosed in an evacuated glass tube with metal end caps. Non-deterioration of the fuse element is one of the most reliable features and is usually more accurate. However, cartridge fuses are more expensive to replace.

Both re-wirable and cartridge type fuses are usually of low rupturing capacity (product of maximum current which the fuse will interrupt, and the supply voltage). They are used in general house-hold, commercial and small scale industrial applications.

6.2.3 High rupturing capacity (HRC) fuses are used for high current applications.



Section of HRC fuse

The HRC fuse is usually a high-grade ceramic barrel containing the fuse element. The barrel is usually filled with sand, which helps to quench the resultant arc produced when the element melts. The barrel is able to withstand the shock-conditions which occur when a high fault current is interrupted. Normally, the fuse elements are in parts connected in the middle by bridges which have a very precise melting point of about 230 °C. These are very accurate. With a specific current, the temperature rises and the bridge melts producing a break in the circuit. The metal vapour diffuses with silica powder and the product is of high resistance. The HRC fuses are expensive to replace once blown.

6.3 Circuit breakers for over current protection

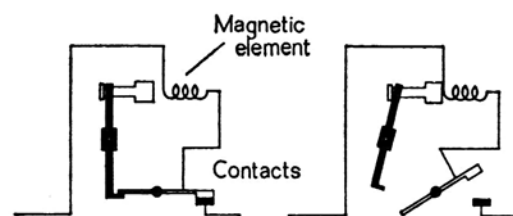
The circuit breaker is a device for making and breaking a circuit (under normal and abnormal conditions). A circuit breaker is selected for a particular duty taking the following into consideration (a) the normal current it will have to carry and (b) the amount of current which the supply system will feed into the circuit under a fault (which current the circuit breaker will have to interrupt without damage to itself). It is able to provide a more accurate degree of over current protection than that normally provided by either semi-enclosed or cartridge fuses.

The circuit breaker has a mechanism which, when it is in the closed position, holds the contacts together. The contacts are separated when the release mechanism of the circuit breaker is operated by hand or automatically.

Miniature Circuit Breakers (mcb), which are commonly used in domestic installations, incorporate most of the features of the circuit breaker in a compact form and are being fitted in place of fuses in consumer units in the home or office. An MCB eliminates the cost of fuse replacement and may be used as a switch for isolating circuits.

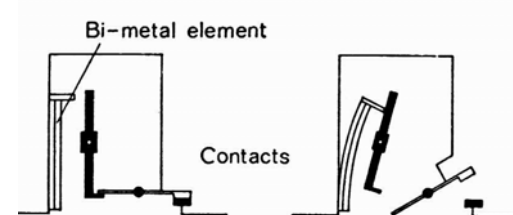
In the mcb, the automatic operation is by magnetic or thermal means. The reason for the two characteristics is to have proper operation during both short circuit and overload conditions.

Magnetic mechanism



The magnetic mechanism uses a solenoid with an iron piece. It is used for short circuit (fault) protection, as high fault currents have to be isolated almost instantly. When the circuit current is above a certain level, the magnetic field strength increases to cause the iron piece to move in the direction of solenoid. This operates the tripping linkage and open the contacts. Even if the mcb is closed again, the contacts will not hold while the fault is still present.

Thermal mechanism



The thermal mechanism uses a heat sensitive bimetal element. When the element is heated to a pre-determined temperature, the resultant deflection trips the circuit breaker. The time taken to heat the element to this temperature depends on the magnitude of the current and provides the necessary time delay characteristics (tripping by this means is not so rapid as with magnetic tripping).

When a small sustained overload occurs, the thermal trip will come into operation after a few seconds or even minutes. However, when a heavier over load occurs, the magnetic trip coil operates quickly to disconnect the faulty circuit. This time delay characteristic is useful to avoid unwanted interruptions during the starting of motors and similar instances where the initial current may be high, but not an overload condition.

Advantages of mcb s over fuses are

- Non destructive determination of tripping characteristics
- Shorter tripping times under moderate over currents than with fuses
- Immediate indication of faulty circuit
- Reclosing can be effected at once after the fault has been cleared
- No stock of fuses are required
- Can be easily used as a circuit control switch when needed

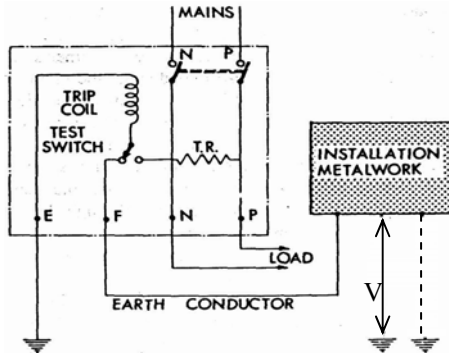
6.4 Circuit Breakers for earth leakage circuit protection:

These are used to detect electrical faults to earth in equipment and to clear the fault by tripping and may be classified into two types:

- Voltage operated protection – Earth Leakage Circuit Breaker (ELCB)
- Current operated protection – Residual Current Circuit Breakers (RCCB) or Residual Current Device (RCD)

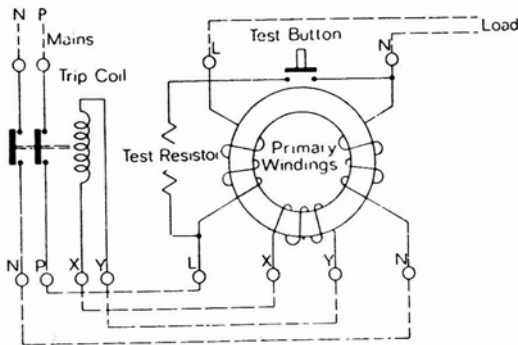
The earth leakage protection device is commonly known as **Trip Switch** by electricians.

Earth Leakage Circuit Breaker (ELCB):



It is to be noted that for the proper operation of the *ELCB*, two earth terminals are required. These are the frame earth to which all non-conducting metallic parts of equipment are connected, and the *ELCB* reference earth. The *ELCB* will normally operate when the voltage across the coil, which corresponds to the voltage of the frame earth with respect to the reference earth, exceeds about 40 V. [Note: Up to about 50V has been traditionally considered as a safe voltage. However, it is now known that what is important is the current that may pass through the human body rather than the voltage, and that too is time dependent. Thus the *RCCB* is now preferred to the *ELCB*.

Residual Current Circuit Breaker (RCCB):



The operation is based on a fault current, causing a difference between the line current and the neutral current (the difference need not actually flow to earth but back to the circuit through an unplanned path). This difference is used to energize the solenoid, which causes the switch to open. Under normal operating conditions, two identical windings, m_1 and m_2 , will carry the main current. Since the currents are equal and opposite through the two windings, there is mmf balance and there will be no induced emf on the detector winding. Thus the operating coil will not be energized. However, in case of a fault the line and neutral currents will not equal and the trip coil will be energized due to the induced currents in the detector winding.

In both the *ELCB* and the *RCCB*, a test switch 'T' is provided to create an artificial fault for test purposes.

Advantages of RCCB:

If the live wire is exposed (the insulation is open) and then some body touches it, he may get a shock if a current passes through him. In the case of voltage operated *ELCB* this earth current is not going through the tripping coil and will cause danger. But in the case of *RCCB*, the return path is going to loose part of the current, which passed through the human body, which in turn would cause a resultant flux within the ring energizing the tripping circuit.

6.5 Earthing or Grounding

Earthing is carried out in an electrical installation for the purpose of,

- limiting the potential (voltage) of current carrying conductors forming a part of the system – “*neutral earthing*”
- limiting the potential of non-current carrying metal work associated with equipment, apparatus and appliances in the system – “*equipment earthing*”.

The potential of an installation is measured with respect to the general mass of the earth or commonly called *earth*. Thus the potential is limited with respect to earth.

Neutral earthing: This is important because the performance of the system in terms of short circuits, stability, protection, etc., is greatly affected by the state of the neutral conductor. When the neutral is properly grounded, voltages of the phases are limited to near phase to ground voltage.

Equipment earthing: This refers to grounding of all metal work of equipment other than the parts which are normally current carrying. This is governed by various regulations such as the IEE regulations. The objective of this grounding is to ensure effective and rapid operation of the protective gear in the event of earth fault currents which might otherwise be undetected and cause fire and also protect against danger to life through shock due to installation metal work being maintained at a dangerous potential relative to earth.

6.5.1 Types of earthing arrangement:

In the regulations for electrical installations, the types of earthing systems are identified as follows, depending on the relationship of the source (supply authority network) and of the exposed conductive parts of the installation, to earth.

These are

- (1) TN - earthing of the installation is done to that supplied by the supply authority
- (2) TT - supply authority earth and the installation earth is independent
- (3) IT - supply authority has effectively an isolated neutral and the installation has an independent earth

In these, the first letter denotes the earthing arrangement at the supply authority side and the second letter denotes the relationship of the exposed conductive parts of the installation to earth.

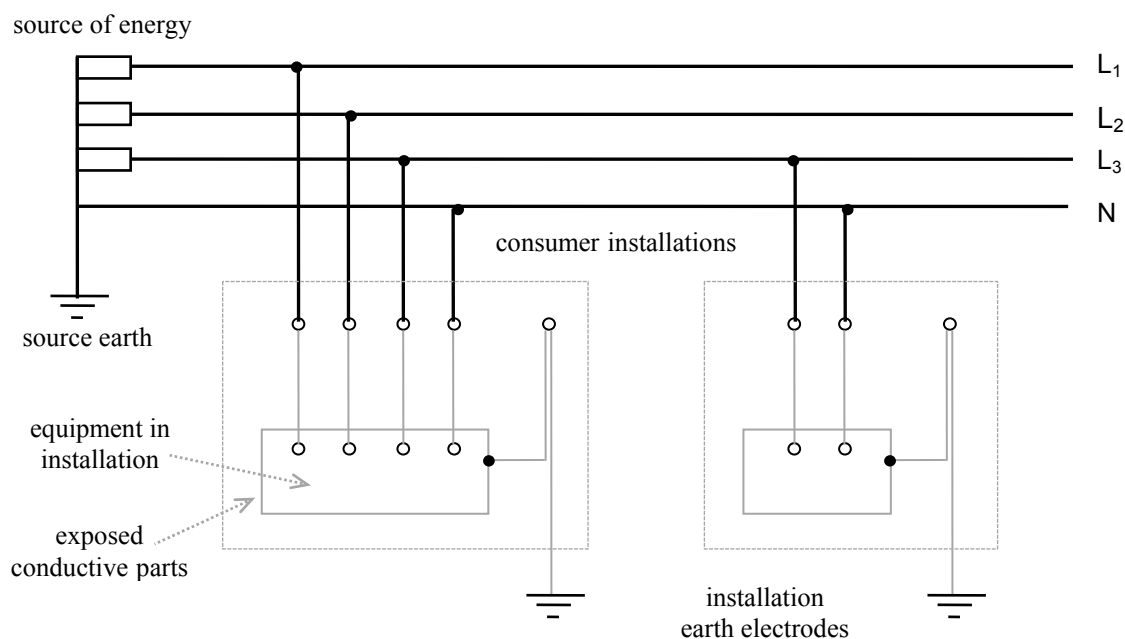
With the First letter, **T** (short for terra or earth) refers to a direct connection of one or more points of the source to earth, and **I** (short for isolated) indicated that all live parts are isolated from earth or one point connected to earth through a high impedance.

With the Second letter, **T** denotes a direct electrical connection of the exposed conductive parts of the consumers installation to earth, independently of the earthing of any point of the supply authority side, while **N** denotes a direct electrical connection of the exposed conductive parts to the earthed point of the supply authority side, which for ac is usually the neutral point.

[There are further sub-divisions of the TN system, but are considered to be beyond the contents of this course. Even the details of the earthing systems other than the one used in Sri Lanka will not be dealt with in this course]

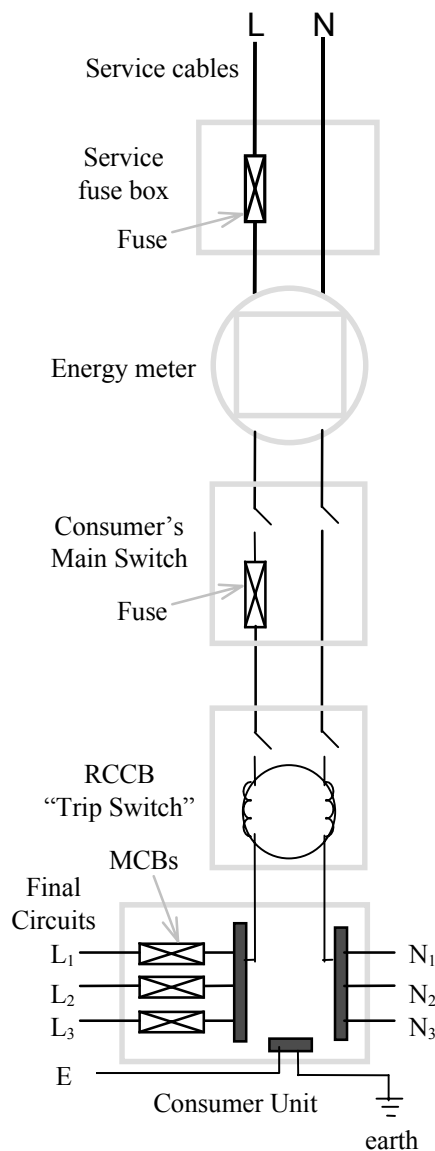
TT System

The TT System of earthing is the one used in Sri Lanka. In this system, the supply is earthed at the source end, and all exposed-conductive parts of the installation are connected to an electrically independent earth electrode at the consumer end.



The normal earthing practice is to provide a circuit protective conductor throughout every installation. A circuit protective conductor connects exposed conductive parts of equipment to the main earthing terminal. As mentioned earlier, the most common method employed for earthing, at the domestic installations in Sri Lanka, is to use an earth electrode (commonly a galvanized iron pipe). The resistance of this electrode to earth also depends on the condition of soil and may have values in excess of 100 Ω . Thus in the TT system of earthing, it is now essential to use an RCCB for protection.

6.6 Basic Domestic Installations:



Most of the domestic installations in Sri Lanka are of single phase (2 wire) type and supplied at 230 V line to neutral. Basic arrangement of the connections from the supply authority's distribution pole is shown. This shows the installation diagram from the *service cable* of the supply authority, which is usually supplied overhead from the distribution pole. This comes to the *service fuse box* (or cut out as commonly known) and then to the *energy meter*. Up to the energy meter belongs to the supply authority. The consumer's installation proper starts from the *Main switch*, which in Sri Lanka is likely not to exceed 30A for a single phase supply. This will be followed by usually one (or more) *RCCBs* (other than some older installations which have an ELCBs, and some even older installations which have no earth leakage protection). Each RCCB would be followed by a *Consumer Unit* (with different rated MCBs) or in older installations a *Distribution Board* (with Fuses). The final circuits are taken from the consumer unit (or distribution unit)

Loop-in Method

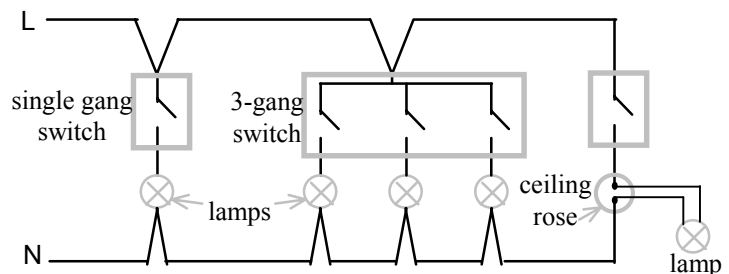
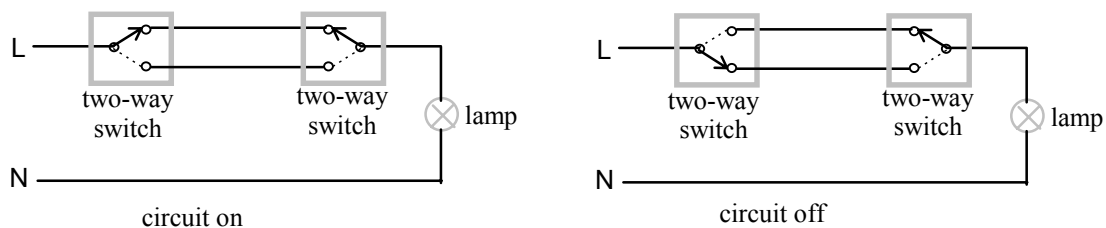


Figure shows the use of loop-in method for wiring a final circuit for lighting. The loop in method enables all joints and terminations in a single final circuit to be made at ceiling roses, switches or other accessories. This makes all joints accessible for the purpose of alterations and for testing. Each final circuit has both its live conductor as well as the neutral conductor terminating at the consumer unit. The wires are usually laid in PVC conduits. Lamp circuits do not normally need an earth wire unless there is a metallic fitting which needs to be earthed for safety.

Two way switches



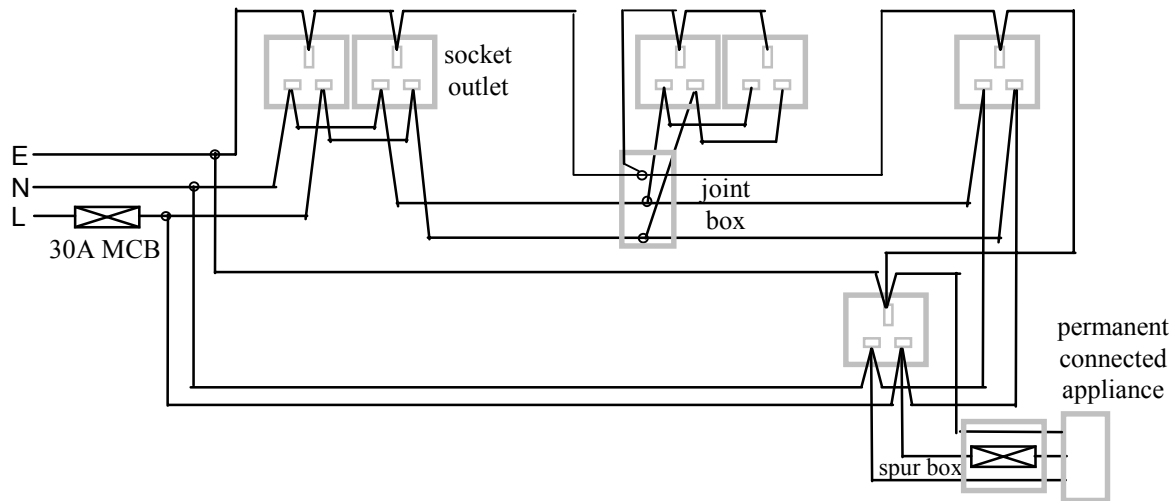
A two-way switch is used when it is necessary to operate a lamp from two positions, such as at the top and bottom of a staircase and at the ends of a long corridor. The connection and operation are shown in the figure.

Final circuits for socket outlets:

Socket outlets (commonly called plug points by electricians) are wired in two ways. These are the ring circuit connection and the radial connection.

(a) Ring circuits

Each circuit commences from consumer unit (or distribution board) through an MCB (or fuse) of specific rating usually 30 A, loops into each socket outlet and returns to the same MCB (or fuse) in the consumer unit (distribution board). Looping must be done for the live conductor, neutral conductor and the protective conductor in separate rings. The ring method of connection is done only for the 13 A socket outlets, as the individual 13A plugs are separately having fuses (fuses may be usually rated at 13 A or 3 A depending on the type of load).



A typical ring circuit connection is shown in the figure. A ring circuit may have an unlimited number of socket outlets provided that the floor area served by the ring does not exceed 100 m^2 and that the maximum demand of the circuit does not exceed the MCB (or fuse) rating. A kitchen should usually have a separate ring circuit.

(b) *Radial circuits*

Each circuit commences from the consumer unit/distribution board through an MCB/fuse of specific rating (e.g. 20A), loop into each socket outlet but ends at a socket outlet (does not return to the original fuse/mcb).

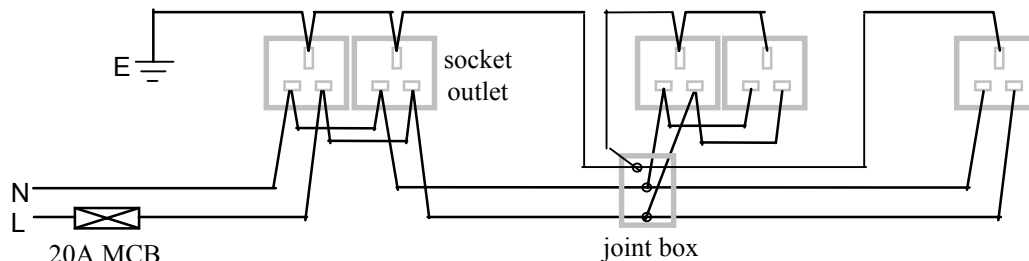
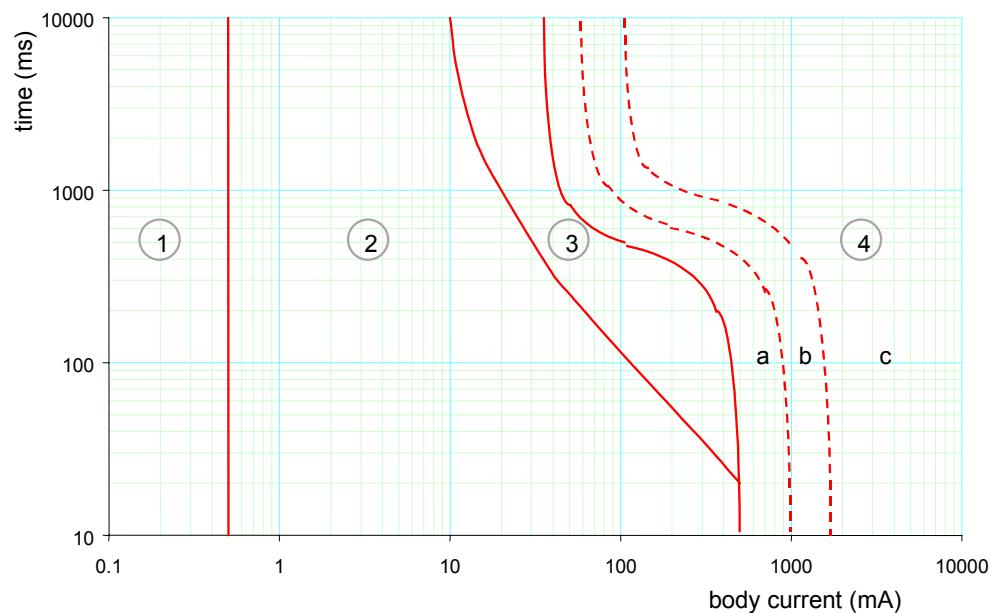


Figure shows a typical radial circuit connection.

6.7 Electric Shock

If an electric current passes through the human body, the effects could be an electric shock or even death. The degree of danger of electric shock depends on the value of the body current and the time for which the current flows. A low current for a long time can easily prove just as dangerous as a high current for a relatively brief time. One of the objects of earthing is to reduce the amount of current available for passage through the human body in the event of the occurrence of an earth leakage current in an installation.

The figure shows the time/current zones of effects of 50 Hz current on the human body.



- Zone 1 - No sensation
- Zone 2 - Perceptibility of current, but no harmful effect (10 mA is the threshold of let-go)
- Zone 3 - Muscular contractions and difficulty in breathing. Usually no danger of ventricular fibrillation (0.5% probability)
- Zone 4 - Probability of ventricular fibrillation increases
 - a - up to 5% , b - up to 50% , c - greater than 50%

Ventricular fibrillation of the heart is the prevention of the heart to act as an effective pump, and thus causing a stoppage of blood circulation to all parts of the body, resulting in death in a very short time.

It can be seen that a current of 30 mA never goes into zone 4, and is thus typically used in residual current devices used for safety of persons.

6.8 IEE Wiring Regulations

It is obvious, even to a lay person, that electricity can, if uncontrolled, present a serious threat of injury to persons or livestock, or damage to property by fire. Thus, rules and regulations have been framed to govern the practice to ensure that all electrical installations provide adequate degree of safety from fire and shock risks, to those who operate the installations and their associated apparatus, equipment and machines. Every person who is involved in design and construction of electrical installation must be familiar with the principal set of regulations issued by the Institution of Electrical Engineers for Electrical Installations, commonly known as the IEE Wiring Regulations. He is also required to be familiar with the main requirements of other regulations, some of which are statutory, such as the Electricity Act of Sri Lanka and the regulations framed under it. The IEE Wiring Regulations have evolved over the past century and is a set of recommendations for safe selection and erection of wiring systems. In Sri Lanka it is also a legal requirement that electrical installations satisfy the IEE Wiring Regulations. At present, the 16th Edition (1992) of IEE Wiring Regulations is used.

Following are some important information available in these regulations:

- The **Regulations are designed to protect** persons, property and livestock *from* electric shock, fire, burns and injury from mechanical movement of electrically actuated equipment.
- **Prevention of electric shock** is carried out by Insulation of live parts, formation of barriers or enclosures, keeping obstacles and making the place out of reach, etc.
- **Fundamental requirements for safety** require the use good workmanship, approved materials and equipment to ensure that the correct type, size and current-carrying capacity of cables is chosen. The regulations also ensure that the equipment is suitable for the maximum power demanded of it and make sure that the conductors are insulated, and sheathed or protected if necessary, or are placed in a position to prevent danger. Joints and connections should be properly constructed to be mechanically and electrically sound. Over-current protection should always be provided for every circuit in an installation (the protection for the whole installation is usually provided by the supply authority). They ensure that protective devices are suitably chosen for their location and the duty they have to perform. Where there is a chance of metalwork becoming live owing to a fault, it should be earthed, and the circuit concerned should be protected by an over-current device or a residual current device (RCD). A fuse, a switch or a circuit breaker should not be placed in an earthed neutral conductor. It requires that all single-pole switches are wired in the phase conductor only. A readily accessible and effective means of isolation must be provided, so that all voltage may be cut off from an installation or any of its circuits. All motors must have a readily accessible means of disconnection. They ensure that any item of equipment which may normally need operating or attending to by persons is accessible and easily operated. Any equipment required to be installed in a situation exposed to weather or corrosion, or in explosive or volatile environments, should be of correct type for such adverse conditions. Before adding to or altering an installation, it should be ensured that such work will not damage/weaken any part of the existing installation. After completion of an installation or an alteration to an installation, the work must be inspected and tested to ensure, as far as reasonably practicable, that the fundamental requirements for safety have been met.
- Among the requirements for **Inspection** includes checking the connection of conductors, identification of conductors, checking routing of cables, checking proper selection of conductors, checking connection of single-pole devices, checking connection of equipment, checking for presence of fire barriers, methods of protection against electric shock, prevention of detrimental influences, presence of appropriate devices for isolating and switching, presence of under-voltage protective devices, choice of setting of protective devices, labelling of protective devices, switches and terminals, selection of equipment appropriate to external influences, access to switchgear and equipment, presence of warning signs and danger notices, presence of diagrams, instructions and similar information and erection methods.
- **Testing** includes continuity of live, neutral and protective conductors, the resistance of earth electrodes, insulation resistance of all live conductors to earth, insulation resistance between live conductors, polarity to ensure all switches are connected in phase conductors and not neutral; phase earth loop impedance tests, operation of residual current devices.