Lecture 9: Basic protection and fault protection

9.1 Protecting electrical equipment, circuits and people

Using electricity is a hazard because it has the 'potential' and the possibility to cause harm. Therefore, the provision of protective devices in an electrical installation is fundamental to the whole concept of the safe use of electricity in buildings.

The electrical installation as a whole must be protected against overload or short-circuit and the people using the building must be protected against the risk of shock, fi re or other risks arising from their own misuse of the installation or from a fault. The installation and maintenance of adequate and appropriate protective measures is a vital part of the safe use of electrical energy.

Definitions

- **Earth** – the conductive mass of the earth whose electrical potential is taken as zero.
- **Earthing** – the act of connecting the exposed conductive parts of an installation to the main earthing terminal of the installation.
- **Bonding conductor** – a protective conductor providing equipotential bonding.
- **Bonding** – the linking together of the exposed or extraneous metal parts of an electrical installation. **Figure 9.4** illustrates this.
- **Circuit protective conductor (CPC)** – a protective conductor connecting exposed conductive parts of equipment to the main earthing terminal of the installation. This is the green and yellow insulated conductor in twin and earth cable.
- **Exposed conductive parts** – the metalwork of an electrical appliance or the trunking and conduit of an electrical system which can be touched because they are not normally live, but which may become live under fault conditions.
- **Extraneous conductive parts** – the structural steelwork of a building and other service pipes such as gas, water, radiators and sinks. They do not form a part of the electrical installation but may introduce a potential, generally earth potential, to the electrical installation.
- **Shock protection** – protection from electric shock is provided by basic protection and fault protection.
- **Basic protection** – is provided by barriers and the insulation of live parts in accordance with Section 416 of the IET Regulations.
- **Fault protection** – is provided by protective equipotential bonding and automatic disconnection of the supply (by a fuse or miniature circuit-breaker, MCB) in accordance with IET Regulations 411.3 to 6.

9.2 Basic protection and fault protection

The human body's movements are controlled by the nervous system. Very tiny electrical signals travel between the central nervous system and the muscles, stimulating operation of the muscles, which enable us to walk, talk and run, and remember that the heart is also a muscle.

If the body becomes part of a more powerful external circuit, such as the electrical mains, and current flows through it, the body's normal electrical operations are disrupted. The shock current causes unnatural operation of the muscles and the result may be that the person is unable to release the live conductor causing the shock, or the person may be thrown across the room. The current which flows through the body is determined by the resistance of the human body and the surface resistance of the skin on the hands and feet. This leads to the consideration of exceptional precautions where people with wet skin or wet surfaces are involved, and the need for special consideration in bathroom installations.

Two types of contact will result in a person receiving an electric shock. ***Direct contact*** with live parts involves touching a terminal or line conductor that is actually live. The regulations call this ***basic protection***. ***Indirect contact*** results from contact with an exposed conductive part such as the metal structure of a piece of equipment that has *become live as a result of a fault*. The regulations call this ***fault protection***.

In installations operating at normal mains voltage, the primary method of *protection against direct contact* is by insulation. All live parts are enclosed in insulating material such as rubber or plastic, which prevents contact with those parts. The insulating material must, of course, be suitable for the circumstances in which they will be used and the stresses to which they will be subjected. The IET Regulations call this *basic protection* (IET Regulation 131.2.1).

Other methods of *basic protection* include the provision of barriers or enclosures which can only be opened by the use of a tool, or when the supply is first disconnected. Protection can also be provided by fixed obstacles such as a guardrail around an open switchboard or by placing live parts out of reach as with overhead lines.

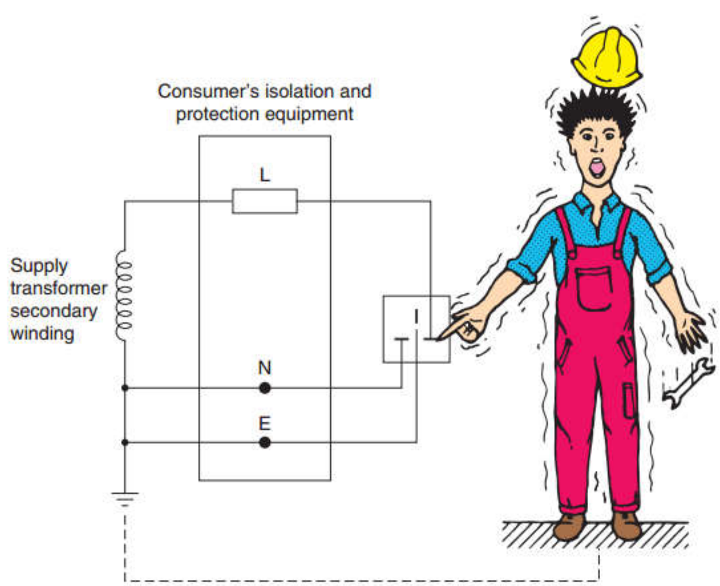

FIGURE 9.1. Touching live and earth or live and neutral makes a person part of the electrical circuit and can lead to an electric shock.

Electric shock occurs when a person becomes part of the electrical circuit, as shown in Fig. 9.1. The level or intensity of the shock will depend upon many factors, such as age, fitness and the circumstances in which the shock is received. The lethal level is approximately 50 mA, above which muscles contract, the heart flutters and breathing stops. A shock above the 50 mA level is therefore fatal unless the person is quickly separated from the supply. Below 50 mA only an unpleasant tingling sensation may be experienced or you may be thrown across a room, roof or ladder, but the resulting fall may lead to serious injury.

To prevent people receiving an electric shock accidentally, all circuits contain protective devices. All exposed metal is earthed, fuses and MCBs are designed to trip under fault conditions.

9.3 Fault protection

Protection against indirect contact, called fault protection (IET Regulation 131.2.2), is achieved by connecting exposed conductive parts of equipment to the main earthing terminal of the installation.

In Chapter 13 of the IET Regulations we are told that where the metalwork of electrical equipment may become charged with electricity in such a manner as to cause danger, that metalwork will be connected with earth so as to discharge the electrical energy without danger. The application of protective equipotential bonding conductors is one of the important principles for safety (IET Regulation 131.2.2). **Figure 9.4** illustrates this.

There are five methods of protection against contact with metalwork which has become unintentionally live, that is, indirect contact with exposed conductive parts recognized by the IET Regulations. These are:

1. Protective equipotential bonding coupled with automatic disconnection of the supply.
2. The use of Class II (double-insulated) equipment.
3. The provision of a non-conducting location.
4. The use of earth-free bonding.
5. Electrical separation.

Methods 3 and 4 are limited to special situations under the effective supervision of trained personnel.

Method 5, electrical separation, is little used but does find an application in the domestic electric shaver supply unit which incorporates an isolating transformer.

Method 2, the use of Class II insulated equipment, is limited to single pieces of equipment such as tools used on construction sites, because it relies upon effective supervision to ensure that no metallic equipment or extraneous earthed metalwork enters the area of the installation.

The method which is most universally used in Kenya is, therefore, Method 1 – protective equipotential bonding coupled with automatic disconnection of the supply.

This method relies upon all exposed metalwork being electrically connected together to an effective earth connection. Not only must all the metalwork associated with the electrical installation be so connected, that is, conduits, trunking, metal switches and the metalwork of electrical appliances, but Regulation 411.3.1.2 tells us to connect the extraneous metalwork of water service pipes, gas and other service pipes and ducting, central heating and air-conditioning systems, exposed metallic structural parts of the building and lightning protective systems to the protective earthing terminal. In this way the possibility of a voltage appearing between two exposed metal parts is removed.

The second element of this protection method is the provision of a means of automatic disconnection of the supply in the event of a fault occurring that causes the exposed metalwork to become live.

IET Regulation 411.3.2 tells us that for final circuits not exceeding 32 A the maximum disconnection time shall not exceed 0.4 s.

The achievement of these disconnection times is dependent upon the type of protective device used, fuse or circuit-breaker, the circuit conductors to the fault and the provision of adequate protective bonding.

9.4 Isolation and switching

Isolation is defined as cutting off the electrical supply to a circuit or item of equipment in order to ensure the safety of those working on the equipment by making dead those parts which are live in normal service.

The purpose of isolation switching is to enable electrical work to be carried out safely on an isolated circuit or piece of equipment. Isolation is intended for use by electrically skilled or supervised persons.

An isolator is a mechanical device which is operated manually and used to open or close a circuit off load. An isolator switch must be provided close to the supply point so that all equipment can be made safe for maintenance. Isolators for motor circuits must isolate the motor and the control equipment, and isolators for discharge lighting luminaires must be an integral part of the luminaire so that it is isolated when the cover is removed or be provided with effective local isolation.

Devices which are suitable for isolation are isolation switches, fuse links, circuit-breakers, plugs and socket outlets. They must isolate all live supply conductors and provision must be made to secure the isolation.

Isolation at the consumer’s service position can be achieved by a double-pole switch which opens or closes all conductors simultaneously. On three-phase supplies the switch need only break the live conductors with a solid link in the neutral, provided that the neutral link cannot be removed before opening the switch.

The switching for mechanical maintenance requirements is similar to those for isolation except that the control switch must be capable of switching the full load current of the circuit or piece of equipment. The purpose of switching for mechanical maintenance is to enable non-electrical work to be carried out safely on the switched circuit or equipment.

Emergency switching involves the rapid disconnection of the electrical supply by a single action to remove or prevent danger. The purpose of emergency switching is to cut off the electrical energy *rapidly* to remove an unexpected hazard.

Emergency switching is for use by anyone. The device used for emergency switching must be immediately accessible and identifiable, and be capable of cutting off the full load current. Electrical machines must be provided with a means of emergency switching, and a person operating an electrically driven machine must have access to an emergency switch so that the machine can be stopped in an emergency.

Functional switching involves the switching on or off, or varying the supply, of electrically operated equipment in normal service.

The purpose of functional switching is to provide control of electrical circuits and equipment in normal service. Functional switching is for the user of the electrical installation or equipment.
The device must be capable of interrupting the total steady current of the circuit or appliance. When the device controls a discharge lighting circuit it must have a current rating capable of switching an inductive load. The regulations acknowledge the growth in the number of electronic dimmer switches being used for the control and functional switching of lighting circuits.

9.5 Overcurrent protection

The consumer's mains equipment must provide protection against overcurrent, that is, a current exceeding the rated value (IET Regulation 430.3). Fuses and MCBs provide overcurrent protection when situated in the live conductors; they must not be connected in the neutral conductor. Where Circuit-breakers are used in place of fuses, the circuit-breaker may also provide the means of isolation, although a further means of isolation is usually provided so that maintenance can be carried out on the circuit-breakers themselves.

When selecting a protective device we must give consideration to the following factors:

- the prospective fault current;
- the circuit load characteristics;
- the current-carrying capacity of the cable;
- the disconnection time requirements for the circuit.

The essential requirements for a device designed to protect against overcurrent are:

- it must operate automatically under fault conditions;
- have a current rating matched to the circuit design current;
- have a disconnection time which is within the design parameters;
- have an adequate fault breaking capacity;
- be suitably located and identified.

An overcurrent may be an overload current, or a short-circuit current. An overload current can be defined as a current which exceeds the rated value in an otherwise healthy circuit. Overload currents usually occur because the circuit is abused or because it has been badly designed or modified. A short-circuit is an overcurrent resulting from a fault of negligible impedance connected between live conductors. Short-circuits usually occur as a result of an accident which could not have been predicted before the event.

An overload may result in currents of two or three times the rated current flowing in the circuit. Short-circuit currents may be hundreds of times greater than the rated current. In both cases the basic requirements for protection are that the fault currents should be interrupted quickly and the circuit isolated safely before the fault current causes a temperature rise or mechanical effects which might damage the insulation, connections, joints and terminations of the circuit conductors or their surroundings.

The selected protective device should have a current rating which is not less than the full load current of the circuit but which does not exceed the cable current rating. The cable is then fully protected against both overload and short-circuit faults (IET Regulation 435.1). Devices which provide overcurrent protection are:

High breaking capacity (HBC) fuses to BS 88-2: 2010. These are for industrial applications having a maximum fault capacity of 80 kA.

- Cartridge fuses to BS 88-3: 2010. These are used for a.c. circuits on industrial and domestic installations having a fault capacity of about 30 kA.
- Cartridge fuses to BS 1362. These are used in 13 A plug tops and have a maximum fault capacity of about 6 kA.
- Semi-enclosed fuses to BS 3036. These were previously called rewireable fuses and are used mainly on domestic installations having a maximum fault capacity of about 4 kA.
- MCBs to BS EN 60898. These are miniature circuit-breakers (MCBs) which may be used as an alternative to fuses for some installations. The British Standard includes ratings up to 100 A and maximum fault capacities of 9 kA. They are graded according to their instantaneous tripping currents – that is, the current at which they will trip within 100ms. This is less than the time taken to blink an eye.
- The 18th Edition of the IET Regulations tells us at Note 5 of Table 53.4 that circuit protective devices and RCDs are not intended for frequent load switching. However, infrequent switching of MCBs is permissible for the purpose of isolation or emergency switching.

Semi-enclosed fuses (BS 3036)

The semi-enclosed fuse consists of a fuse wire, called the fuse element, secured between two screw terminals in a fuse carrier. The fuse element is connected in series with the load and the thickness of the element is sufficient to carry the normal rated circuit current. When a fault occurs an overcurrent flows and the fuse element becomes hot and melts or ‘blows’.

This type of fuse is illustrated in Fig. 9.2. The fuse element should consist of a single strand of plain or tinned copper wire having a diameter appropriate to the current rating of the fuse. *This* *type of fuse was very popular in domestic installations, but less so these days because of its disadvantages.*

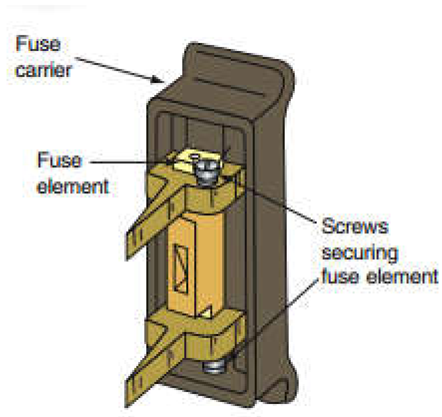

Figure 9.2 A semi-enclosed fuse

Advantages of semi-enclosed fuses

- They are very cheap compared with other protective devices both to install and to replace.
- There are no mechanical moving parts.
- It is easy to identify a 'blown' fuse.

Disadvantages of semi-enclosed fuses

- The fuse element may be replaced with wire of the wrong size either deliberately or by accident.
- The fuse element weakens with age due to oxidization, which may result in a failure under normal operating conditions.
- The circuit cannot be restored quickly since the fuse element requires screw fixing.
- They have low breaking capacity since, in the event of a severe fault, the fault current may vaporize the fuse element and continue to flow in the form of an arc across the fuse terminals.
- They are not guaranteed to operate until up to twice the rated current is flowing.
- There is a danger from scattering hot metal if the fuse carrier is inserted into the base when the circuit is faulty.

Cartridge fuses [(BS 88-3: 2012)

The cartridge fuse breaks a faulty circuit in the same way as a semi-enclosed fuse, but its construction eliminates some of the disadvantages experienced with an open-fuse element. The fuse element is encased in a glass or ceramic tube and secured to end-caps which are firmly attached to the body of the fuse so that they do not blow off when the fuse operates. Cartridge fuse construction is illustrated in Fig. 9.3. With larger size cartridge fuses, lugs or tags are sometimes brazed on the end-caps to fix the fuse cartridge mechanically to the carrier. They may also be filled with quartz sand to absorb and extinguish the energy of the arc when the cartridge is brought into operation.

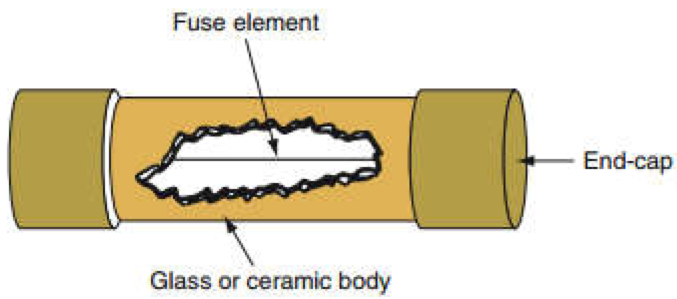

Figure 9.3 Cartridge fuse.

Advantages of cartridge fuses.

- They have no mechanical moving parts.
- The declared rating is accurate.
- The element does not weaken with age.
- They have small physical size and no external arcing which permits their use in plug tops and small fuse carriers.
- Their operation is more rapid than semi-enclosed fuses. Operating time is inversely proportional to the fault current, so the bigger the fault current the quicker the fuse operates.
- They are easy to replace.
- Small current sizes clip in place.
- Larger current sizes have bolt-hole fixings.

Disadvantages of cartridge fuses.

- They are more expensive to replace than fuse elements that can be rewired.
- They can be replaced with an incorrect cartridge.
- The cartridge may be shorted out by wire or silver foil in extreme cases of bad practice.
- It is not possible to see if the fuse element is broken.

Miniature circuit-breakers (BS EN 60898)

The disadvantage of all fuses is that when they have operated they must be replaced. An MCB overcomes this problem since it is an automatic switch which opens in the event of an excessive current flowing in the circuit and can be closed when the circuit returns to normal. An MCB of the type shown in Fig. 3.28 incorporates a thermal and magnetic tripping device. The load current flows through the thermal and the electromagnetic devices in normal operation but under overcurrent conditions they activate and trip the MCB.

The circuit can be restored when the fault is removed by pressing the ON toggle. This latches the various mechanisms within the MCB and 'makes' the switch contact. The toggle switch can also be used to disconnect the circuit for maintenance or isolation, or to test the MCB for satisfactory operation.

Advantages of MCBs

- They have factory-set operating characteristics.
- Tripping characteristics and therefore circuit protection is set by the installer.
- The circuit protection is difficult to interfere with.
- The circuit is provided with discrimination.
- A faulty circuit may be quickly identified.
- A faulty circuit may be easily and quickly restored.
- The supply may be safely restored by an unskilled operator.

Disadvantages of MCBs

- They are relatively expensive but look at the advantages to see why they are so popular these days.
- They contain mechanical moving parts and therefore require regular testing to ensure satisfactory operation under fault conditions.

Residual current protection by RCD

The IET Regulations recognize the particular problems created when electrical equipment such as lawnmowers, hedge-trimmers, drills and lights are used outside buildings. In these circumstances the availability of an adequate earth return path is a matter of chance. The regulations, therefore, require that any socket outlet with a rated current not exceeding 20 A, for use by ordinary people and intended for general use, shall have the additional protection of a residual current device (RCD) which has a rated operating current of not more than 30 milliamperes (mA).

An RCD is a type of circuit-breaker that continuously compares the current in the line and neutral conductors of the circuit. The currents in a healthy circuit will be equal, but in a circuit that develops a fault, some current will flow to earth and the line and neutral currents will no longer balance. The RCD detects the imbalance and disconnects the circuit.

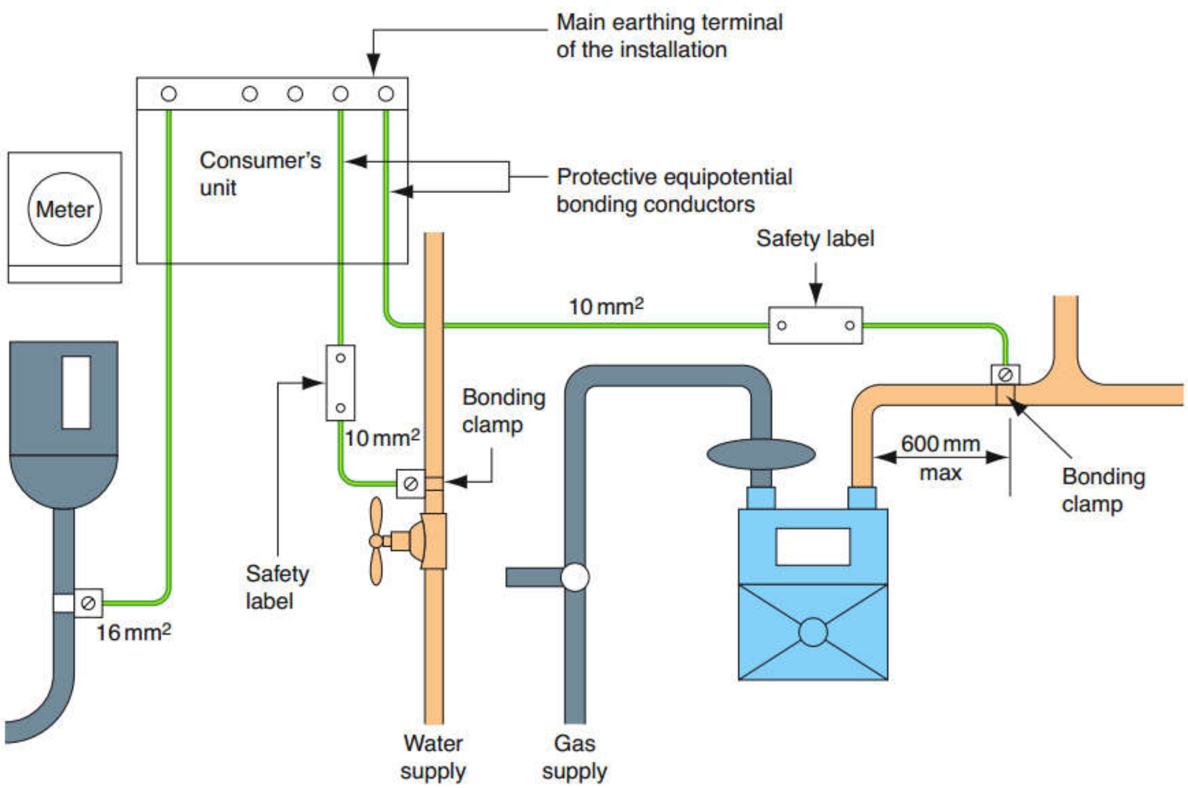

Figure 9.4 Main protective equipotential bonding of gas and water supplies.