Basic Principles
The proper selection of the correct circuit protective device requires an understanding of the potential hazards against which protection for safety is required. The Wiring Regulations identify several hazards:

- electric shock
- thermal effects
- overcurrent
- undervoltage
- isolation

Electric shock - is divided into two parts:

- direct contact: contact with parts which result in an electric shock in normal service
- indirect contact: contact with exposed conductive parts which result in an electric shock in case of a fault.

To protect against direct contact the Wiring Regulations suggest the following basic measures should be taken:
(1) by insulation of live parts
(2) by enclosures or barriers
(3) by obstacles
(4) by placing out of reach

To protect against indirect contact the Wiring Regulations suggest the following basic measures should be taken:
(1) earthed equipotential bonding and automatic disconnection of supply
(2) use of class II equipment or equivalent insulation
(3) non-conducting location
(4) earth-free local equipotential bonding
(5) electrical separation

Of these five measures, the first is by far the most commonly used -
(1) earthed equipotential bonding and automatic disconnection of supply:

In each installation main equipotential bonding conductors shall connect the main earthing terminal of the installation; this metalwork comprises exposed conductive parts which are part of the electrical installation itself and extraneous conductive parts including the following:

- main water pipes
- gas installation pipes
- other service pipes and ducting
- risers of central heating and air conditioning systems
- exposed metal parts of the building structure

This bonding creates a zone within which any voltages appearing between exposed conductive parts and extraneous conductive parts, are minimised; the earth fault loop impedance must have an value low enough to allow sufficient current to flow for the circuit protective device to operate rapidly to disconnect the supply; disconnection must be sufficiently fast so that voltages appearing on the bonded metalwork cannot persist long enough to cause danger; depending on the operating characteristics of the protective device and the earth impedance, such disconnection may be achieved either by overcurrent devices, Fuses, Miniature Circuit Breakers, (i.e. MCBs) or by Residual Current Devices, (i.e. RCDs).

Thermal Effect - refers to heat generated by the electrical equipment in normal use and under fault conditions. The proper selection of equipment complying with the latest product standards is essential in providing protection against thermal effects.

Overcurrent - is defined as a current exceeding the rated value of the circuit components. It may be caused by the overloading of a healthy circuit or it may take the form of a short-circuit current, defined as an "overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions". Overcurrent protection may be provided by using fuses or circuit breakers singly or in combination.

Undervoltage - refers to the dangers that could be caused by the reduction or loss in voltage and the subsequent restoration, such as the unexpected re-starting of motors or the automatic closing of protective devices. The proper selection of control and protective devices must take the protection against undervoltage into consideration.

Isolation - every circuit shall be provided with means of isolation (except in certain cases) to prevent or remove hazards associated with the installation, equipment and machines. The new standards for circuit breakers and switch-fuses now take this into account.

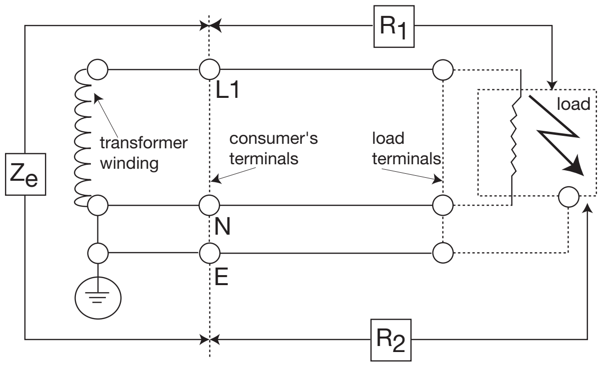
Protection against shock by indirect contact
Indirect contact - is the contact of persons or livestock with exposed conductive parts made live by a fault and which may result in electric shock. An example would be where the insulation of an electric heater has broken down resulting in a live conductor internally touching the casing. This could result in the heater casing being raised to a hazardous voltage level, causing electric shock to a person touching it.

Two important measures must be taken to prevent this hazard:

- the impedance of circuit conductors is kept to a minimum. The earth fault loop impedance (Z_S) is used as a measure of the circuit impedance under fault conditions.
- the overcurrent device protecting the circuit is selected to rapidly disconnect an earth fault.

The effect of these two measures is inter-related.

1. By ensuring that the circuit protective conductor is of a low impedance, the voltage to which the live casing is raised, under fault conditions, is kept to a minimum.
2. The low impedance path provided by the circuit conductors and the circuit protective conductor will result in a high level of current in the event of an earth fault. This high fault current ensures that the overcurrent protective device will disconnect the fault in a short time, reducing the interval during which the casing of the faulty equipment is live.



Components of earth fault loop impedance (Z_L) in a system.
(Earth fault at load between conductor and casing).
$Z_L = Z_L + (R1 + R2)$

Earth fault loop impedance (Z_L)
To ensure the impedance of conductors in a circuit is sufficiently low the system designer has to establish the value of the earth fault loop impedance.
Z_L - is a measure of the earth fault current loop, comprising the phase conductor and the earth conductor. It comprises the complete loop including the winding of the transformer from which the circuit is supplied as defined by the following:
Z_L - is the part of the earth fault loop impedance external to the installation, its value can be measured or a nominal value can be obtained from the supply authority.

(R_1 +R_2) - where R_1 is the resistance of the phase conductor within the installation and R_2 is the resistance of the circuit protective conductor. These two components constitute the loop impedance within the installation.

Therefore: $Z_L = Z_L + (R_1 + R_2)$

Once the value of Z_L has been established a suitable overcurrent protective device has to be selected to ensure disconnection of an earth fault within the specified time.The times are:

- 5 seconds for fixed equipment.
- For portable equipment and for fixed equipment installed outside the equipotential bonding zone, the disconnection times are dependent on the nominal voltage to earth, i.e. 220 to 277 volts = 0.4 seconds.

Z_L by calculation
To establish whether the relevant disconnection time can be achieved a simple calculation must be made, based on Ohm's law:

$$I_f \text{ (fault current)} = \frac{\text{Uo (open circuit voltage)*}}{Z_L \text{ (earth fault loop)}}$$

* voltage between phase and earth (240V)

The fault current (I_f) must be high enough to cause the circuit protective device to trip in the specified time. This can be established by consulting the time/current characteristic for the protective device. If the maximum trip time for the fault current calculated is less than or equal to the relevant value (5s for fixed equipment; 0.4s for portable equipment) then compliance is achieved. It is important that when consulting the characteristic curve the worst case is used, i.e. the maximum tripping time including any tolerance. An example is shown in Figs 1 and 2.

Z_L by tables
The above procedure can be used for any type of protective device providing a time/current characteristic curve is available. Frequently, however, a much simpler method is available using tables listing maximum Z_L values which have been interpreted from the characteristic curves for the relevant devices. Providing the system Z_L is equal to or less than the value given in the table, compliance is achieved. Tables for a number of 'standard' devices (certain fuses and MCBs) are given in the Wiring Regulations.

Z_L too high
If the system Z_L value is too high to achieve rapid enough disconnection with the overcurrent protective devices available then it is necessary to use one of the two following methods:

- fit a cable with a larger cross-section and consequently a lower impedance. This may be a very expensive solution especially when the installation is complete before the problem is discovered.
- use a Hager residual current device (RCD). Subject to certain conditions being met this provides a simple and economical solution.

Example

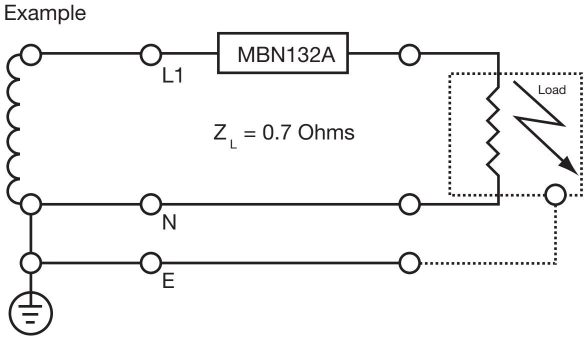


Fig 2

Fig 2 shows a fixed circuit with an earth loop impedance Z_L of 0.7 ohms protected with an MBN132A. The fault current (I_f) will therefore be U_o/Z_L = 240/0.7 = 343A

By referring to the characteristic for MBN132A (see Fig 3) it can be seen that the breaker will disconnect in 0.02 seconds for this current. The breaker therefore easily satisfies the requirement for disconnection in 5 seconds.

If the circuit Z_L was 2.0 ohms then the fault current would be: 240/2 = 120A and the disconnection time would be 10 seconds, in which case compliance would not be achieved.

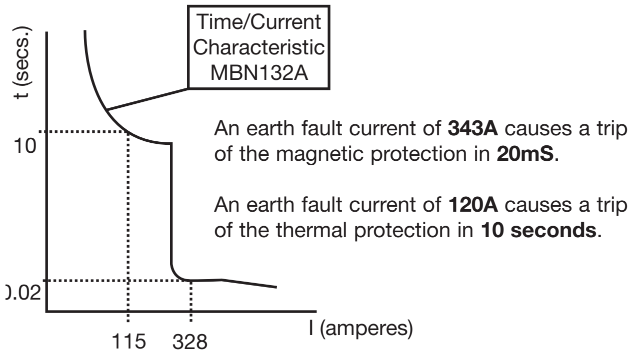


Fig 3

Protection against overcurrent
Overcurrent - "A current exceeding the rated value. For conductors the rated value is the current-carrying capacity"

Overload Current - "An overcurrent occurring in a circuit which is electrically sound"

Short-Circuit Current - "An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions."

Protection against Overload Current
For the protection against overload current, protective devices must be provided in the circuit to break any overload current flowing in the circuit conductors before it can cause a temperature rise which would be detrimental to insulation, joints, terminations or the surroundings of the conductors.

In order to achieve this protection the nominal current of the protective device I_n should be not less than the design current of the circuit I_b and that I_n should not exceed the current-carrying capacity of the conductors I_z, and that the current causing effective operation of the protective device I2 does not exceed 1.45 times the current-carrying capacity of the conductor I_z, expressed as
$I_b \leq I_n \leq I_z$
$I_2 \leq 1.45 I_z$

Protection against Short-Circuit Current
Protective devices must be provided to break any short-circuit current before it can cause danger due to thermal and mechanical (electro-dynamic) effects produced in the conductors and connections. The breaking capacity of the protective device shall not be less than the prospective short-circuit current at the point at which the device is installed. However a lower breaking capacity is permitted provided that a properly co-ordinated back-up device having the necessary breaking capacity is installed on the supply side.

Positioning of Overcurrent Devices
Devices for the protection against overload and short-circuit must be placed at the point where a reduction occurs in the current-carrying capacity of the conductors. This reduction could be caused by a change in the environmental conditions as well as the more obvious change in the cross-sectional area of the cable.

There are of course exceptions to this general rule which relate to a very few special applications. These are set out in detail in the the Wiring Regulations.