CONTROL AND PROTECTION

Safe Electrical Design

Topic 3-4

FUSES

INTRODUCTION

- A **fuse** is a type of low resistance resistor that acts as a sacrificial device to provide overcurrent protection, of either the load or source circuit.
- In essence a fuse consists of a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected.
- Short circuit, overloading, mismatched loads or device failure are the prime reasons for excessive current.

INTRODUCTION

- A fuse interrupts excessive current (blows) so that further damage by overheating or fire is prevented.
- Fuses are selected to allow passage of normal current plus a marginal percentage and to allow excessive current only for short periods.

FUSE TERMINOLOGY

- **Current rating**: is the current the fuse will carry continuously without overheating or deterioration.
- **Voltage rating**: is the voltage at which the fuse normally operates and should not be less than the highest voltage between conductors of the circuit the fuse is protecting. If a fuse is installed in an application greater than its voltage rating, the I^2t characteristics of the given fuse are exceeded.
- **Time-current characteristic**: is a plot of prospective currents against pre-arcing time.

FUSE TERMINOLOGY

- **Pre-arcing time**: is the elapsed time between the start of a current large enough to melt the fuse element and the instant that the break in the fuse element occurs.
- **Arcing time**: is the time that the arc continues; that is the elapsed time between the end of the pre-arcing time and the instant at which the circuit is opened and the current falls to zero.
- **I^2t characteristic**: is the let-through energy in A^2s at a given voltage.

FUSE TERMINOLOGY

- **Fusing factor**: is the ratio of minimum fusing current to the current rating of the fuse. Semi-enclosed fuses commonly have a factor of 2 while HRC fuses can have a factor as low as 1.
- **Total operating time**: is the sum of the pre-arcing time and the arcing time, which is the total time for the fuse to isolate the circuit completely.
- **Cut-off**: is the action of the fuse whereby the fuse element melts and limits the value of prospective current before it reaches it first peak value.

FUSE TERMINOLOGY

- **Category of duty** is the fault handling ability of the fuse in terms of the value of prospective fault current. The fuse can interrupt up to this value of current without damage to the fuse carrier or holder. If value is exceeded the carrier and holder may be permanently damaged. For example AC1 = 1000A, AC2 = 2000A, AC3 = 16.4kA, AC4 = 33kA, AC5=50kA, AC80 = 80kA

SEMI ENCLOSED REWIREABLE FUSES

- ***NOTE:*** *This type of fuses is no longer permitted and the following information is provided for information only. Some older residential installations may still have this type of fuse installed*
- The fuse is made of ceramic material and has two parts, the base to which the wiring is connected and the wedge which holds the replaceable fuse wire (fuse element) – see Fig **F-3-4-1**

SEMI ENCLOSED REWIREABLE FUSES

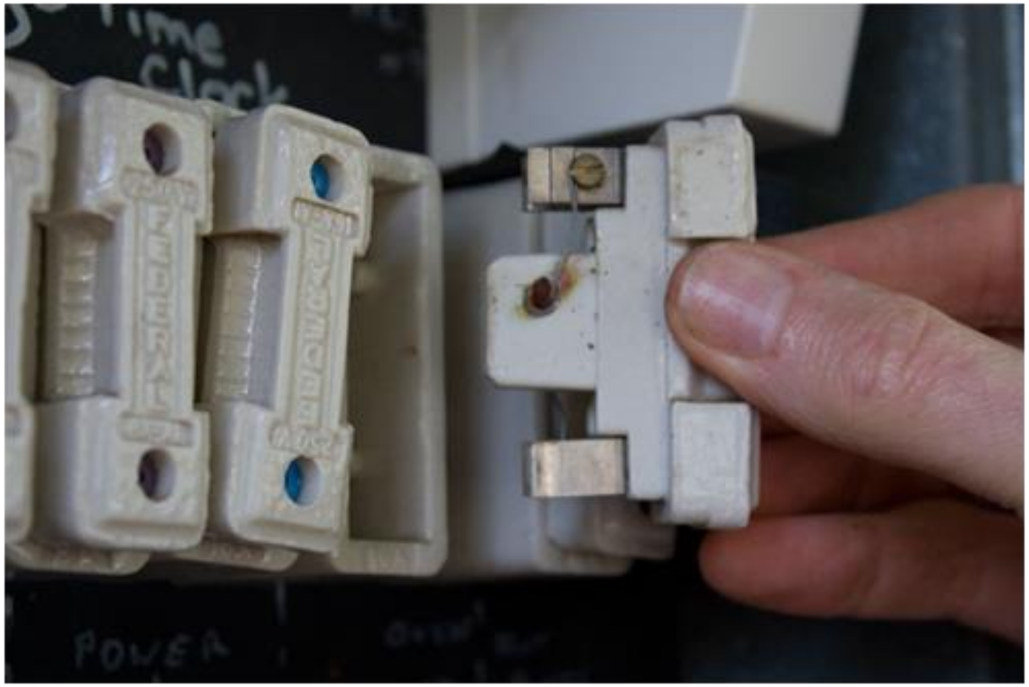


Fig. PF-3-4-1 Rewireable Fuses

SEMI ENCLOSED REWIREABLE FUSES

- The fuse wire connects the contacts on the wedge, and passes through a hole in a section of the wedge. When current through the fuse wire exceeds its rating, the wire heats and the section inside the hole heats more quickly than the rest of the wire. The wire eventually melts and separates.
- Some of the reasons that this type of fuse was banned are:
  - ➢ It cannot interrupt high short circuit currents. A very large current may cause an arc to form between the contacts and this could allow the fault current to continue to flow.

SEMI ENCLOSED REWIREABLE FUSES

- The fuse element is not sealed and may not eliminate arcing.
- It is not obtainable in a range of fusing factors
- The current rating is not clearly marked. The fuse wire could have been replaced with an incorrectly rated wire.
- It has no reliable operation within prescribed limits. The time it takes to blow and the current required to make it blow are more variable than other fuses.
- It has poor discrimination
- It has relatively slow operation under fault conditions
- It deteriorates over time

GLASS FUSES

- Glass fuses mainly find application in instruments and consumer electronic devices and are still used in older automotive applications – see **Fig F-3-4-2**

Fig. PF-3-4-2 (a) Glass Fuses

Fig. PF-3-4-2 (b) Slow Blow Fuse

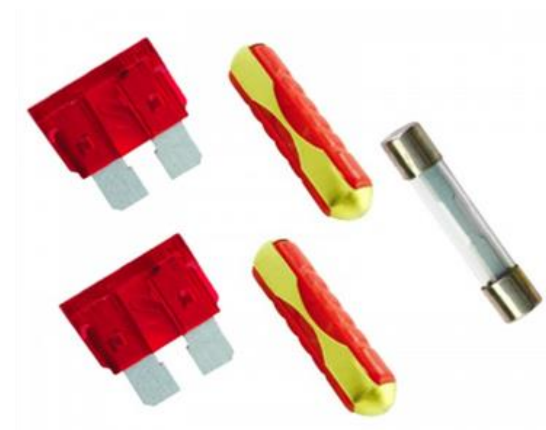


Fig. PF-3-4-2 (c) Assorted Automotive Fuses

GLASS FUSES

- Glass fuse current ratings range from 50mA to over 20A.
- They are used in mains voltage equipment, as well as 12V systems like motor vehicles and instruments.
- Some types of automotive fuses are open. These have the fuse element mounted on top of a ceramic former fitted with end caps.
- Glass/Ceramic fuses usually fit inside a fuse holder, which may enclose the fuse, or simply have sockets that take the fuse.

GLASS FUSES

- It is sometimes possible to see when a glass fuse has blown, but more often, because the wire is so thin, it needs to be tested with a continuity tester
- There are two basic types of fuses available for appliances and consumer electronics:
  - fast-acting (single strand of wire or strip of metal) or
  - time-delay (have a coiled wire, a thick element wrapped in wire, or a spring)

HIGH RUPTURING CAPACITY (HRC) FUSES

- This is a cartridge fuse, and it has a higher category of duty than a rewireable fuse.
- The HRC fuse has a fuse element made of silver inside a barrel made from a strong ceramic material that is a good conductor of heat.
- The barrel contains a fine grade of silica sand.
- Most HRC fuse cartridges have some form of “blown” indication.
- The HRC fuse is more expensive than a rewireable fuse but offers better protection.

HIGH RUPTURING CAPACITY (HRC) FUSES

- It can operate more quickly, interrupt higher values of current than other types of fuse, and completely contain the energy dissipated by the fuse element.
- The HRC fuse fits in a carrier that in turn plugs into a fuse base.
- Typical fuse cartridges, carriers and bases are shown in **Fig PF-3-4-3**, while **Fig PF-3-4-4** shows a sectioned view of a HRC fuse cartridge

HIGH RUPTURING CAPACITY (HRC) FUSES

Fig PF-3-4-3 (a) Typical HRC Fuse Cartridges

HIGH RUPTURING CAPACITY (HRC) FUSES

Fig PF-3-4-3 (b) Typical HRC Fuse Assembly

HIGH RUPTURING CAPACITY (HRC) FUSES

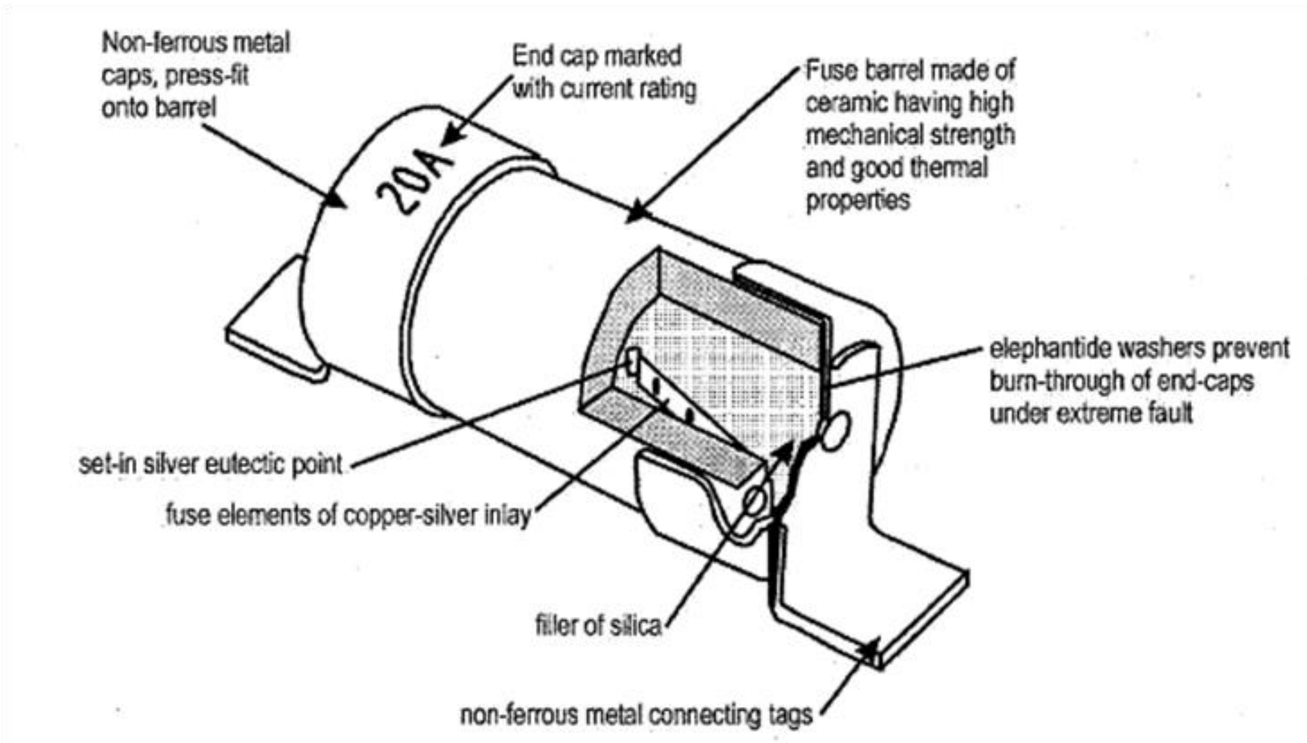


Fig. PF-3-4-4 Construction of a HRC fuse

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuse Links

- **Fig PF-3-4-5** shows the construction of typical fuse elements.
- Reduced sections (A in **Fig PF-3-4-5**) are located along the length of the fuse element creating short circuit zones of high current density, which rupture rapidly with high fault currents
- The centre of the fuse link element (B in **Fig PF-3-4-5**) has a band of pure silver which is formed into a trough and then filled with tin.

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuse Links (Cont'd)

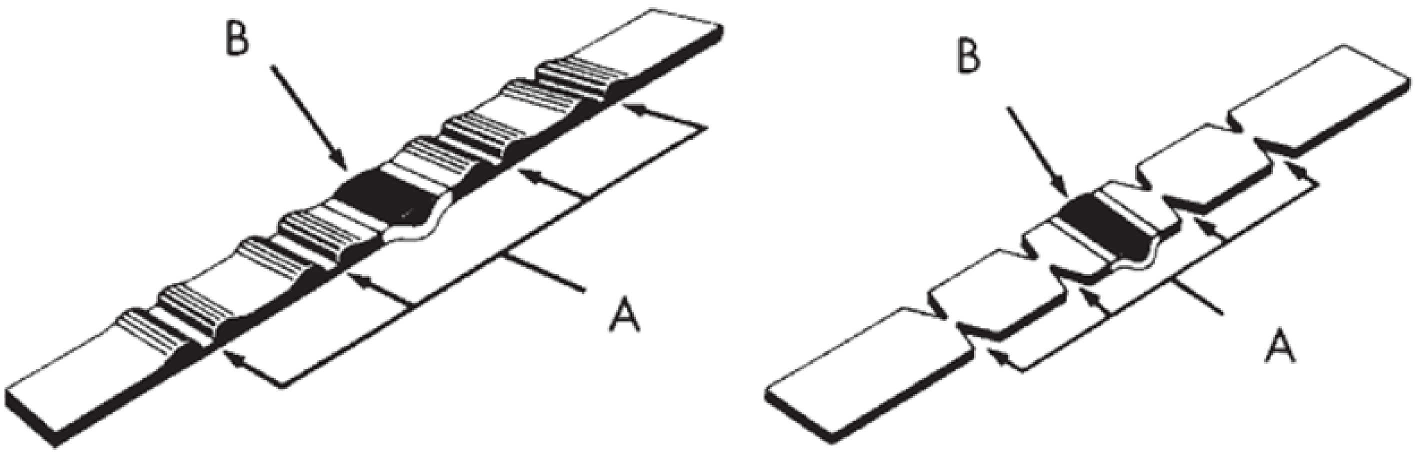


Fig. F-3-4-5 HRC Fuse Links

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuse Links (Cont'd)

- At a critical temperature the silver and tin form a low melting point alloy (around 230°C), which causes the centre of the element to melt at this temperature.
- Without this metallurgical effect the centre of this element would need to be raised to 960°C (the melting point of pure silver) under overcurrent conditions.

HIGH RUPTURING CAPACITY (HRC) FUSES

Filler

- The filler which totally surrounds the fusible elements consists of high grade silica sand
- The purpose of this filler is twofold:
  - Cools the fuse elements and therefore, enables less material to be used for a given rated current.
  - During a short circuit the molten element combines with the silica to forming a high resistance material which rapidly interrupts the current severely restricting the energy let-through to the fault.

HIGH RUPTURING CAPACITY (HRC) FUSES

Utilisation categories

- Some fuse links have only partial range breaking capacity, that is, they interrupt short circuit fault currents, but are unable to interrupt overload currents safely.
- To distinguish these types from the much more widely used general purpose fuse, the concept of utilisation categories has been introduced.

HIGH RUPTURING CAPACITY (HRC) FUSES

Utilisation categories (Cont'd)

- AS/NZS 60269.1 includes utilisation categories, each of which are defined by a two letter code:
  - The first letter indicates the breaking capacity of the fuse link

    g - full range breaking capacity

    a - partial range breaking capacity
  - The second letter indicates the utilisation category

    G - fuse link for general application

    M - fuse link for protection of motor circuits

HIGH RUPTURING CAPACITY (HRC) FUSES

Utilisation categories (Cont'd)

- Fuses labelled with the letter 'M' are motor rated fuses which have an increased inverse time/current characteristic that allows for motor starting currents
- A class gM fuse link has a dual basis of current rating, for example 32M63:
  - 32A is the continuous current carrying capacity of the fuse link and holder
  - 63A denotes the time/current characteristic of the fuse link

HIGH RUPTURING CAPACITY (HRC) FUSES

Cutoff

- The high performance of the HRC fuse as an interrupting device under fault conditions is largely due to current restriction to which the designation 'cut off' is given.
- **Fig PF-3-4-6** shows the generalised characteristic for HRC fuses and identifies the fuse's ability to interrupt a circuit well before the peak value of prospective fault current is reached.

HIGH RUPTURING CAPACITY (HRC) FUSES

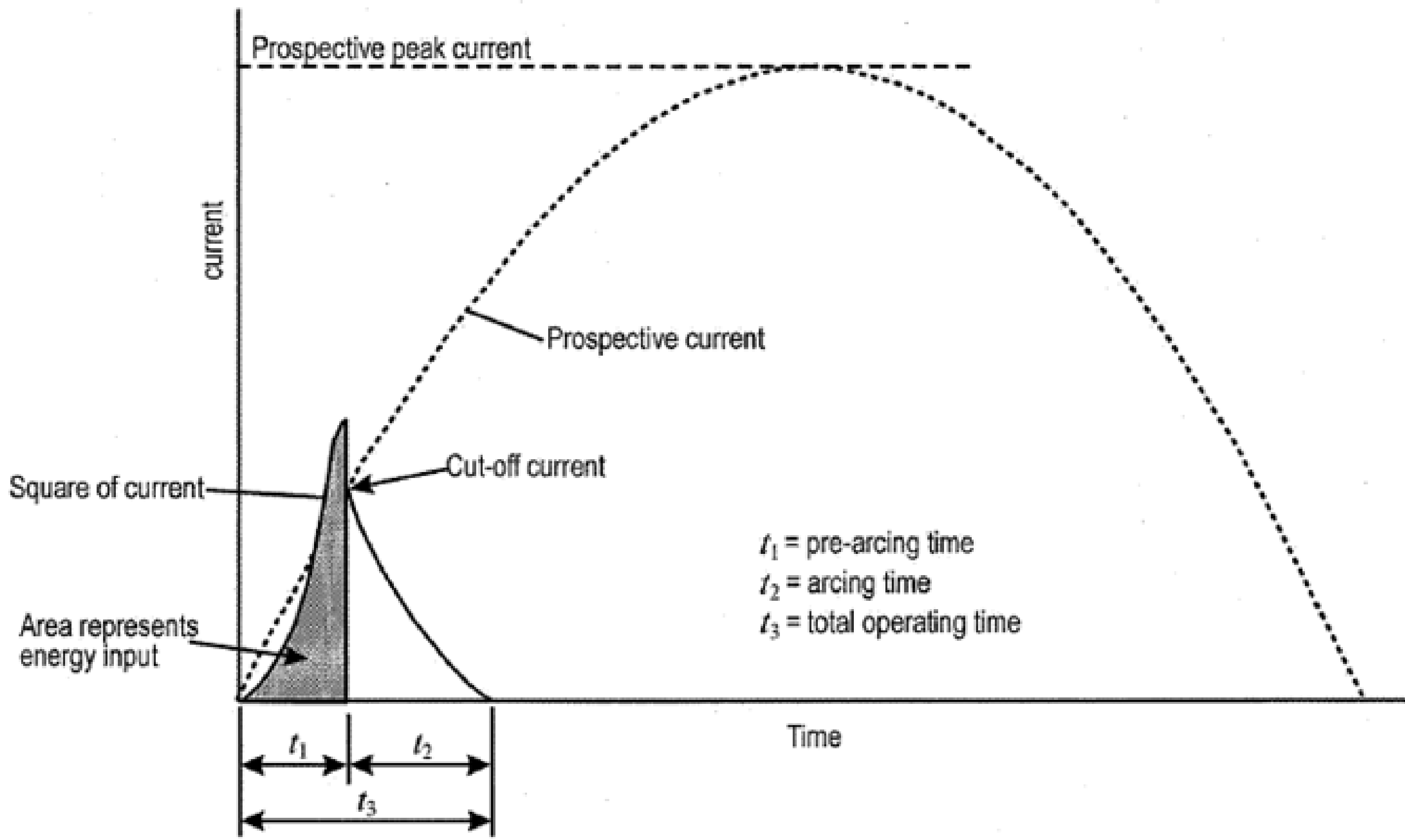


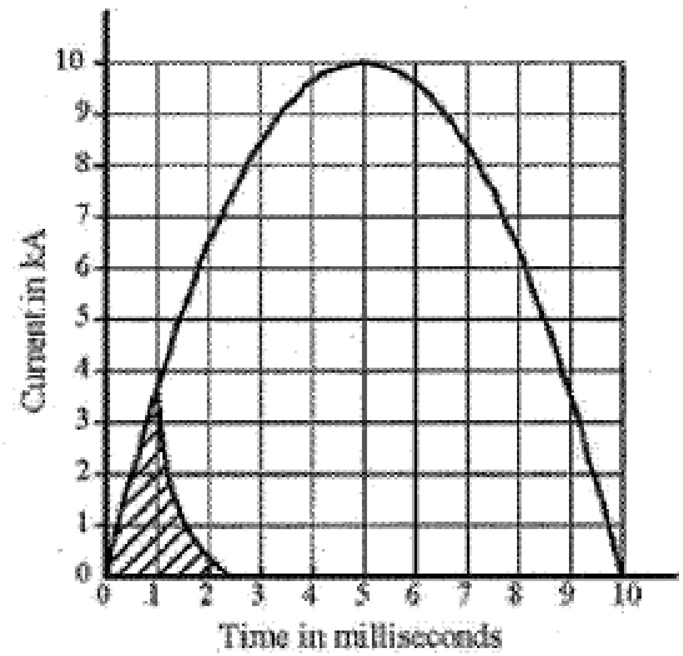
Fig. PF-3-4-6 HRC Fusing Characteristic

HIGH RUPTURING CAPACITY (HRC) FUSES

EXAMPLE

For the HRC fuse characteristic shown:

- Fault current is limited to 3.5A by the fuse
- Pre arcing time is 1 ms
- Arcing time is 1.5 ms
- Total operating time is 2.5 ms



HIGH RUPTURING CAPACITY (HRC) FUSES

Types of HRC fuse

- HRC fuses arc available as
  - High voltage fuse links - protection of distribution transformers & motors
  - Low voltage fuse links - service fuses
  - Semi conductor fuse links - different in construction as they are thinner with smaller reduced sections made of pure silver. More responsive to fault current (faster acting)

HIGH RUPTURING CAPACITY (HRC) FUSES

Time-current Characteristics

- **Fig. PF-3-4-7** Shows time-current characteristics of HRC fuses.
- The curves show prospective fault current versus pre-arcing time, i.e. melting curve.
- The characteristics are used to assess fuse link's ability to withstand surge currents, such as, motor starting currents and for determining discrimination.

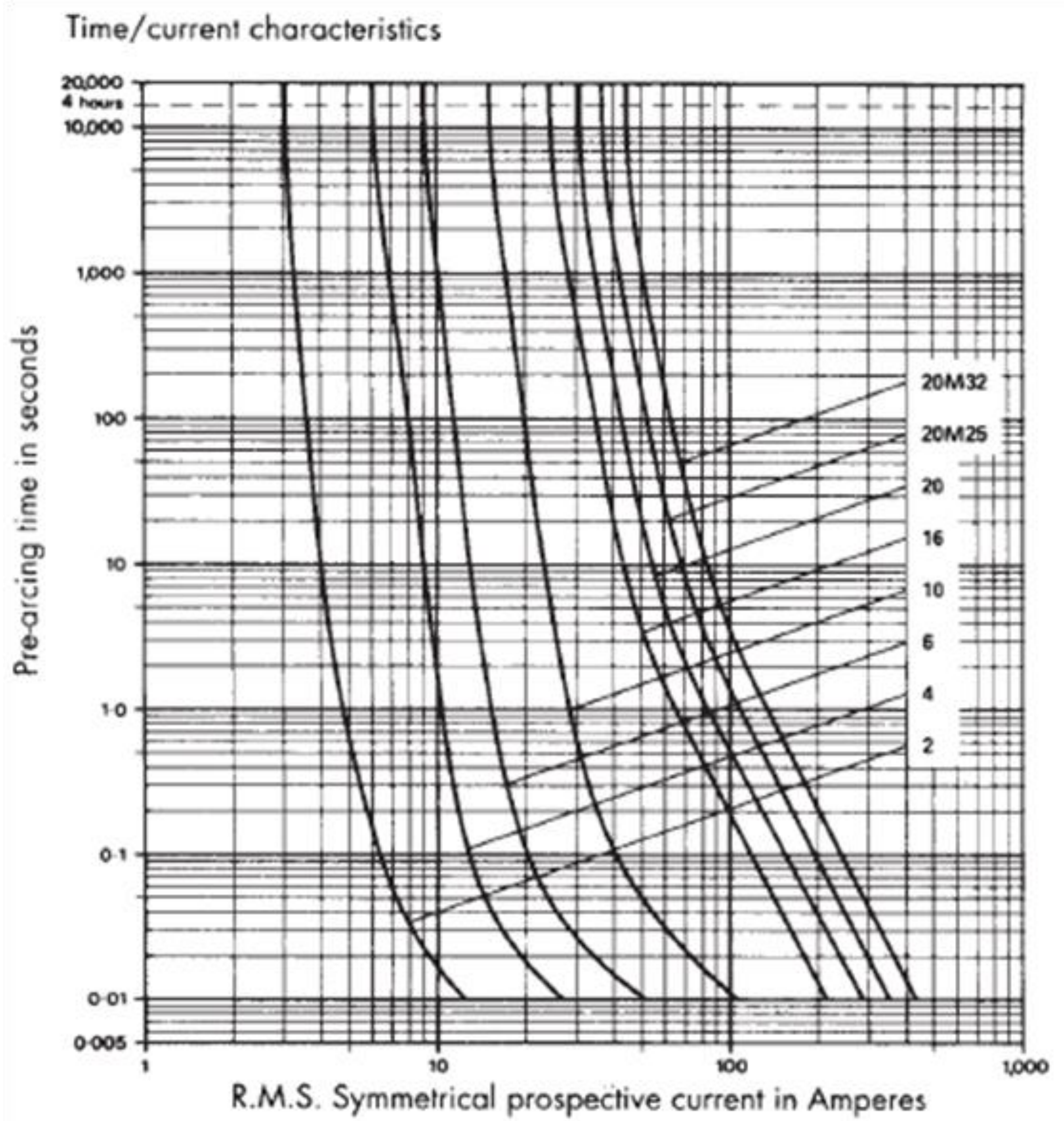


Fig. PF-3-4-7 HRC Fuses Time-Current Characteristics

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuses and Fault Loop Impedance

- Table 8.1 of AS/NZS 3000:2007 contains the maximum values of fault loop impedance, using approximate mean tripping currents for fuses as per AS2005.21.2 and the approximate disconnection time.

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuses and Fault Loop Impedance (Cont'd)

- The values of Z_s are derived from: $$Z_s = \frac{U_0}{I_a}$$
- Where:

Z_s = Complete fault loop impedance

U_0 = Nominal phase voltage (230V)

I_a = Current causing automatic operation of the protective device.

Note I_a for fuses are the approximate mean values taken from AS/NZS60269.2, (See **Fig. PF-3-4-8**)

-

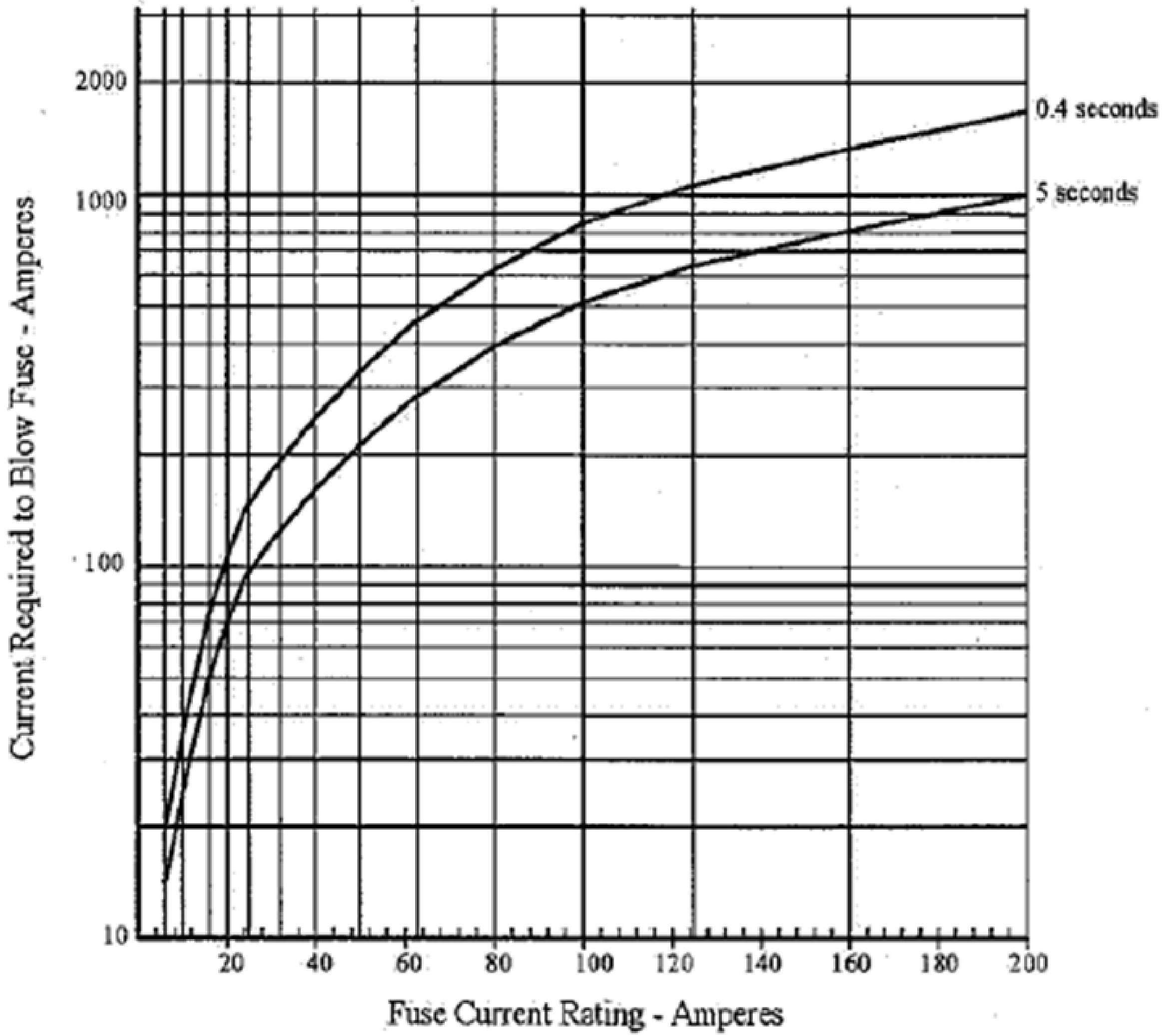


Fig. PF-3-4-8 HRC Fuse Current Rating Versus Fusing Current Curves

HIGH RUPTURING CAPACITY (HRC) FUSES

<u>Fuses and Fault Loop Impedance</u> (Cont'd)

- The following rules for disconnection times are from AS/NZS 3000:2007
  - *1.5.5.3 (b) - Touch-voltage limits In the event of a fault between a live part and an exposed conductive part that could give rise to a prospective touch voltage exceeding 50 Va.c. or 120 V ripple-free d.c, a protective device shall automatically disconnect the supply to the circuit or electrical equipment concerned.*

HIGH RUPTURING CAPACITY (HRC) FUSES

Fuses and Fault Loop Impedance (Cont'd)

- *1.5.5.3 (d) -* ***Disconnection times.*** *The maximum disconnection time for 230/400 V supply voltage shall not exceed the following:*
  - *i. 0.4s for final sub-circuits that supply—*
    - *A. socket-outlets having rated currents not exceeding 63 A; or*
    - *B. hand-held Class I equipment; or*
    - *C. portable equipment intended for manual movement during use.*
  - *ii. 5s for other circuits including submains and final subcircuits supplying fixed or stationary equipment*

HIGH RUPTURING CAPACITY (HRC) FUSES

I^2t Values

- To ensure the temperature limit of conductors is not exceeded, the device protecting a cable against short circuit must operate to limit the let through energy.
- For short circuits up to 100ms duration, it is necessary to satisfy

(from clause 2.5.4.5(b) of AS/NZS 3000:2007)

$$K^2S^2 > I^2t$$

HIGH RUPTURING CAPACITY (HRC) FUSES

I^2t Values (Cont'd)

- Where:

K = factor dependent on the material of the conductor, the insulation and the initial and the final temperatures

S = cross-sectional area of the conductor in mm^2

I = effective short-circuit current in amps (r.m.s)

t = duration of short circuit in seconds

- **Fig. PF-3-4-9** shows typical Time-Current curves of Fuse and Circuit Breaker. Cable is protected if protective device curve falls to left of cable curve.

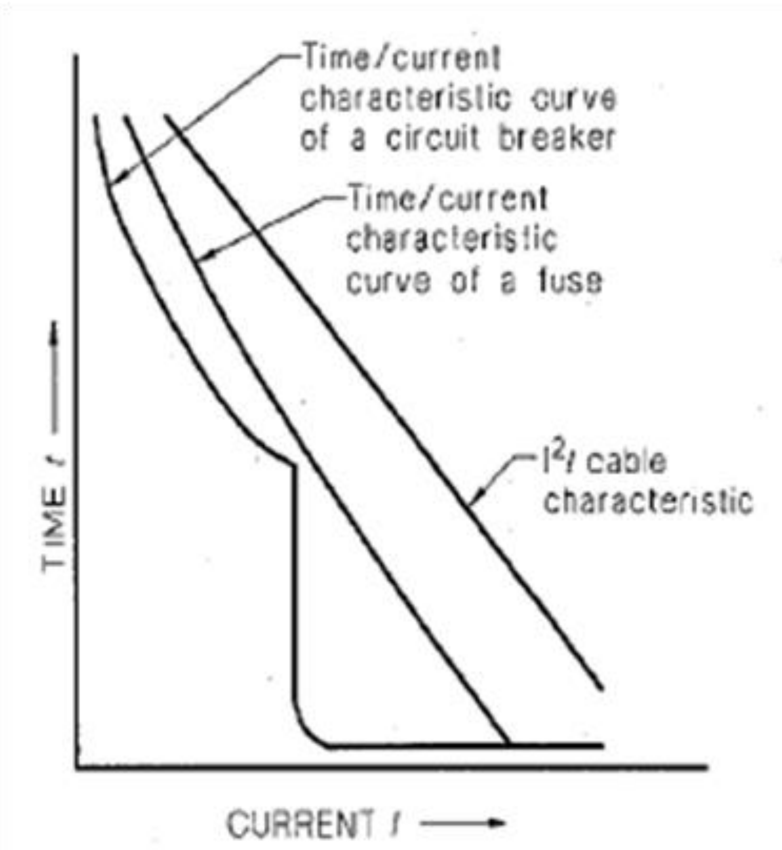


Fig. PF-3-4-9 Time-Current characteristics of Fuse and Circuit Breaker.
Cable is protected if protective device curve falls to left of cable curve

Topic 3-5

CIRCUIT BREAKERS

INTRODUCTION

- A circuit breaker (CB) is a type of switch that opens automatically if the current through it exceeds its maximum load current rating.
- Unlike a fuse, which needs replacing when it blows, a CB can be reset after clearing the fault in the circuit.
- CBs have current ratings from a few amperes to thousands of amperes.
- The CB has a toggle that is used manually, like a switch.

INTRODUCTION

- In addition there is an internal mechanism that can also open the switch if the current is too high.
- Classification of circuit breakers is by the method used to cause the mechanism to trip open:
  - thermal
  - magnetic
  - thermal-magnetic

THERMAL CIRCUIT BREAKER

- The tripping mechanism consists of a bimetallic strip heated either by the load current (or a fixed proportion of the load current) passing through it, or indirectly by a heater (See **Fig. PF-3-5-1**).
- When heated, the two metals of the bimetallic strip expand at different rates, causing the strip to bend and operate a toggle, which opens the CB.
- Because the bimetallic strip takes time to heat up, it has the necessary inverse time characteristics for wiring protection.

THERMAL CIRCUIT BREAKER

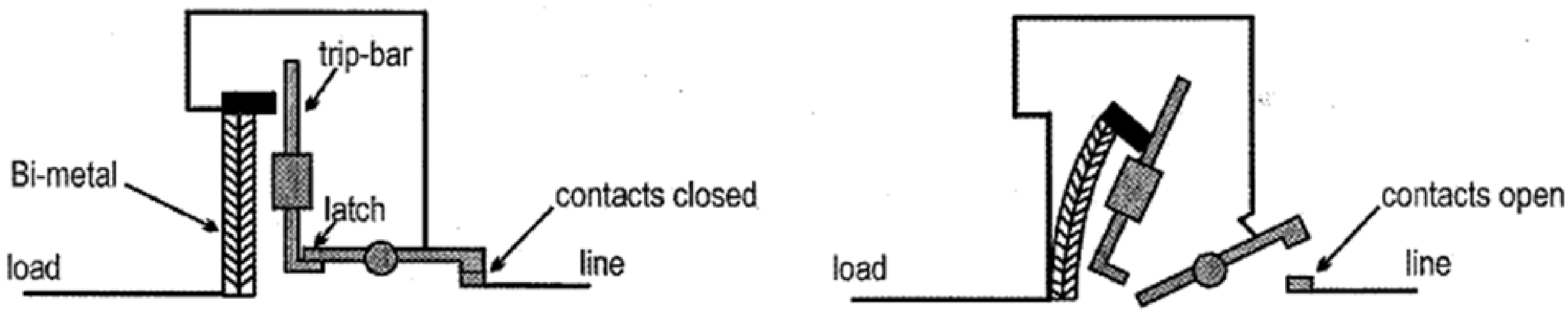


Fig. PF-3-5-1 Thermal Circuit Breaker Trip Mechanism

- If the CB is installed in the same ambient temperature conditions as the circuit protected, the time to trip will reduce, as the ambient temperature of the protected cables will also have risen.

THERMAL CIRCUIT BREAKER

- The time lag of the thermal strip ensures that overloads of short duration do not cause tripping;
- Repeated overloads will have a cumulative heating effect and will eventually trip the CB in time to avoid exceeding the temperature rise limits of the cable.
- In practice, if a thermal CB is operated in an ambient temperature higher than its rating or grouped in an enclosure with other equipment where the temperature will exceed its 'free air' temperature rating, it must be de-rated.

THERMAL CIRCUIT BREAKER

- One manufacturer recommends a de-rating factor of 0.8 for an individual enclosure and 0.7 for distribution board mounting.
- This means that a 100A CB would be de-rated to 80A and 70A respectively for these two positions.

THERMAL CIRCUIT BREAKER

- A Thermal CB while ideal for overload protection is unsatisfactory for short circuit protection.
- This is because it cannot open the circuit quickly enough to prevent damage due to the high prospective currents.
- This type of circuit breaker is often backed up with a fuse that provides short-circuit protection.

MAGNETIC CIRCUIT BREAKER

- In a magnetic CB, the load current or a fraction of it passes through the coil of an electromagnet.
- The magnet attracts an iron armature and mechanically breaks the linkage holding the CB in the 'on' position, thus tripping it.
- To prevent immediate operation with moderate overcurrent, a time delay mechanism is incorporated.
- This is often in the form of an oil filled dashpot.
- See **Figs. PF-3-5-2(a) to (e**) for operating principle

MAGNETIC CIRCUIT BREAKER

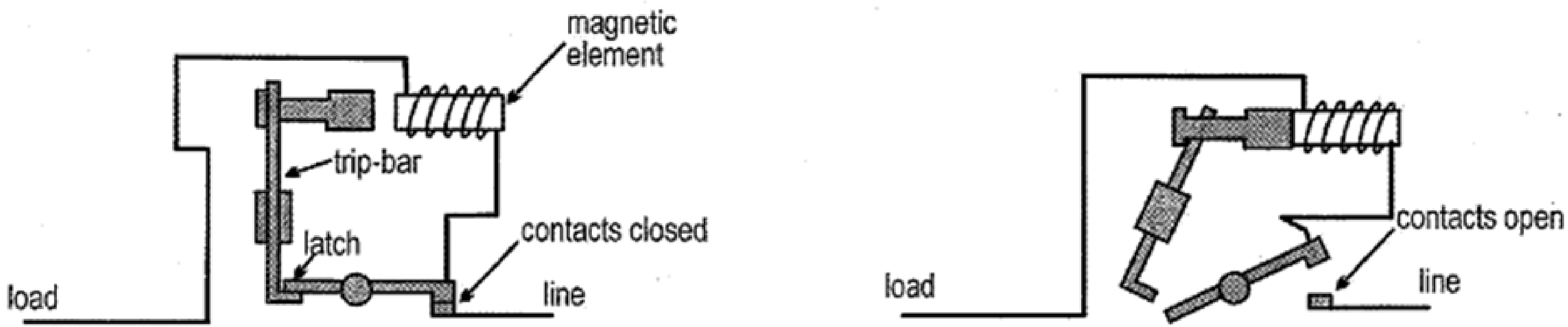


Fig. PF-3-5-2(a) Magnetic Circuit Breaker Trip Mechanism

MAGNETIC CIRCUIT BREAKER

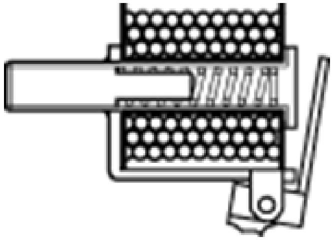


Fig. PF-3-5-2(b) Current within rating – magnetic field insufficient to attract tripping armature or to move core

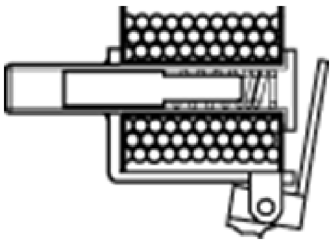


Fig. PF-3-5-2(c) Moderate overload - magnetic field insufficient to attract tripping armature but is strong enough start moving core

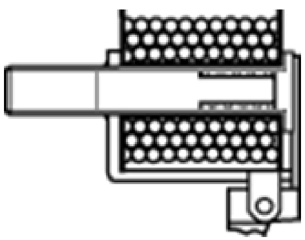


Fig. PF-3-5-2(d) Moderate overload persists – core continues its movement until it reaches the pole piece reducing the reluctance of the magnetic circuit attracting the armature and tripping the CB

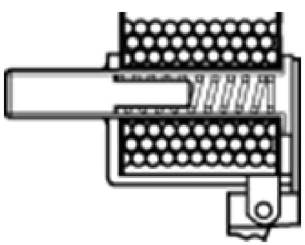


Fig. PF-3-5-2(e) Short Circuit Fault - magnetic field generated is strong enough to instantly attract the armature without the aid of the core, thus tripping the CB instantly

MAGNETIC CIRCUIT BREAKER

- The magnetic CB will provide a near instantaneous trip on heavy overloads (usually ten times the full load) or on a short circuit.
- The magnetic trip action is independent of ambient-temperature conditions.

THERMAL-MAGNETIC CIRCUIT BREAKER

- The most common CB is the thermal-magnetic type.
- This CB uses a bimetallic element for delayed overload tripping and magnetic element for near instantaneous short circuit tripping
- Typical interrupting time for a short-circuit fault is 0.01 seconds.
- **Fig. F-3-5-3** shows the thermal-magnetic circuit breaker trip mechanism

THERMAL-MAGNETIC CIRCUIT BREAKER

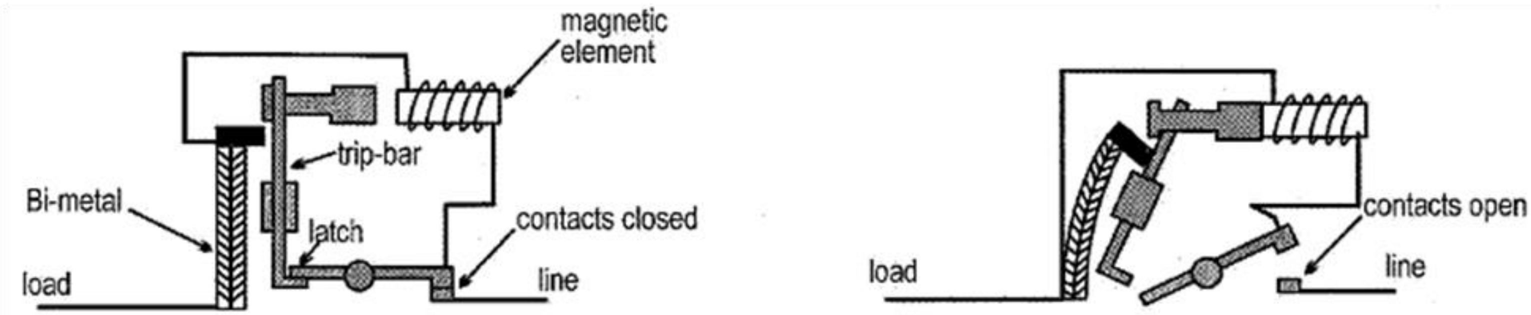


Fig. PF-3-5-3 Thermal-Magnetic Circuit Breaker Trip Mechanism

CIRCUIT BREAKERS GENERALLY

- When a CB trips, it is important to remove the cause of the overload before closing the circuit breaker and restoring the power.
- Most CBs have a three-position switch/toggle mechanism (off/tripped/on):
  - ON – toggle fully up
  - TRIPPED – toggle automatically moves to centre position
  - OFF – toggle fully down
- The ‘trip-free’ feature on most CBs prevent resetting the CB onto a fault

CIRCUIT BREAKERS GENERALLY

Arc Suppression

- When CBs interrupt high fault currents, an arc is drawn between the contacts.
- In large CBs, blasts of air or oil extinguish the arc.
- For smaller CBs, arc extinction is assisted by the use an arc suppression grid as shown in **Fig. PF-3-5-4** .
- An arc behaves like a current-carrying conductor and is thus surrounded by a magnetic field the strength of which is proportional to the magnitude of the current.

CIRCUIT BREAKERS GENERALLY

Arc Suppression (Cont’d)

- The arc forms between U-shaped metal plates, which distort the circular field around the arc and the resultant magnetic field acts on the arc to push it into the plates, which cut the arc into a number of small sections.
- The cooling effect of the plates and the lengthening and cutting of the arc cause its rapid extinction.

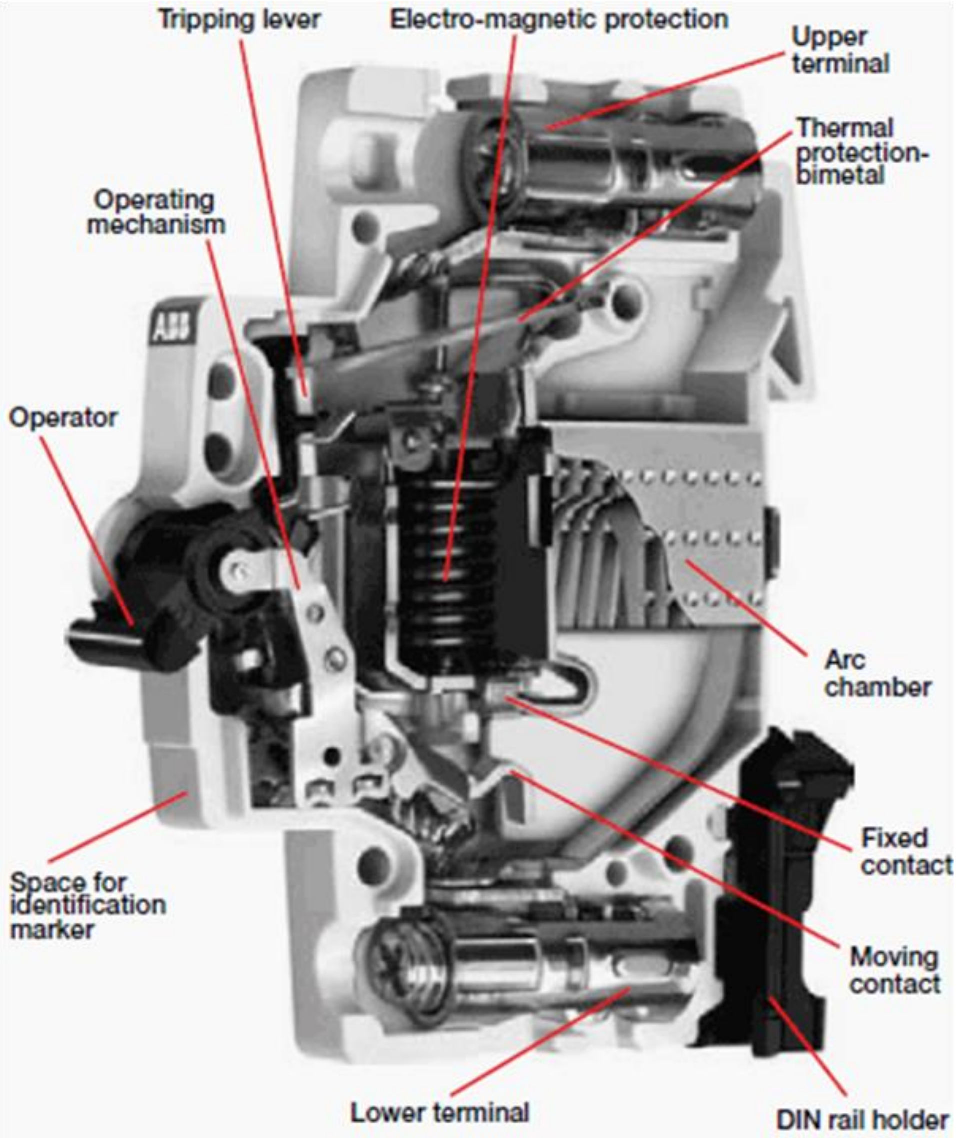


Fig. PF-3-5-4 Thermal-Magnetic Circuit breaker showing the arc suppression grid (Arc Chamber)

CIRCUIT BREAKERS GENERALLY

Classification Of Circuit Breakers

- Circuit breakers are classified by:
  - number of poles (ranging from single pole to four pole with the two and four pole types available with one unprotected pole)
  - Protection against external influences (enclosed or unenclosed)
  - Rated voltage, frequency and current (230/400V; 50Hz with current ratings such as 6A, 8A, 10A, 13A, 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A, and 125A)

CIRCUIT BREAKERS GENERALLY

<u>Classification Of Circuit Breakers</u> (Cont'd)

- range of instantaneous tripping current
  - Type B having a tripping range of 3 to 5 times rated current (mean trip 4 times)
  - Type C having a tripping range of 5 to 10 times rated current (mean trip 7.5 times)
  - Type D having a tripping range of 10 to 50 times rated current
- See the time current curves in **Fig. PF-3-5-5**.

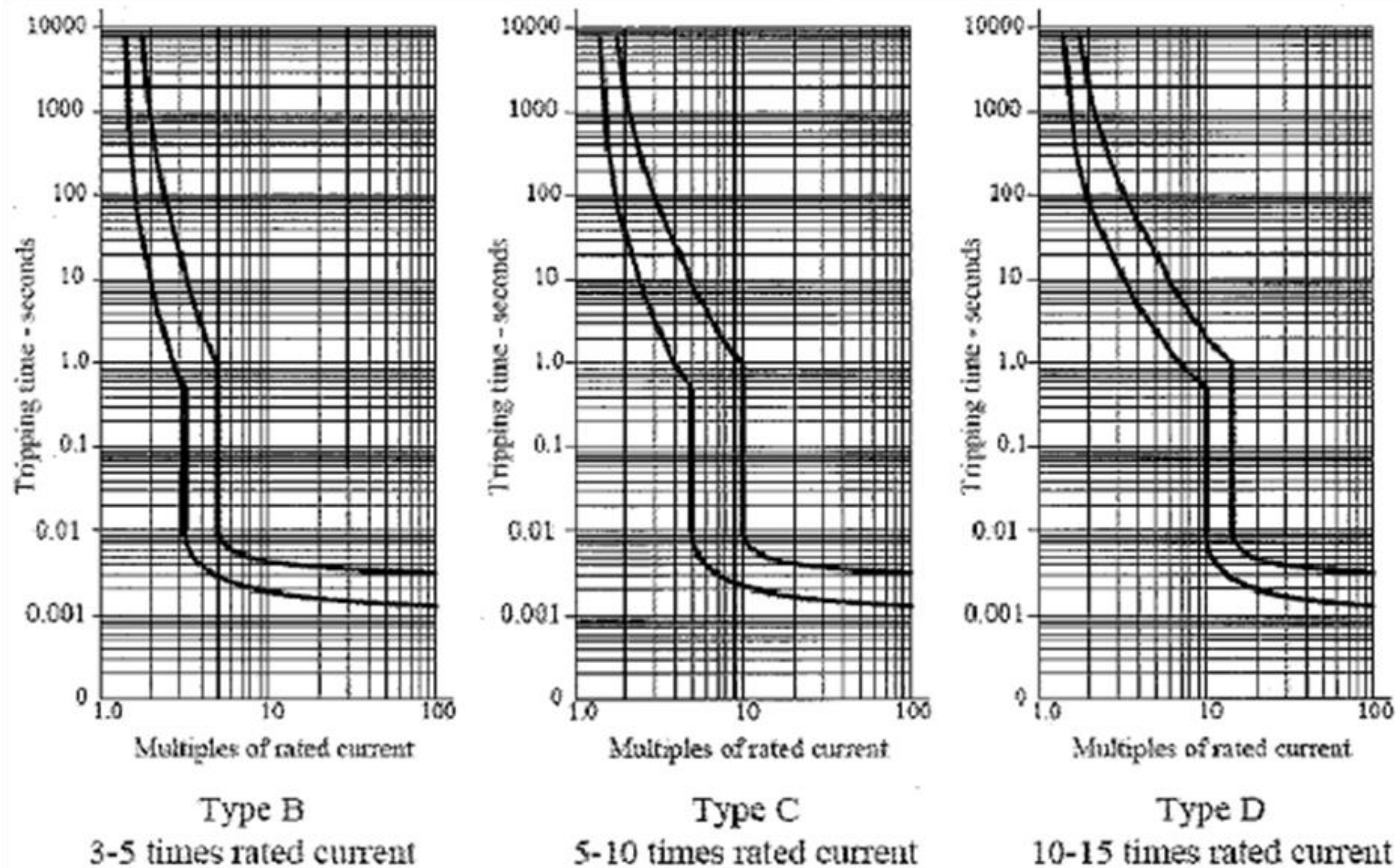


Fig. PF-3-5-5 Time-Current Tripping Curves for type B, C, and D Circuit Breaker

Topic 3-6

RESIDUAL CURRENT DEVICES (RCD)

INTRODUCTION

- Residual Current Devices (RCDs), commonly called 'safety switches', are protective devices that isolate supply to a circuit if an earth fault current occurs (Clause 1.4.80 of AS/NZS 3000:2007).
- See Fig **Figure F-3-6-5** for images of typical 2-pole and 4-pole RCDs.
- Clause 2.6.1 (and 1.5.1) of AS/NZS 3000:2007 requires RCD's to be installed for the protection of persons and livestock.

INTRODUCTION

- The use of RCDs is not recognized as a sole means of protection and does not obviate the need to apply the protective measures specified in Clause 2.4 of AS/NZS 3000:2007
- Accidents that result in electrocution can be caused by a number of factors:
  - faults in tools, appliances, leads or any electrical equipment
  - damp conditions
  - improper use of electrical equipment

INTRODUCTION

- The use of RCDs can reduce the risk of fatalities from these situations, and their installation is now mandatory in all new installations.

HISTORICAL

- Systems for protection against electric shock have developed alongside the development of electricity.
- Early measures aimed at the prevention of contact with live parts by insulating, providing barriers, enclosing live parts or locating live parts out of reach.
- This, however, did not offer protection from direct or indirect contact with live parts in the event of insulation breakdown
- To give protection against indirect contact with live parts, earthing systems were introduced.

HISTORICAL

- Together with appropriately sized fuses or circuit breakers, 'fault protection' methods evolved.
- Earthing systems fail to provide protection against the risk of electric shock when the earth fault resistance is high.
- To overcome this RCDs are used as additional protection to the earthing system.

HISTORICAL

DEVELOPMENT OF RESIDUAL CURRENT PROTECTION

- RCDs have provided additional protection in some industrial activities, most medical treatment areas and the construction industry for a number of years.
- RCDs have also been known as 'core balance units' or 'current-operated earth-leakage circuit breakers‘, or more recently, as 'safety switches'.
- Use of these devices is mandatory in all new domestic installations.

HISTORICAL

DEVELOPMENT OF RESIDUAL CURRENT PROTECTION

- The purpose remains the same: to rapidly cut off the power to a circuit when a current, at a level likely to cause physical harm, is leaking to earth.
- Early electrical systems only provided limited protection against electric shock, as little was known about the causes of death from electrocution.
- It was not until the 1930s that the mechanisms of electrocution (the effects on the heart, lungs and other organs as well as the burning effect) were better understood.

ELECTROCUTION

- Severity of the effects of electric shock depends on:
  - the magnitude of the current,
  - the duration of current flow and
  - the current path through the body.
- A current of sufficient magnitude and duration passing through the heart will cause it to fibrillate.
- Under these conditions, permanent brain damage occurs within a few minutes, followed by death within several minutes.

ELECTROCUTION

- Ventricular fibrillation is the main cause of death by electrocution involving low-voltage AC (50V to 1000V) currents, while burns are a greater contributing factor in high-voltage electric shock.

ELECTROCUTION

- **Figure PF-3-6-1** shows the time-current effects 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 (sub-zone **a** : up to 5% , sub-zone **b** : up to 50% , sub-zone **c** : greater than 50%):

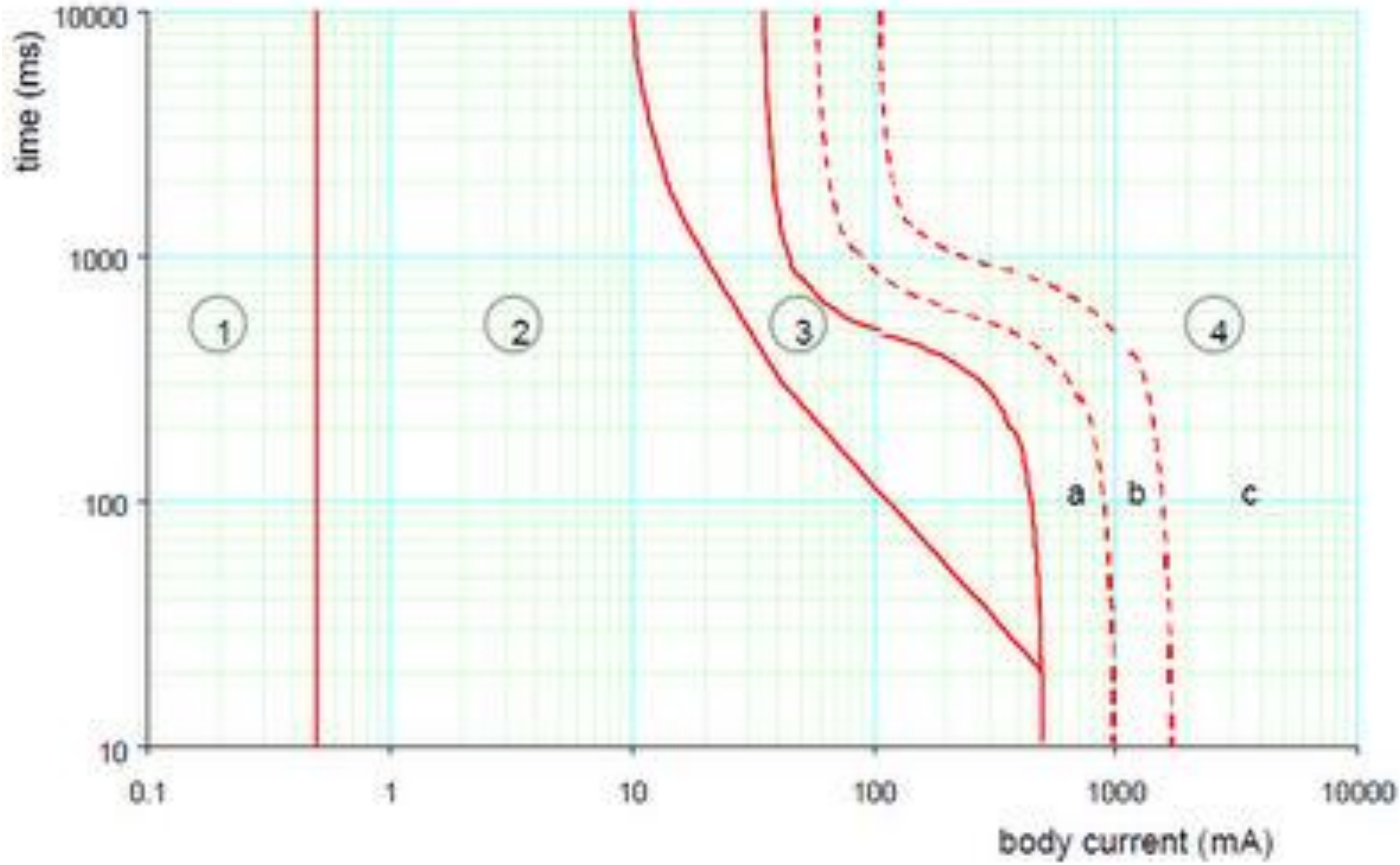


Figure PF-6-6-1 Time-current zone effects on humans

ELECTROCUTION

- Increase in current and time beyond zone 4 is likely to cause cardiac arrest and cessation of breathing; burning might also occur
- This information on current effects on the human body has served as the basis for determining the operating characteristic for effective RCDs.

    As an illustration: a Type II RCD (30 mA) must operate as required by AS 3190, and will trip the circuit that it is protecting well below the threshold of the probability of ventricular fibrillation (that is below **zone 4**).

ELECTROCUTION

- Note: The information in this topic is based on AS 3190 and AS/NZS 3175. More recently, the Standard AS/NZS 61009.1 was introduced to align more closely with international Standards criteria.

OPERATING PRINCIPLE OF THE RCD

- The RCD uses a toroidal transformer, similar to a current transformer, to detect leakage current.
- The secondary winding is known as the 'sensing winding' or 'fault detection winding'.
- It is connected to a trip relay, which, when activated by an earth leakage current, operates main contacts to switch off the circuit.
- The active and neutral conductors supplying the circuit to be protected are installed so that they pass through the toroidal core as **Fig. PF-3-6-2** shows.

OPERATING PRINCIPLE OF THE RCD

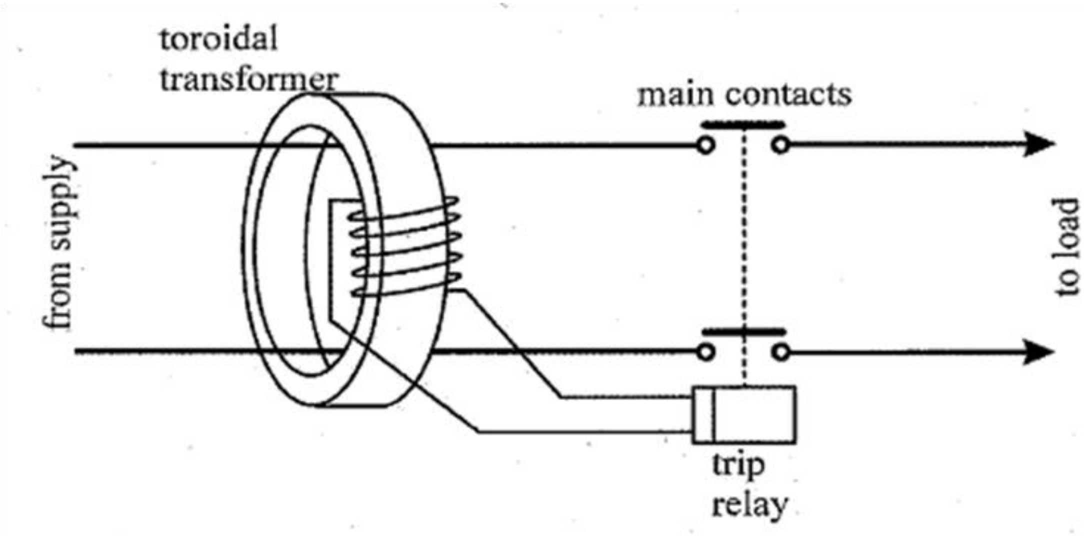


Figure PF-6-6-2 Operating principle of an RCD

- Under normal conditions the current that flows in the active conductor is equal and opposite to the current in the neutral conductor, thus the resultant flux in the core is zero as **Fig. F-3-6-3** shows.

OPERATING PRINCIPLE OF THE RCD

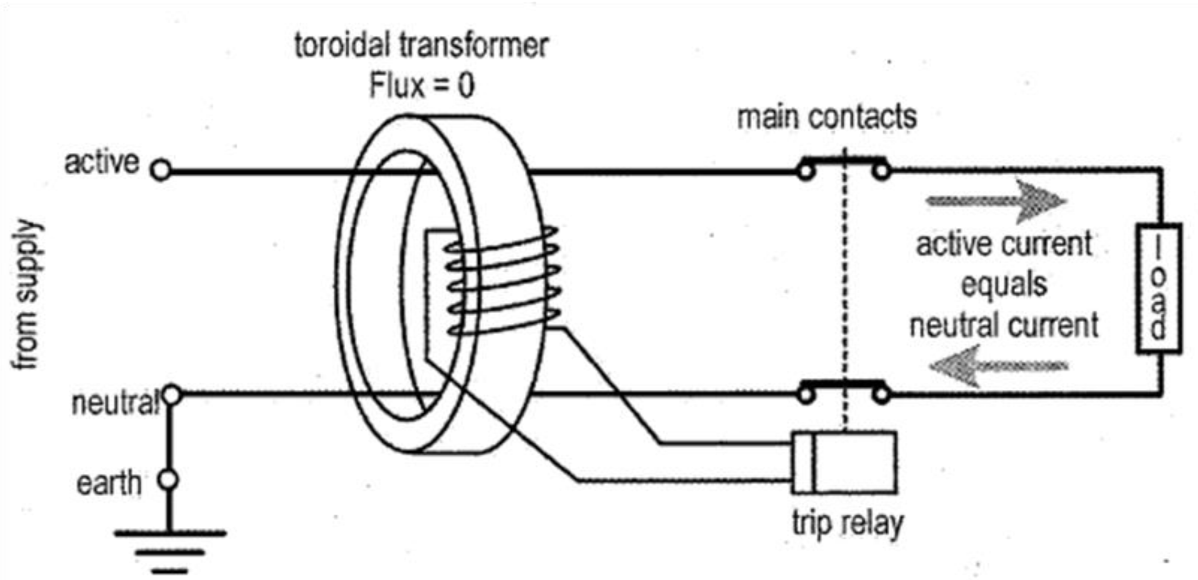


Figure PF-6-6-3
Operation of RCD - no fault

- If an earth fault occurs as shown in **Figure PF-3-6-4**, there is a second current path from the active to the source, which bypasses the toroidal core.

OPERATING PRINCIPLE OF THE RCD

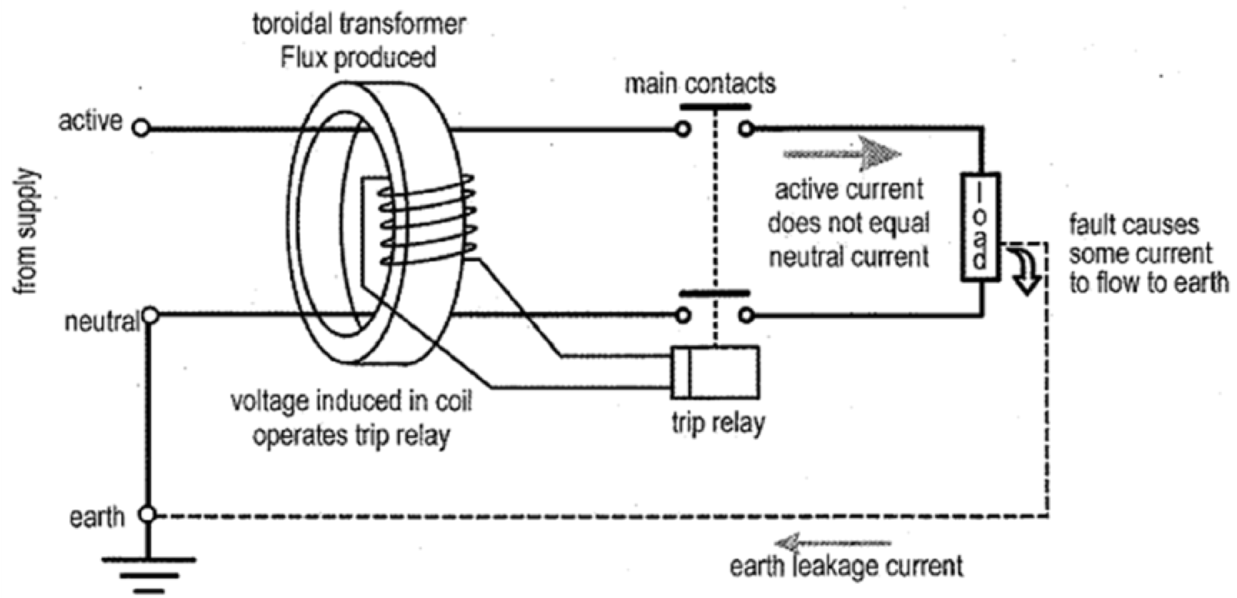


Figure PF-6-6-4
Operation of RCD - earth fault

- The current in the active conductor is now the sum of the load current and the earth fault current (current bypassing the toroidal core), while the current in the neutral is equal to the load current.

OPERATING PRINCIPLE OF THE RCD

- A net resultant magnetic flux is established in the toroidal core by this fault current (that is a residual current).
- The net flux in the core induces a voltage in the sensing (secondary) winding, which is then used to operate the trip relay to isolate the circuit.
- In multiphase AC circuits, the phasor sum of the currents in all conductors (including neutral) is normally zero.

OPERATING PRINCIPLE OF THE RCD

- All RCDs must be provided with an accessible testing facility to allow periodic testing of the tripping operation.
- The three main types of operating mechanism are:
  - Magnetically held trip relay
  - Electronic relay
  - Magnetically held relay with electronic time delay

OPERATING PRINCIPLE OF THE RCD

Magnetically Held Trip Relay

- A permanent magnet, holds a spring-loaded armature in the closed position.
- The sensing winding of the toroidal transformer is connected to the trip relay coil.
- An output from the sensing winding causes a disturbance in the magnetic circuit, which weakens the flux and releases the armature.
- The energy from the spring-loaded armature mechanically trips the main contacts.

OPERATING PRINCIPLE OF THE RCD

Magnetically Held Trip Relay (Cont'd)

- No connection between trip circuit and supply is required.
- Two types of trip relays use this same principle.
  - A polarised-type relay that only responds to the positive half-cycle of a fault current.
  - A saturation-type relay that responds to both the positive and negative half-cycles of a fault current, improving the response time by half a cycle or 10 milliseconds for a 50Hz supply.

OPERATING PRINCIPLE OF THE RCD

Electronic Relay

- The small output signal of the toroidal transformer is used to trigger a SCR or is amplified to operate a relay or shunt trip circuit to trip the main contacts.

Magnetically Held Relay with Electronic Time Delay

- The circuit from the sensing winding in this type of relay includes filtering or delay elements to provide discrimination against unwanted tripping.

TYPES OF RCD

- AS 3190 classifies four types of RCDs as well as portable RCDs.
- The rated residual current ($I_{\Delta n}$) of an RCD is the residual (fault) current at which tripping operation of the RCD is ensured.
- This is also known as the sensitivity of an RCD.
- The RCD must operate within a maximum rated time, and also must be able to distinguish between 'true' leakage current and other disturbances that might cause 'nuisance' tripping.

TYPES OF RCD

- RCDs are specified by trip sensitivity rating and load-current rating, e.g. 30mA/20A.
- AS 3190 sensitivity rating are as follows:
  - **Type I**: residual current rating not exceeding 10mA
  - **Type II**: residual current rating exceeding 10 mA but not exceeding 30 mA
  - **Type III**: residual current rating exceeding 30 mA but not exceeding 300 mA without selective tripping-time delay
  - **Type IV**: residual current rating exceeding 30 mA but not exceeding 300 mA with selective tripping-time delay.

TYPES OF RCD

- Portable RCDs are classified as follows:
  - **Class L**: single-phase portable devices primarily intended for household and similar general use
  - **Class H**: portable devices primarily intended for general industrial use.
- The waveform of fault current is not necessarily 50Hz sinusoidal and may have higher frequencies and DC components superimposed on it due to electronic control and switching devices.

TYPES OF RCD

- AS/NZS61008.1 and AS/NZS61009.1 designate additional classifications for RCDs based on ability to operate at different waveforms of residual current as follows:
  - **AC type**, for alternating current only
  - **A type**, for alternating and/or pulsating current with DC components
  - **B type**, for alternating and/or pulsating current with DC components and continuous fault current
-

RCD APPLICATIONS

Type I RCD

- Specified for use in patient treatment areas by AS/NZS 3003, also suitable for use in research and educational laboratories.
- Must trip on a leakage current of no more than 10mA in less than 40 ms
- Medical equipment often contains rectifying components, thus Type I RCD must also respond to DC pulses.

RCD APPLICATIONS

Type II RCD

- Must operate within 300 ms (250 ms for residual current relays) at 30mA-leakage current and within 40 ms at 150mA-leakage current.
- The device must not trip at leakage currents below 15 mA. In practice, a typical design point would be 22.5 mA to trip in less than 40 milliseconds.

RCD APPLICATIONS

Type II RCD (Cont'd)

- AS/NZS 3000:2007 Clause 2.6.2.4 requires final sub-circuits supplying lighting, socket-outlets and directly connected hand held equipment in a residential installation to be protected by a Type II (30 mA) RCD at the origin of the circuit
- AS/NZS 3000:2007 Clause 2.6.3.2 requires RCD protection of socket-outlets with ratings up to 20A in installations other than residential.

RCD APPLICATIONS

<u>Type II RCD</u> (Cont'd)

- Lighting and directly connected hand held equipment also require RCD protection.
- Types I and II are available in an RCD/CB combination providing circuit protection and residual current protection in one unit.
- RCDs incorporated in a standard combination outlet assembly also available

RCD APPLICATIONS

Type III RCDs

- manufactured with residual current ratings of 100mA and 300mA, with a maximum tripping time of 300 milliseconds (250 milliseconds for residual current relays)
- Type III RCDs are intended for protection against indirect contact with live parts or where a high standing leakage current would cause a Type II RCD to trip.

RCD APPLICATIONS

- **NOTE**: The only method of discrimination that can be incorporated into the operating characteristics of an RCD is one that uses different response times to a given fault.

Type IV RCDs

- Also known as **S-type** because they have selective tripping-time delay
- are available with the same residual current ratings as Type III.

RCD APPLICATIONS

<u>Type IV RCDs</u> (Cont'd)

- Selective tripping between 50 ms and 150 ms
- Intended for similar use as Type III RCDs, as back-up protection to Type II RCDs or for fire prevention and installation protection on circuits where no other type of RCD is installed.
- May not be suitable for personal protection

RCD APPLICATIONS

Portable RCDs

- These incorporate Type I or II devices, which protect one or more socket-outlets, cord extension sockets or a combination of both.
- The requirements for these devices as specified in AS 3190 include limitations on the lengths of supply flexible cords for a given RCD load-current rating and cord conductor size.

RCD APPLICATIONS

Coal Mines

- AS 2081: *Electrical Equipment for Coal and Shale Mines - Electrical Protection Devices* covers, in part, earth fault protection devices with rated tripping currents above 300mA but not exceeding 500mA.
- The Standard is used by the mining authority in each State to detail permissible earth leakage devices under local regulations.
- Devices usually require approval by the relevant mining authority before they can be installed.

RCD APPLICATIONS

Coal Mines (Cont'd)

- In mining activities, earthing systems are required to be regularly monitored, and most cables are of the neutral-screened or armoured type, making protection necessary only against indirect contact (that is the voltage between exposed metal and earth during an earth fault).

RCD OPERATION

- An RCD must be able to:
  - Detect leakage current up to the rating of the RCD
  - Switch off the supply rapidly after detecting such leakage current
  - Ignore leakage currents below 50% of the rating of the RCD
  - Discriminate between leakage current caused by an earth fault and other line disturbances (avoid unwanted tripping)
- The main causes of or nuisance tripping include:
  - Standing leakage currents
  - Electrical disturbances
  - Installation practices and faults

RCD INSTALLATION

- The following points need to be considered in providing residual current protection:
  - The level of protection required by regulation
  - Additional protection by the consumer
  - Installation limitations
  - Overall cost
- Residual current protection is a mandatory requirement for all final sub-circuits supplying lighting and socket outlets in new installations.

RCD INSTALLATION

- Domestic installations require the residual current protection device to be installed on the main switchboard
- Arrangements are as follows:
  - ➢ Not more than three final sub-circuits are be protected by any one RCD.
  - ➢ If more than one lighting circuit is installed lighting circuits are to be distributed between RCD's.
  - ➢ Minimum of two RCD's required.

2 and 4 Pole RCDs

Figure PF-3-6-5 Typical 2-pole and 4-pole RCDs

Connecting a 2 Pole RCD

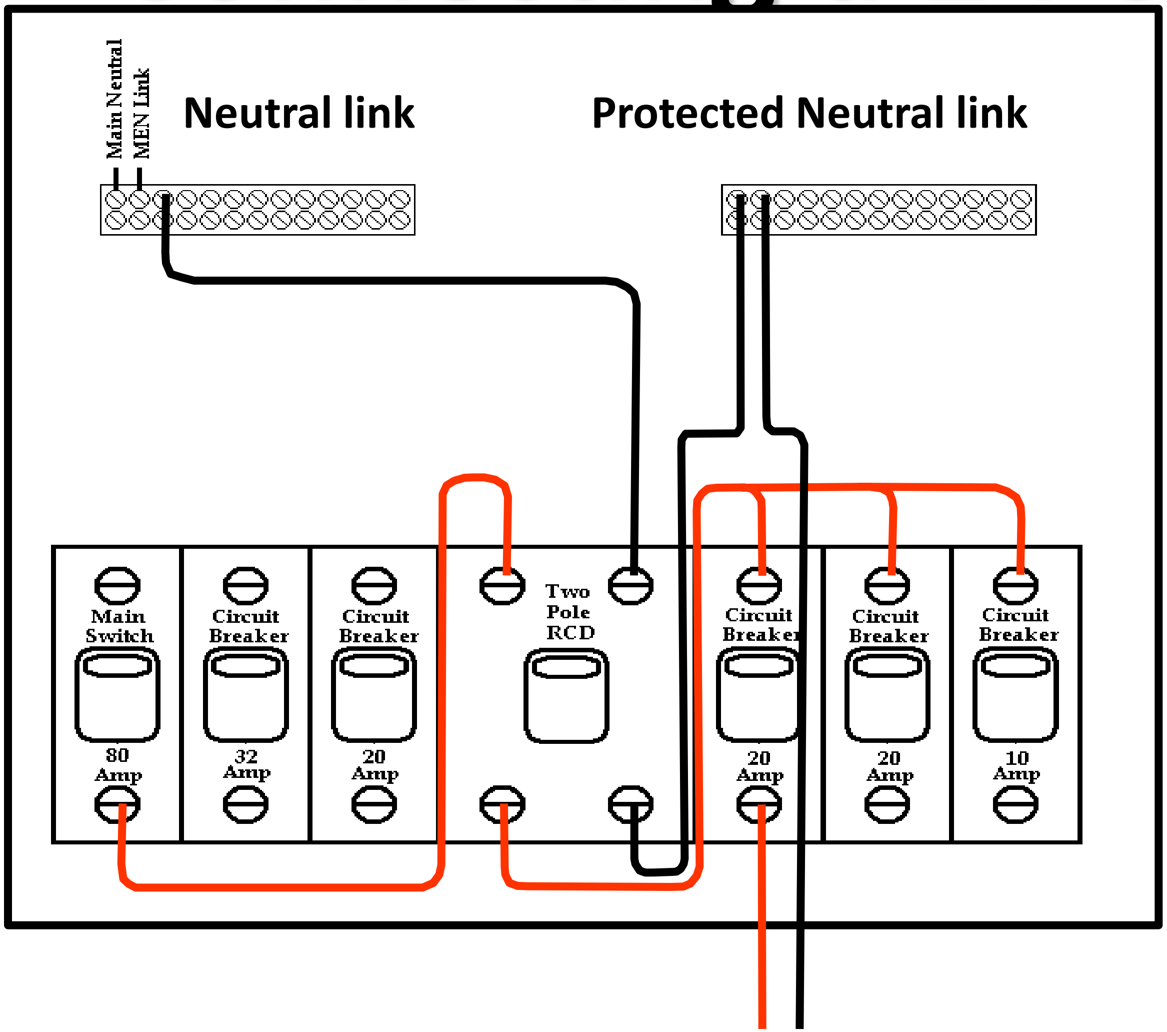


Figure PF-3-6-6 Connecting a 2 Pole RCD

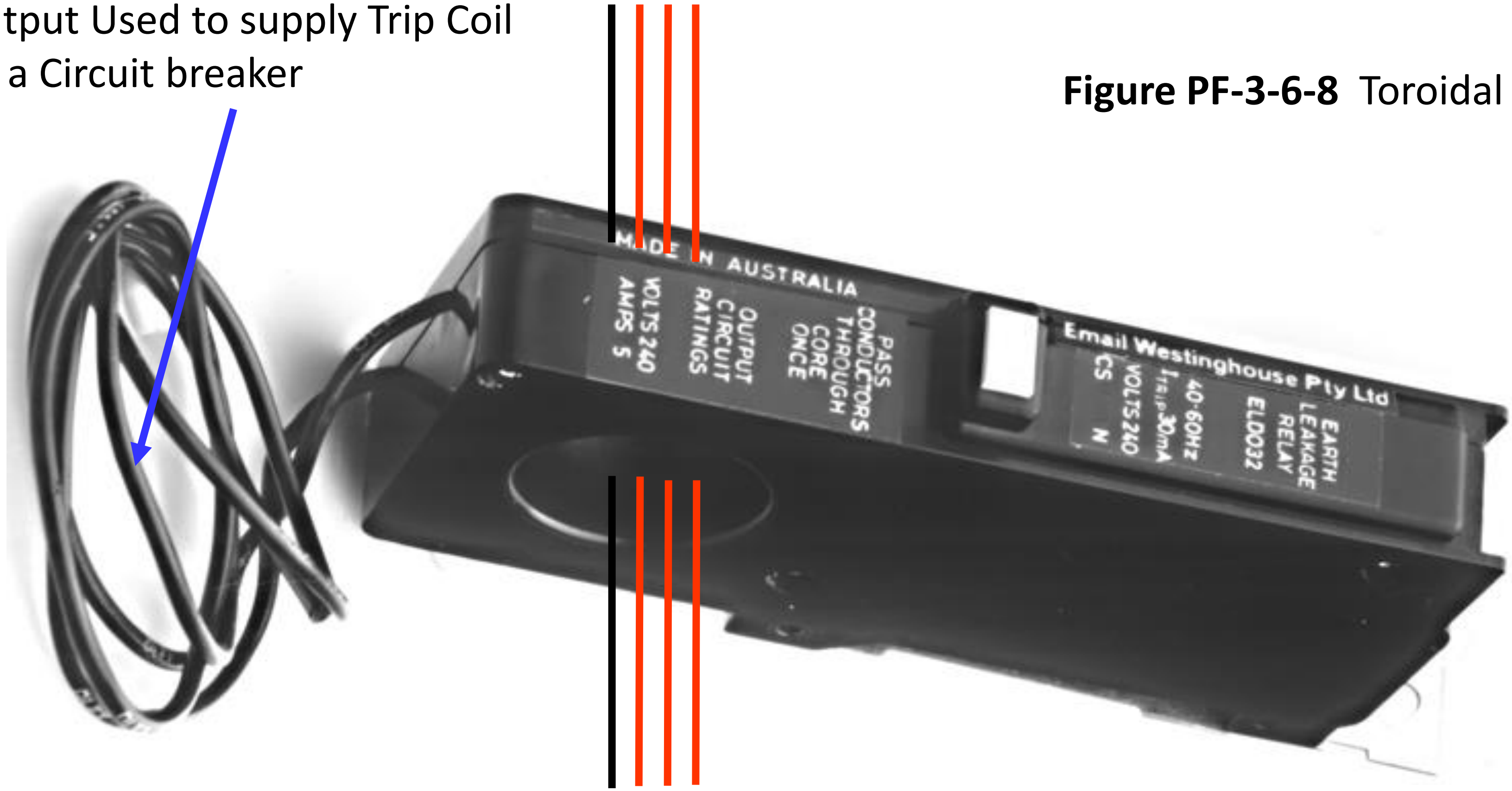
RCD Power Point

Figure PF-3-6-7 RCD Power Point

Toroidal RCD

Output Used to supply Trip Coil on a Circuit breaker

Figure PF-3-6-8 Toroidal RCD



Topic 3-7

UNDERVOLTAGE AND OVERVOLTAGE PROTECTION

INTRODUCTION

- Protection against excessive variations in supply voltage is essential to protect electrical equipment and personnel.
- These variations in supply may be caused by external factors such as:
  - high voltage switching transients
  - lightning
  - supply faults.
- Equipment within an electrical installation may also cause disturbances to the supply.

VOLTAGE LEVELS

- In clause 1.4.98 of AS/NZS 3000:2007, voltage levels are defined as:
  - Extra-low voltage: Not exceeding 50 V AC or 120 V ripple-free DC
  - Low voltage: Exceeding extra-low voltage, but not exceeding 1000 V AC or 100 V DC.
  - High voltage: Exceeding low voltage.

SUPPLY CHARACTERISTICS

- The nominal voltage and tolerances for low voltage supply systems and electrical installations in Australia are 230/400V +10% to -6%.
- Within a distribution system installations closer to the distribution transformer will have higher voltages than those that are further away

NSW SERVICE AND INSTALLATION RULES

- *The NSW Service and Installation Rules* is an industry code intended to provide requirements that an electricity distributor should apply in connecting a customer to its distribution system. The Service Rules contain information relating to standard policy, design, and material and construction requirements for service and metering equipment, (see Ref **R-3-F**)

EXCESSIVE FLUCTUATIONS and DISTORTION TO SUPPLY

- Clause 1.10.2 of *The NSW Service and Installation Rules*, stipulates that:

  > *"The equipment in an electrical installation must be arranged and operated so as to minimise or prevent adverse effects to the distribution system and other electrical installations connected to the distribution system."*

- The effects are considered under the following categories:

EXCESSIVE FLUCTUATIONS and DISTORTION TO SUPPLY

Excessive fluctuations - equipment which would cause excessive voltage disturbances on the distribution system as a result of large or fluctuating load demands include arc furnaces, welding machines, x-ray units, frequently started motors including air conditioning equipment.

Excessive distortion - equipment which would cause excessive distortion of the supply wave shape includes rectifiers, frequency converters, electronic load control devices, saturable reactors.

EXCESSIVE FLUCTUATIONS and DISTORTION TO SUPPLY

Interference with frequency load control system - equipment which would adversely affect the electricity distributor's load control equipment includes shunt capacitors used in power factor correction of fluorescent lighting.

Generating systems - which may have adverse effects on the network or the customer's installation.

UNDERVOLTAGE

- Under-voltage could be considered a:
  - Complete loss of one or more phases of the supply or
  - A brief interruption to the supply voltage.
- Clause 2.8 of AS/NZS 3000:2007 stipulates that suitable protective measures shall be taken where the loss and subsequent restoration of voltage, or a drop in voltage could cause danger to persons or property – for example process machinery that is attended by operators e.g. punches presses, conveyor belts etc.

UNDERVOLTAGE

- Undervoltage protection usually comes in the form of Undervoltage Relays such as the one shown in **Fig. F-3-7-1**. Modern under-voltage relays usually have set point adjustment and can incorporate many other functions such as overvoltage protection, frequency monitoring, phase failure relay and more.

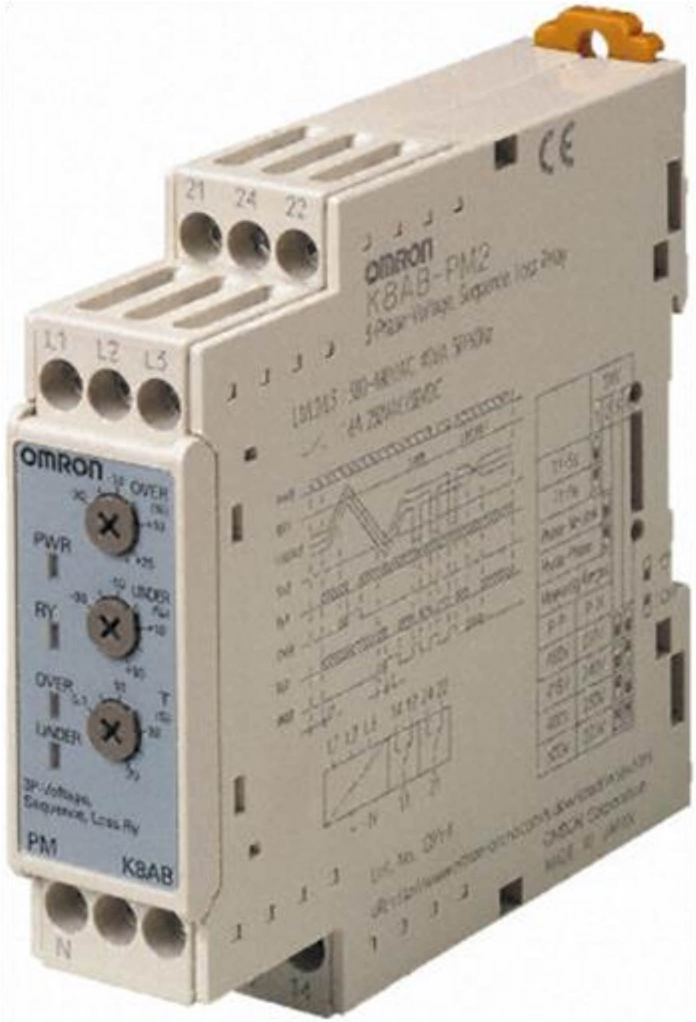


Fig. PF-3-7-1
Undervoltage relay

UNDERVOLTAGE

- Another method, which is quite often incorporated into electrical systems to perform other functions is the use of the non-latched relay. Relays usually drop out at about 75% of rated voltage, thus if system voltage drops below this level the relay will drop out and disconnect any circuits it controls

OVERVOLTAGE

- Clause 2.1.2 of AS/NZS 3000:2007 stipulates that switchgear and control gear must be selected and installed to provide protection from both overvoltage and under-voltage conditions.
- The causes of overvoltage include the following:
  - An insulation fault between the electrical installation and a circuit of higher voltage.
  - Switching operations.
  - Lightning.
  - Resonant phenomena.

OVERVOLTAGE

- Clause 2.7.3 of AS/NZS 3000:2007 stipulates that devices installed to protect against the effects of overvoltage should:
  - limit the (transient) voltage to a value below the insulation level of the electrical installation or the part thereof that the device protects; and
  - operate at voltages not less than or equal to the highest voltage likely to occur in normal operation; and
  - cause no hazard to persons or livestock during operation.

SURGE DIVERTERS

- Surges in voltage can be caused by:
  - ➢ Electricity Distributor switching operations
  - ➢ Close lighting strikes
  - ➢ Changes in demand caused by large energy consumers such as factories, shopping centres and hospitals.
- These high voltages are variously known as:
  - ➢ voltage surges
  - ➢ overvoltage
  - ➢ voltage transients
  - ➢ voltage spikes.

SURGE DIVERTERS

- Switching of electrical equipment such as lights and motors can also cause voltage surges.
- If adequate protection is not installed, voltage surges may damage sensitive electronic equipment.
- Appendix F of AS/NZS 3000:2007 supplies guidelines for the installation of Surge Protective Devices (SPDs)
- Surge diverters generally incorporate Metal Oxide Varistors (MOVs) - which are fast acting voltage dependent resistors), to pass voltage surges to earth via the neutral.

SURGE DIVERTERS

- Surge diverters can be broken into two levels of protection, basic and fine
  - **Basic protection** against voltage surges can be provided by switchboard mounted surge diverters, which limit peak voltages to around 1.9kV. The resistance of the MOV is around 430 kΩ at 430 volts RMS. The resistance drops to only 2.3 Ω ohms at 700 volts peak (See Fig. PF-3-7-2(a)).
  - **Fine protection** is provided by socket outlet type surge diverters that limit peak voltages to approximately 800V (See Fig. PF-3-7-2(b)).

Fig. F-3-7-2(a) Switchboard Type Surge Protector

Fig. F-3-7-2(b) Socket Outlet Type Surge Protector

END