Chapter 3

CONTROL AND PROTECTION

Topic 3.1 Protection for Safety

Reading

1. Chapter 8 "*Protection – Earthing and Protective Methods*" from: Pethebridge, K & Neeson, I 2009, *Electrical wiring practice. Volume 1*, 7th edn, McGraw Hill, North Ryde, NSW. (**Ref. R-3-B**)
2. Section 1.5 "*Fundamental Principles*" and Section 4.2 "*Protection Against Thermal Effects"* from: Standards Australia 2007, *Wiring Rules,* (AS/NZS 3000), Standards Australia, Sydney (**Ref R-3-C**)

Introduction

The intent of AS/NZS 3000 is to ensure the safety of people, livestock and property against dangers and damage that could occur in the reasonable use of electrical installations. The standard identifies three types of risk:

1. **Shock current.** Shock current coming in contact with parts that are live in normal service (known as direct contact) or parts that become live under fault conditions (known as indirect contact)
2. **Excessive temperatures.** Excessive temperatures likely to cause burns, fires and other injurious effects. Persons, fixed equipment, and fixed materials adjacent to electrical equipment shall be protected against harmful effects of heat developed by electrical equipment, or thermal radiation, particularly the following effects:
    - Combustion or degradation of materials,
    - Risk of burns, and
    - Impairment of the safe function of installed equipment.
3. **Explosive atmospheres.** Equipment installed in areas where explosive gases or dusts may be present shall provide protection against the ignition of such gases or dusts.

Electric shock

The effects of electricity on the human body are complex and to a certain extent are not completely understood. However, it is known that the effects on the lung and heart function depend mainly on:

- AC or DC current
- Magnitude of current
- Duration of current
- Path through body

Touch voltage/current

To protect against faults from insulation failure an appliance connects to active and neutral and the metal case on the appliance connects to earth. If the insulation within the equipment develops a fault, the active conductor may contact the conductive metal case. As the case connects to earth, a short circuit path exists and a large current will flow. This large current will cause the fuse or circuit breaker to operate and disconnect the faulty circuit. See **Figure F-3-1-1** for a diagrammatic illustration of this, also read **Section 8.1** of **Ref. R-3-1-B** for an explanation of Earthing.

If the case on this equipment did not connect to earth, it would be a dangerous situation. The case would assume the same voltage as the active conductor and anyone touching the case and earth at the same time would provide the current path for the fault current. Another way of avoiding this situation is to provide two effective layers of insulation between the live parts and the operator — this is known as double insulation.

The voltage present at the moment the fault occurs between the live case and the general mass of earth is known as the ‘touch voltage’. An effective earth system limits the touch voltage in an installation to a value less than the nominal supply voltage. It is important the circuit automatically disconnects from the supply when a fault could result in a touch voltage greater than 50V AC.

Earthing also keeps the casing of equipment at the same potential as earth for safety reasons. This type of earthing is equipotential bonding and is used wherever there is a risk of voltage differences between metal components associated with the power installation and other nearby conductive components.

Water pipes are equipotential bonded. This minimises the risk of voltage differences existing between plumbing fittings like laundry taps (connected to earth through an equipotential bond) and an appliance like a washing machine (connected to earth through a protective earth).

To determine the magnitude of touch voltage use the equation:

$$V_t = \frac{V_O \times Z_{PE}}{\left(Z_A + Z_{PE}\right)} \qquad \text{(E-3-1-1)}$$

Where:

V_t is touch voltage

V_0 is operating voltage

Z_A is impedance of active conductor

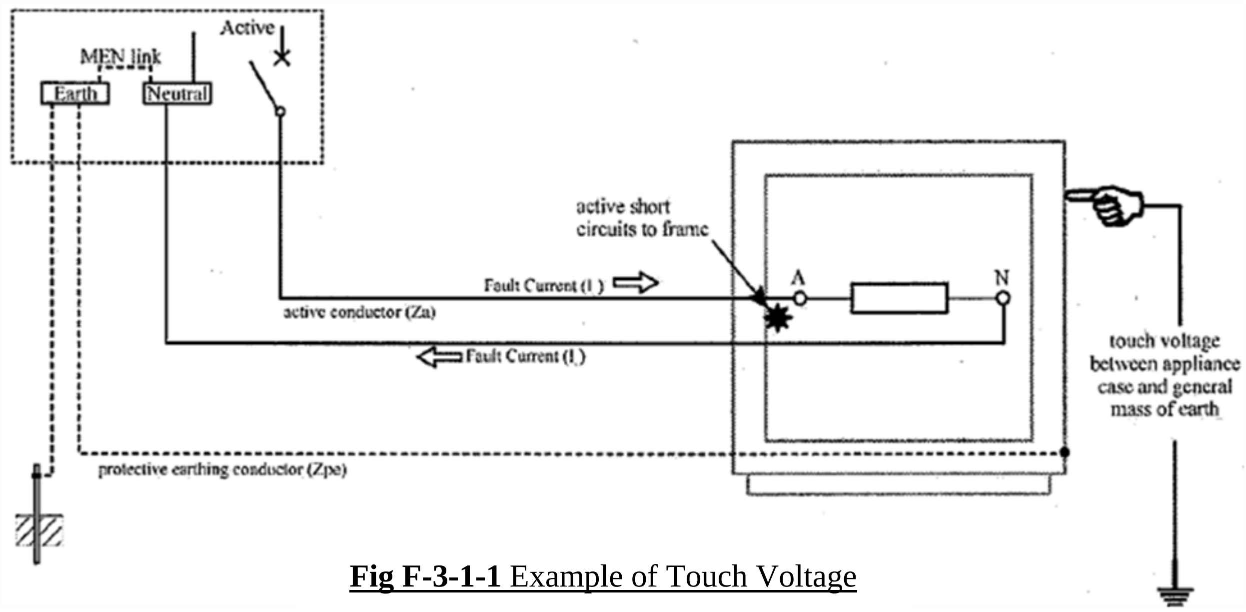


Fig F-3-1-1 Example of Touch Voltage

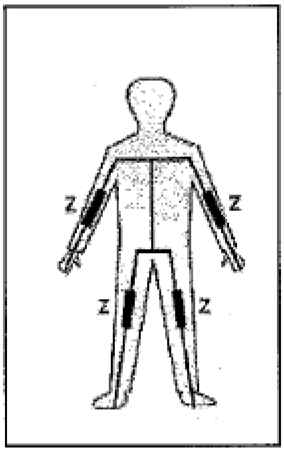
Current paths through the human body

Typical impedance values for various current paths through the human body are given below and illustrated in **Fig F-3-1-2** :

Hand to hand	1000 Ω
Hand to foot	1000 Ω
Hand to both feet	750 Ω
Hand to seat	500 Ω
Both hands to seat	250 Ω

Using the above values of body resistances the touch current for each path when coming in contact with 230V 50Hz AC source would be

Hand to hand	230 mA
Hand to foot	230 mA
Hand to both feet	307 mA
Hand to seat	460 mA
Both hands to seat	920 mA



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Paths through the Human

Physiological Effects Of Electric Current Through The Human Body

The effect of electric current on the human body is dependent on the magnitude of the current and the duration of the current. The following diagram (**Fig F-3-1-3**) and accompanying table (**Table T-3-1-1**) illustrate this:

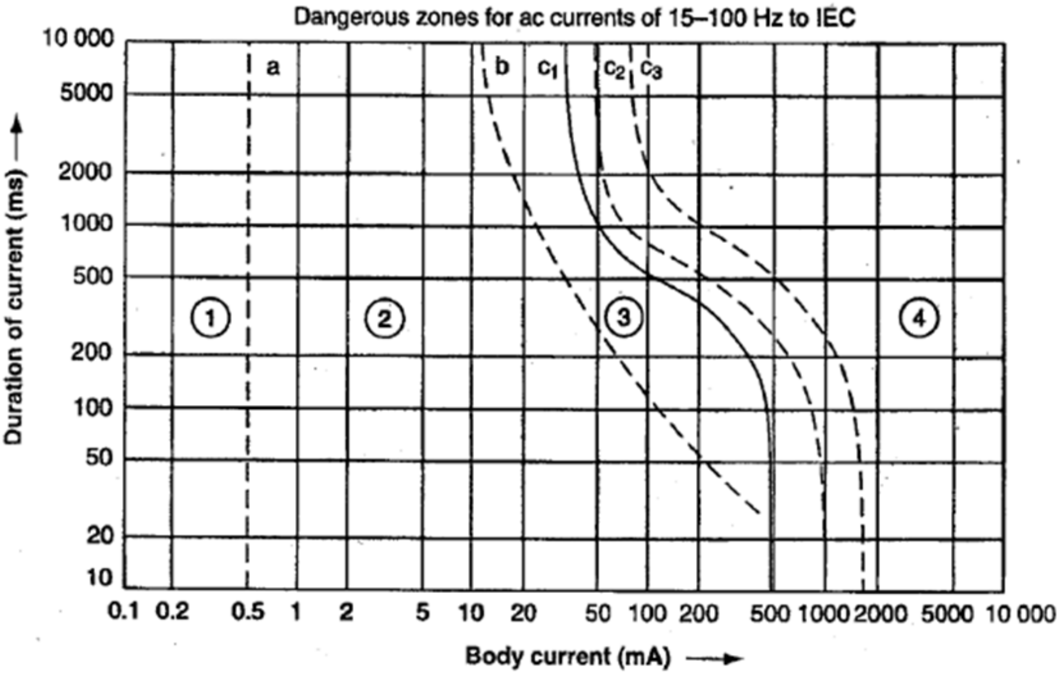


Fig F-3-1-3 Time/current zones on the human body

Table T-3-1-1 Time/current zones on the human body

Zone	Physiological effects
1	Usually no reaction
2	Usually no harmful physiological effects
3	Likelihood of muscular contractions and difficulty in breathing Possibility of cardiac arrest increasing with value of current and time
4	Effects of zone 3 C1 - probability of ventricular fibrillation 5% C2 - probability of ventricular fibrillation 50% C3 - probability of ventricular fibrillation >50% Further increases in current and/or time are likely to cause arrest & burns

Illustration.

If a current of 200mA is maintained through a human body for less than 50 ms, the resultant locus on **Fig F-3-1-3** remains in zone 2, which according to **Table T-3-1-1** results in “Usually no harmful physiological effects”. If the same current were maintained for more than 50ms the locus would cross into zone 3 (likely muscular contractions and possible cardiac arrest). Beyond about 400ms the locus traverses into zone 4 (possibility of ventricular fibrillation).

Protection against Thermal Effects

It is necessary to arrange installations so that there is no risk of ignition of flammable materials due to high temperature or electric arc in normal operation. Furthermore, there should be no risk of persons or livestock suffering burns during the normal operation of electrical equipment.

There are four effects of current flow. They are:

- Magnetic
- Physiological
- Chemical, and
- Heat

When current flows through a conductor heat is generated. The amount of heat generated within a conductor is dependent on the load, and by factors such as the length, cross-sectional area and the type of material of the conductor.

When copper circuit conductors are used to carry current to a load, the intent is to limit the heat (temperature) of the cables to a minimum so the appropriate sized conductors are selected for the task. In this situation heat is unwanted.

In the above situation if inappropriate (undersized) cables are used, the cables will overheat due to the I^2R of the conductors. If the temperature rises above the temperature rating of the cable, e.g., V75, V90, etc. then the cable’s insulation will breakdown, i.e., melt. The heat generated may start a fire in a confined place with flammable material near it. If the cables are installed in such a manner that they are tightly touching or crossing, depending on the prospective fault current, the damage that may arise from a short circuit will be immense.

In some circuits, the aim is to create thermal effect (heat). These circuits supply loads such as hot water services, ovens, electric ranges, space heaters, etc. When electricity is used to create heat, there are risks associated with it.

Equipment used primarily for the production of heat has inherent risks associated with it due to the danger of exposed elements. In some equipment it is impossible to completely avoid the risk of danger from burning or scalding. With equipment such as hot water services that have sheathed and enclosed elements, the risk is minimal whereas with a cooking hotplate, the risk of inadvertently touching the switched on exposed coiled sheathed element is greater.

Some equipment presents an element of risk by the fact that a dangerous situation can be created by the inappropriate behaviour of the user. For instance, a radiator heater with exposed elements has a safety grid to prevent direct contact but if flammable materials are placed too close to the heater, it will create a fire. Also due to the safety grid mesh holes on the front of the radiator being fairly large, a child may easily poke their hand or fingers through the grid.

Tutorial 3.1

For the following tutorial questions in addition to response please quote the relevant reference to AS/NZS 3000 where appropriate

TQ.3.1 Calculate the touch voltage for a single-phase final sub-circuit having 4.0mm^2 active conductor having a per unit impedance of 1.0Ω and a 2.5mm^2 earthing conductor having a per unit impedance of 2.4Ω where the operating voltage of the installation is 230V.

[Source: Ref R-3-A Part1, Section 1- Exercise P10]

TQ.3.2 List 4 methods of protect against direct contact.

*[Source: Ref **R-3-D** P44 Activity 29 Q1]*

TQ.3.3 What degree of protection is needed where barriers provide the method for protecting against direct contact with live parts?

*[Source: Ref **R-3-A** Part1, Section 1- Exercise 2, Q2, P11]*

TQ.3.4 For a 240-volt final subcircuit supplying fixed equipment or submain, what is the maximum disconnection time for automatic disconnection devices?

*[Source: Ref **R-3-A** Part1, Section 1- Exercise 3, Q6, P14]*

TQ.3.5 What means are suitable for providing protection from the risk of ignition of flammable materials in normal service?

*[Source: Ref **R-3-A** Part1, Section 1- Exercise 4, Q1, P17]*

TQ.3.6 When a number of cables from various circuits are grouped or bundled together what is it necessary to do to the current carrying capacity of circuit conductors?

*[Source: Ref **R-3-A** Part1, Section 1- Exercise 4, Q8, P18]*

TQ.3.7 What means are suitable for protecting an installation from the effect of:

- Over-current?
- Fault currents?

*[Source: Ref **R-3-A** Part1, Section 1- Exercise 5, Qs 2 & 3, P19]*

TQ.3.8 What conditions must be satisfied before being able to remove a barrier that prevents contact with live parts of electrical equipment?

*[Source: Ref **R-3-A** Part1, Section 1- Review Question 5, P21]*

TQ.3.9 Simultaneously accessible parts at different voltages must not be within arm's reach. What does this mean?

*[Source: Ref **R-3-A** Part1, Section 1- Review Question 6, P21]*

TQ.3.10 Within what time must an over-current device automatically disconnect a final subcircuit supplying 10A socket outlets?

*[Source: Ref **R-3-A** Part1, Section 1- Review Question 8, P22]*

Topic 3.2 Fault Loop Impedance

Reading

1. Chapter 8 “Protection – Earthing and Protective Methods” from:
   Pethebridge, K & Neeson, I 2009, *Electrical wiring practice. Volume 1*, 7th edn, McGraw Hill, North Ryde, NSW. (Ref. R-3-B)
2. Section 5.7 “Earth Fault-Loop Impedance ” and Section B.4 “The Earth Fault Loop” from:
   Standards Australia 2007, Wiring Rules, (AS/NZS 3000), Standards Australia, Sydney (Ref R-3-C)

Introduction

Fault-loop impedance is the impedance of the fault-current loop (active to earth) starting and ending at the point of the earth fault.

AS/NZS 3000 requires that each circuit is protected such that automatic disconnection of supply occurs within a specified disconnection time when a fault of negligible impedance occurs between an active conductor and a protective earthing conductor or an exposed conductive part anywhere in an electrical installation. This condition is satisfied when the fault-loop impedance is sufficiently low to allow enough current to flow in the fault-loop to cause the circuit protection device to operate within the specified time.

The Fault-Loop

The fault-loop in the MEN system comprises the following:

- protective earthing conductor (PE), including the main earthing terminal, connection, or bar and MEN link
- neutral return path, comprising the neutral conductor between the main neutral terminal or bar and the neutral point at the transformer
- path through the neutral point of the transformer and the transformer winding
- active conductor as far as the point of the fault

The fault-loop can be divided into two parts:

- conductors external to the installation
- conductors within the installation

The following diagram from fig B5 of **Ref R-3-C** details the fault-loop circuit.

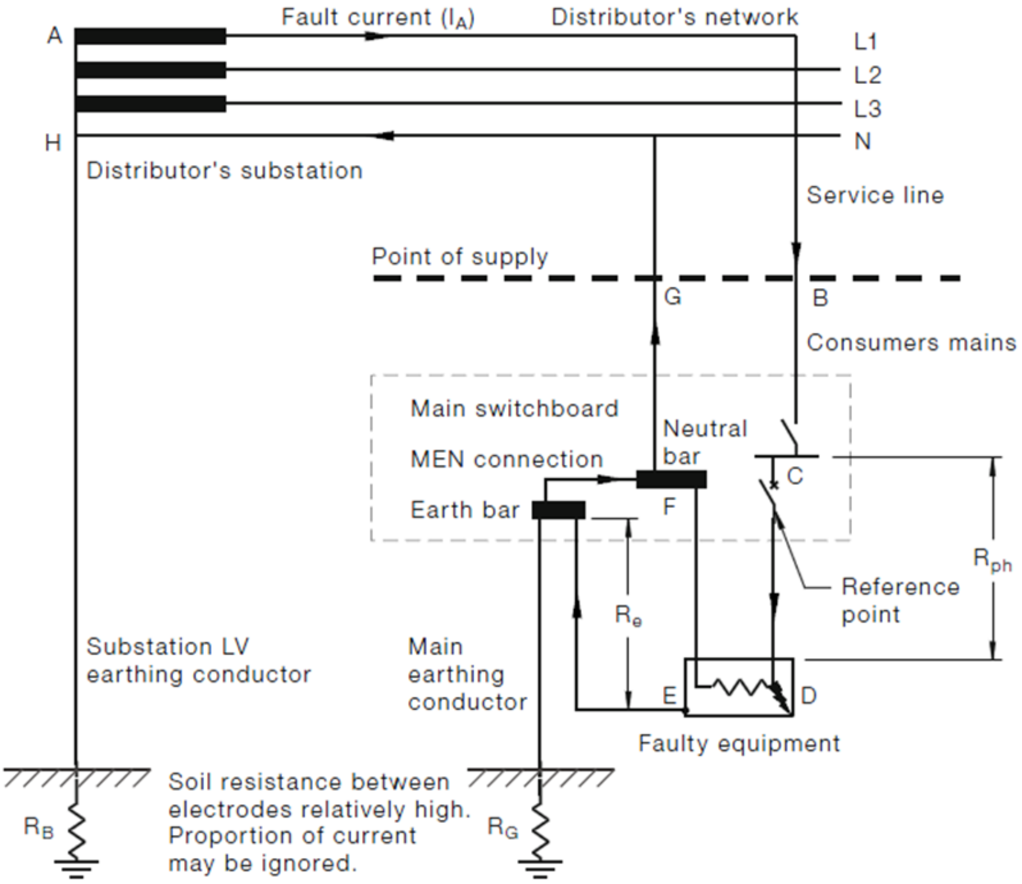


Fig F-3-2-1 Men System (Simplified)—Showing Fault Current (I_a) Path (Earth Fault-Loop)

Fault loop impedance is obtained from the addition of all the individual impedances as follows:

$$\mathbf{Z_S = Z_{AB} + Z_{BC} + Z_{CD} + Z_{DE} + Z_{EF} + Z_{FG} + Z_{GH} + Z_{HA}}$$

Impedances upstream of the protective device are regarded as being external to the reference point therefore:

$$\mathbf{Z_{EXT} = Z_{AB} + Z_{BC} + Z_{CD} + Z_{FG} + Z_{GH} + Z_{HA}}$$

Remainder are downstream and called ‘internal’ or Z_{INT}

Therefore: $\mathbf{Z_S = Z_{INT} + Z_{EXT}}$

At the instant a fault occurs, current will flow through the fault loop. Only the total system impedance (Zs) limits the magnitude of this current.

Example of Measuring Fault-Loop Impedance at 230V (Supply Available)

Fault loop impedance is obtained from the addition of all the individual impedances as follows:

> A final sub-circuit supplies a load consisting of a 32A socket outlet and is protected by a 32A type C circuit breaker. To determine the fault-loop impedance of the final sub-circuit when supply is available, proceed as follows:
>
> > Step 1: An instrument that has the facility for measuring and indicating low values of impedance, (suitable for work on live equipment) is used
> >
> > Step 2: MEN connection is left intact
> >
> > Step 3: The most distant point of the circuit is identified.
> >
> > Step 4: A measurement is made between the active conductor and the protective earthing conductor. In this example let's say the reading obtained is 0.9Ω.
> >
> > Step 5: Table 8.1 of **Ref R-3-C** (reproduced below as **Fig F-3-2-2**) is used to determine the maximum fault-loop impedance for a 32A type C circuit breaker. In this example the maximum fault-loop impedance is $Z_S = 0.96\Omega$.
> >
> > Step 6: The measured value must be lower than 0.96Ω. The value obtained is 0.9Ω therefore it satisfies the requirement of **Ref R-3-C** .

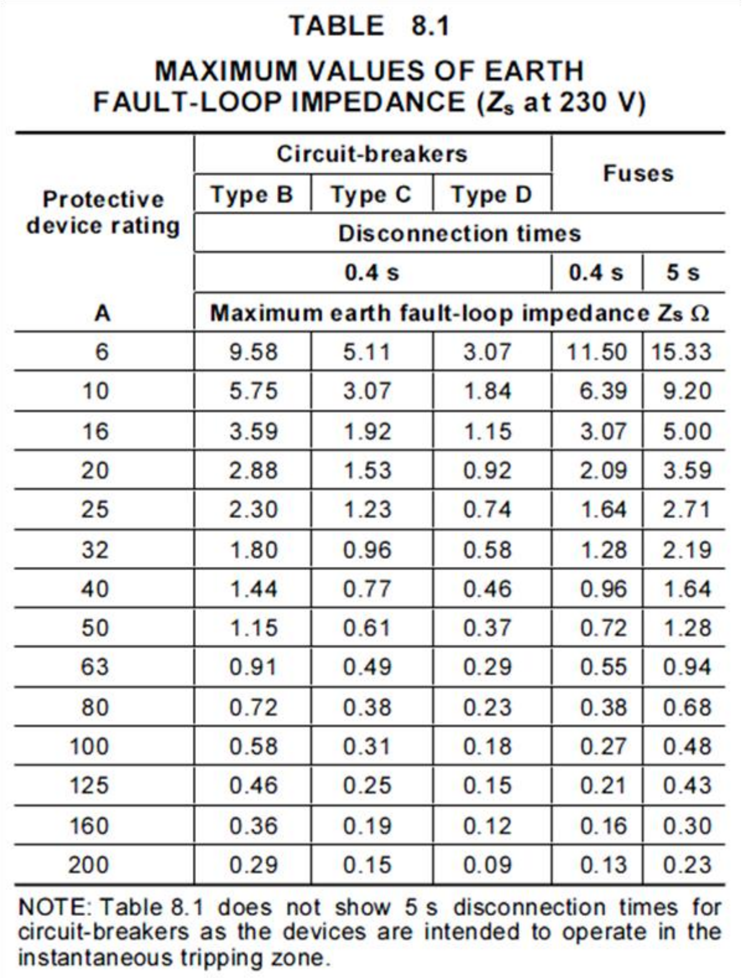


TABLE 8.1

MAXIMUM VALUES OF EARTH FAULT-LOOP IMPEDANCE (Z_s at 230 V)

Protective device rating	Circuit-breakers			Fuses	
	Type B	Type C	Type D		
	Disconnection times				
	0.4 s			0.4 s	5 s
A	Maximum earth fault-loop impedance Z_s Ω				
6	9.58	5.11	3.07	11.50	15.33
10	5.75	3.07	1.84	6.39	9.20
16	3.59	1.92	1.15	3.07	5.00
20	2.88	1.53	0.92	2.09	3.59
25	2.30	1.23	0.74	1.64	2.71
32	1.80	0.96	0.58	1.28	2.19
40	1.44	0.77	0.46	0.96	1.64
50	1.15	0.61	0.37	0.72	1.28
63	0.91	0.49	0.29	0.55	0.94
80	0.72	0.38	0.23	0.38	0.68
100	0.58	0.31	0.18	0.27	0.48
125	0.46	0.25	0.15	0.21	0.43
160	0.36	0.19	0.12	0.16	0.30
200	0.29	0.15	0.09	0.13	0.23

NOTE: Table 8.1 does not show 5 s disconnection times for circuit-breakers as the devices are intended to operate in the instantaneous tripping zone.

Fig F-3-2-2 Copy of Table 8.1 from **Ref R-3-C**

The values in table 8.1 are obtained by the equation:

$$Z_S = \frac{U_O}{I_a} \qquad \text{(E-3-2-1)}$$

Where:

Z_S = Complete fault loop impedance

U_0 = Nominal phase voltage (230V)

I_a = Current causing automatic operation of the protective device (circuit breakers) are as follows:

Type B = 4 times rated current

Type C = 7.5 times rated current

Type D = 12.5 times rated current

Note: I_a values for fuses are approximate mean values from AS 60269

<u>Example of Measuring Fault-Loop Impedance at 230V (Supply Not Available)</u>

A final sub-circuit supplies a load consisting of 10A socket outlets and is protected by a 16A type C circuit breaker. To determine the fault-loop impedance of the final sub-circuit when supply is unavailable, the procedure is as follows:

Step 1:	The circuit breaker of final sub-circuit under test is switched to OFF position.
Step 2:	A short length of conductor is used to bridge between the final sub-circuit active conductor downstream of the circuit protection device and the earth bar.
Step 3:	The furthermost socket outlet installed on the final sub-circuit is located.
Step 4:	A low-reading ohmmeter is used to measure the resistance between the active terminal, with the switch on the socket outlet in the ON position, and the earth terminal of the selected socket outlet. In this example let's say the reading obtained is 0.75Ω.
Step 5:	Table 8.2 of **Ref R-3-C** (reproduced in **Fig F-3-2-3**) is used to determine the maximum fault-loop impedance for a 16A type C circuit breaker. In this example the maximum fault-loop impedance is R_{PHE}=1.22Ω (R_{PH}=0.61 + R_E=0.61).
Step 6:	As the measured value is 0.75Ω and the maximum is 1.22Ω the circuit satisfies the requirement of **Ref R-3-C**.
Step 7:	The temporary bridging conductor of Step 1 is removed.

The values in table 8.2 of **Ref R-3-C** are approximately 64% of the values in table 8.1 of **Ref R-3-C** because of the following:

A reduction to 80% (0.8) because of the conductor temperature of 20 degrees.

A further reduction as the lengths given in table B1 of **Ref R-3-C** were calculated using 80% (0.8) of supply voltage. This further reduction assumes that 20% of the impedance is associated with the supply transformer. Therefore 0.8 x 0.8 = 0.64.

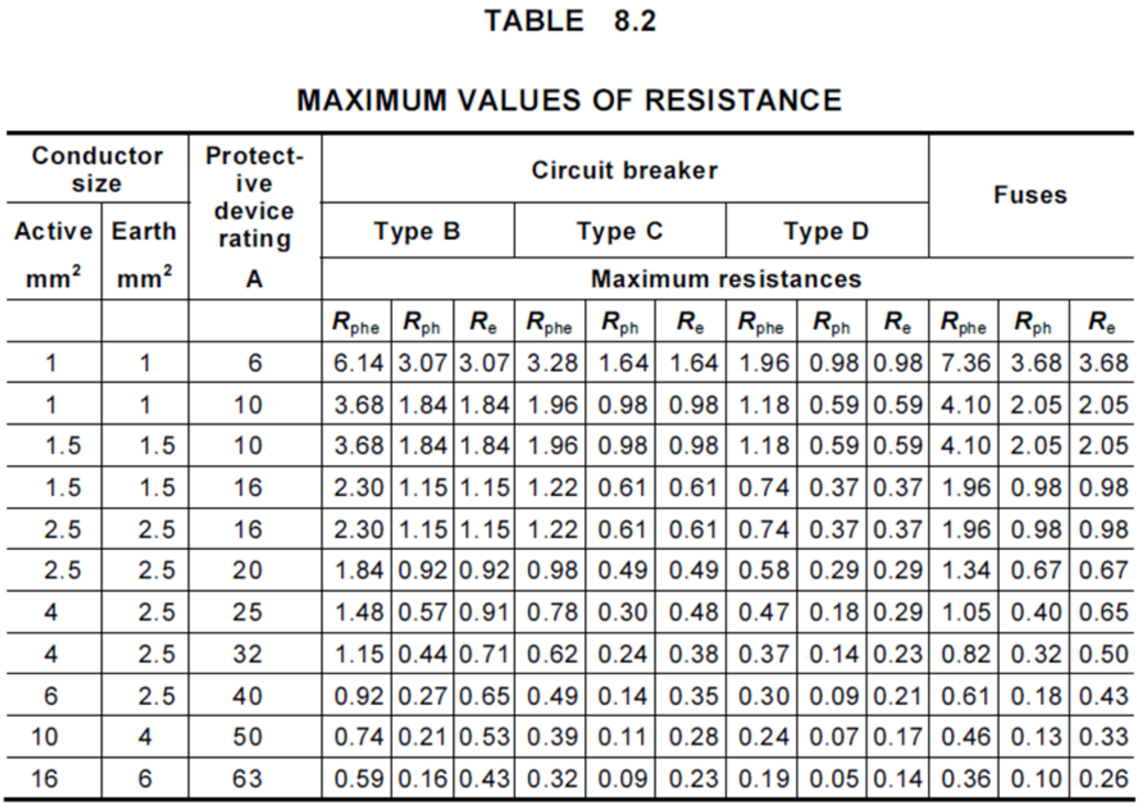


TABLE 8.2

MAXIMUM VALUES OF RESISTANCE

Conductor size		Protective device rating	Circuit breaker									Fuses		
Active	Earth		Type B			Type C			Type D					
mm^2	mm^2	A	Maximum resistances											
			R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e
1	1	6	6.14	3.07	3.07	3.28	1.64	1.64	1.96	0.98	0.98	7.36	3.68	3.68
1	1	10	3.68	1.84	1.84	1.96	0.98	0.98	1.18	0.59	0.59	4.10	2.05	2.05
1.5	1.5	10	3.68	1.84	1.84	1.96	0.98	0.98	1.18	0.59	0.59	4.10	2.05	2.05
1.5	1.5	16	2.30	1.15	1.15	1.22	0.61	0.61	0.74	0.37	0.37	1.96	0.98	0.98
2.5	2.5	16	2.30	1.15	1.15	1.22	0.61	0.61	0.74	0.37	0.37	1.96	0.98	0.98
2.5	2.5	20	1.84	0.92	0.92	0.98	0.49	0.49	0.58	0.29	0.29	1.34	0.67	0.67
4	2.5	25	1.48	0.57	0.91	0.78	0.30	0.48	0.47	0.18	0.29	1.05	0.40	0.65
4	2.5	32	1.15	0.44	0.71	0.62	0.24	0.38	0.37	0.14	0.23	0.82	0.32	0.50
6	2.5	40	0.92	0.27	0.65	0.49	0.14	0.35	0.30	0.09	0.21	0.61	0.18	0.43
10	4	50	0.74	0.21	0.53	0.39	0.11	0.28	0.24	0.07	0.17	0.46	0.13	0.33
16	6	63	0.59	0.16	0.43	0.32	0.09	0.23	0.19	0.05	0.14	0.36	0.10	0.26

Fig F-3-2-3 Copy of Table 8.2 from **Ref R-3-C**

Example of Determining Maximum Circuit Lengths

When the length and cross-sectional area of conductors are not known it may be assumed that there will always be 80% or more of the nominal phase voltage available at the position of the circuit protective device. Therefore Z_{int} should be not greater than 0.8 Z_S and may be expressed as follows:

$$Z_{\text{int}} = \frac{0.8U_O}{I_a} \qquad \text{(E-3-1-2)}$$

This equation may be expressed in terms of circuit length by considering conductor sizes (active and earth) and protective device tripping current. This gives rise to the following equation:

$$L_{\max} = \frac{0.8U_O S_{ph} S_{pe}}{I_a \rho \left(S_{ph} + S_{pe}\right)} \qquad \text{(E-3-1-3)}$$

Where:

L_{max} = maximum route length in meters— (see Table B1 of **Ref R-3-C**)

U_0 = nominal phase volts (230 V)

ρ = resistivity at normal working temperature in Ω-mm^2/m
= 22.5 x 10^{-3} for copper
= 36 x 10^{-3} for aluminium

I_a = trip current setting for the instantaneous operation of a circuit-breaker; or the current that assures operation of the protective fuse concerned, in the specified time

S_{ph} = cross-sectional area of the active conductor of the circuit concerned in mm^2

S_{pe} = cross-sectional area of the protective earthing conductor concerned in mm^2

NOTES:

1. Mean tripping currents, as outlined in Note 1 to Paragraph B4.4 of **Ref R-3-C**, are used for I_a
2. This method is only reliable where the conductors that make up the earth-fault-current loop are in close proximity to each other and are not separated by ferromagnetic materials
3. This calculation method is considered valid for cable sizes up to 120 mm^2. For larger sizes Z_S should be calculated by other methods taking account of cable inductance.
4. Table B1 of **Ref R-3-C** contains typical maximum circuit lengths above which the impedance of the conductors could limit the magnitude of short circuit current to a level below that required to operate the protective device in the required time to ensure safety against indirect contact.

Tutorial 3.2

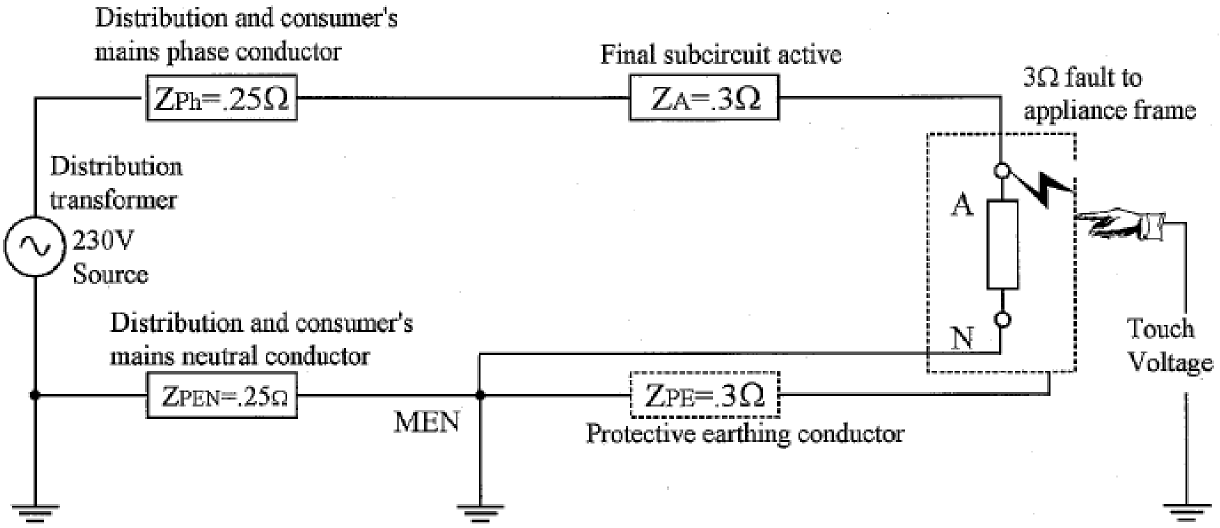
TQ.3.11 For the loop shown below:

*[Source: Ref **R-3-A** Part 1, Section 2- Exercise 1(top) P26]*

a. Calculate the fault loop impedance (Remember not to include fault impedance)

b. The maximum fault current that will flow in the circuit.

c. The fault current if the fault resistance at the appliance is 3Ω



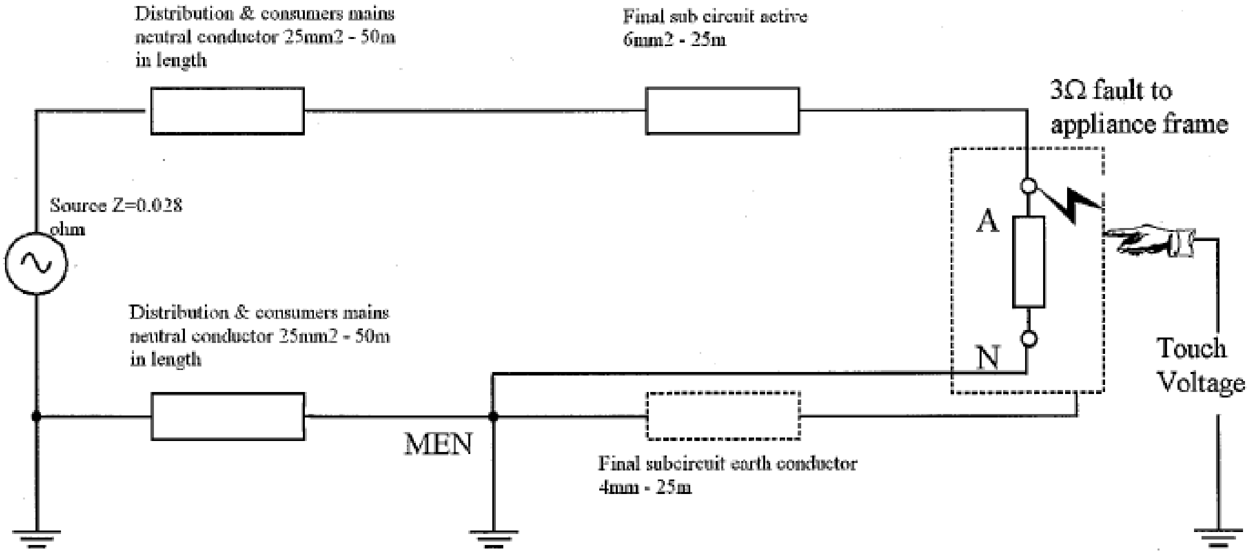
TQ.3.12 Using the cable information given in the table below determine:

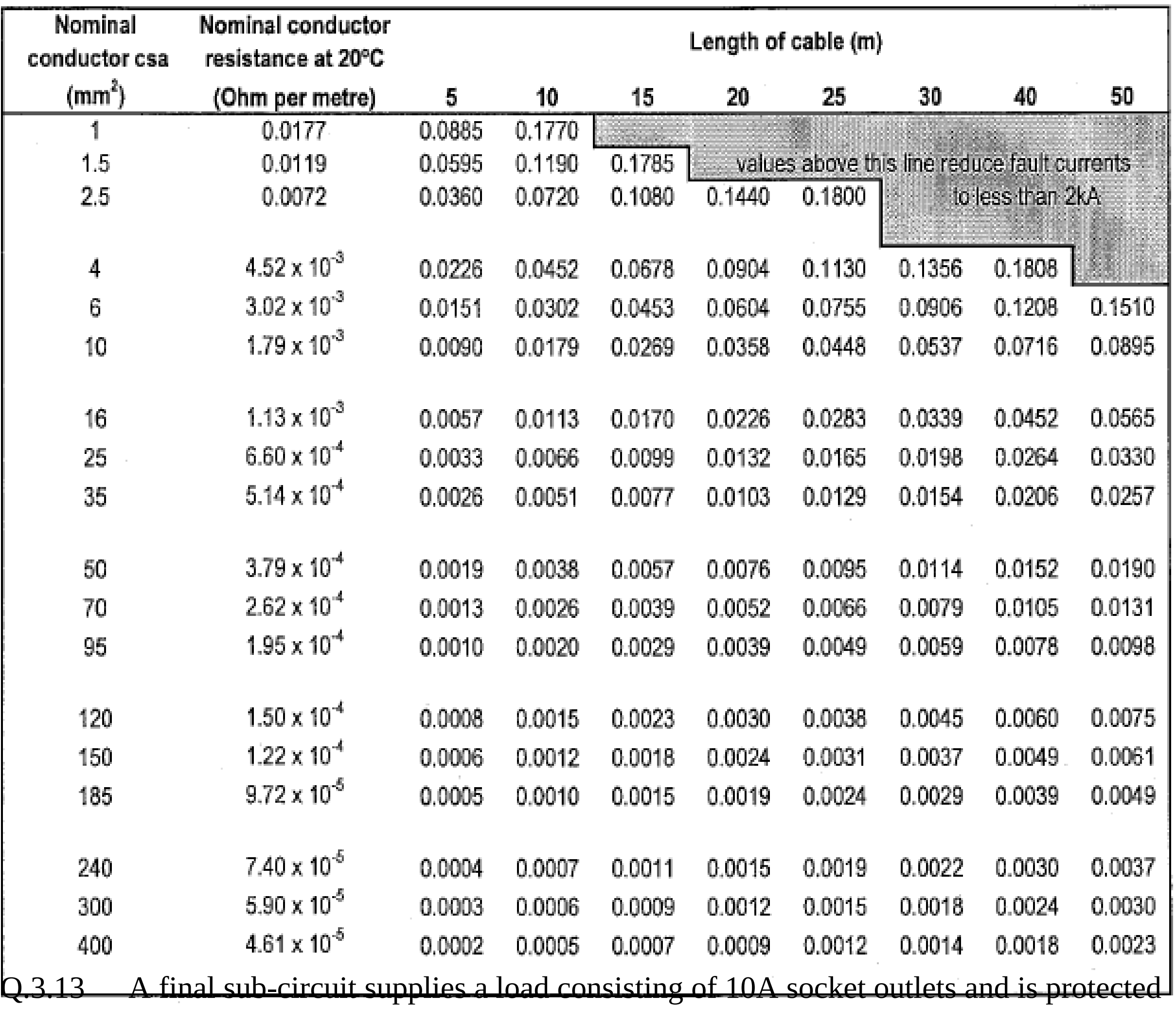
a. The fault loop impedance of the following circuit:

*[Source: Ref **R-3-A** Part 1, Section 2- Exercise 1(bottom) , P26]*

b. The Maximum fault current that will flow in the circuit

c. The fault current if the fault resistance at the appliance is 3Ω





Nominal conductor csa (mm²)	Nominal conductor resistance at 20°C (Ohm per metre)	Length of cable (m) 5	10	15	20	25	30	40	50
1	0.0177	0.0885	0.1770						
1.5	0.0119	0.0595	0.1190	0.1785					
2.5	0.0072	0.0360	0.0720	0.1080	0.1440	0.1800			
4	4.52×10^{-3}	0.0226	0.0452	0.0678	0.0904	0.1130	0.1356	0.1808	
6	3.02×10^{-3}	0.0151	0.0302	0.0453	0.0604	0.0755	0.0906	0.1208	0.1510
10	1.79×10^{-3}	0.0090	0.0179	0.0269	0.0358	0.0448	0.0537	0.0716	0.0895
16	1.13×10^{-3}	0.0057	0.0113	0.0170	0.0226	0.0283	0.0339	0.0452	0.0565
25	6.60×10^{-4}	0.0033	0.0066	0.0099	0.0132	0.0165	0.0198	0.0264	0.0330
35	5.14×10^{-4}	0.0026	0.0051	0.0077	0.0103	0.0129	0.0154	0.0206	0.0257
50	3.79×10^{-4}	0.0019	0.0038	0.0057	0.0076	0.0095	0.0114	0.0152	0.0190
70	2.62×10^{-4}	0.0013	0.0026	0.0039	0.0052	0.0066	0.0079	0.0105	0.0131
95	1.95×10^{-4}	0.0010	0.0020	0.0029	0.0039	0.0049	0.0059	0.0078	0.0098
120	1.50×10^{-4}	0.0008	0.0015	0.0023	0.0030	0.0038	0.0045	0.0060	0.0075
150	1.22×10^{-4}	0.0006	0.0012	0.0018	0.0024	0.0031	0.0037	0.0049	0.0061
185	9.72×10^{-5}	0.0005	0.0010	0.0015	0.0019	0.0024	0.0029	0.0039	0.0049
240	7.40×10^{-5}	0.0004	0.0007	0.0011	0.0015	0.0019	0.0022	0.0030	0.0037
300	5.90×10^{-5}	0.0003	0.0006	0.0009	0.0012	0.0015	0.0018	0.0024	0.0030
400	4.61×10^{-5}	0.0002	0.0005	0.0007	0.0009	0.0012	0.0014	0.0018	0.0023

values above this line reduce fault currents to less than 2kA

TQ.3.13 A final sub-circuit supplies a load consisting of 10A socket outlets and is protected by a 20A type C circuit breaker. Determine the maximum internal fault-loop impedance of the final sub-circuit, based on 230V, when supply is unavailable:

[Source: Ref ***R-3-A*** *Part 1, Section 2- Review Question 1, P32]*

TQ.3.14 A final sub-circuit supplies a load consisting of 10A socket outlets and is protected by a 16A type C circuit breaker. The internal fault-loop impedance, measured at the furthermost socket outlet is 1.2Ω. Determine whether this value of internal fault-loop impedance, based on 230V, satisfies the requirements of AS/NZS 3000:2007.

[Source: Ref ***R-3-A*** *Part 1, Section 2- Review Question 2, P32]*

TQ.3.15 A final sub-circuit supplies a load consisting of fluorescent luminaires and is protected by a 10A type C circuit breaker. Determine the maximum internal fault-loop impedance of the final sub-circuit, based on 230V, when supply is unavailable:

[Source: Ref R-3-A Part 1, Section 2- Review Question 3, P32]

TQ.3.16 A final sub-circuit supplies a load consisting of a range in a domestic installation and is protected by a 32A type C circuit breaker. Determine the maximum internal fault-loop impedance of the final sub-circuit, based on 230V, when supply is unavailable:

[Source: Ref ***R-3-A*** *Part 1, Section 2- Review Question 4, P32]*

TQ.3.17 A final sub-circuit supplies a load consisting of 15A socket outlets and is protected by a 25A HRC fuse. Determine the maximum internal fault-loop impedance of the final sub-circuit, based on 230V, when supply is unavailable.

*[Source: Ref **R-3-A** Part 1, Section 2- Review Question 7, P33]*

TQ.3.18 Determine the maximum route length of a circuit, in accordance with AS/NZS 3000:2007, for a single phase circuit that has an active conductor size of 6 mm^2 and a 2.5 mm^2 earthing conductor if the circuit is protected by a 40A circuit breaker with a type D curve.

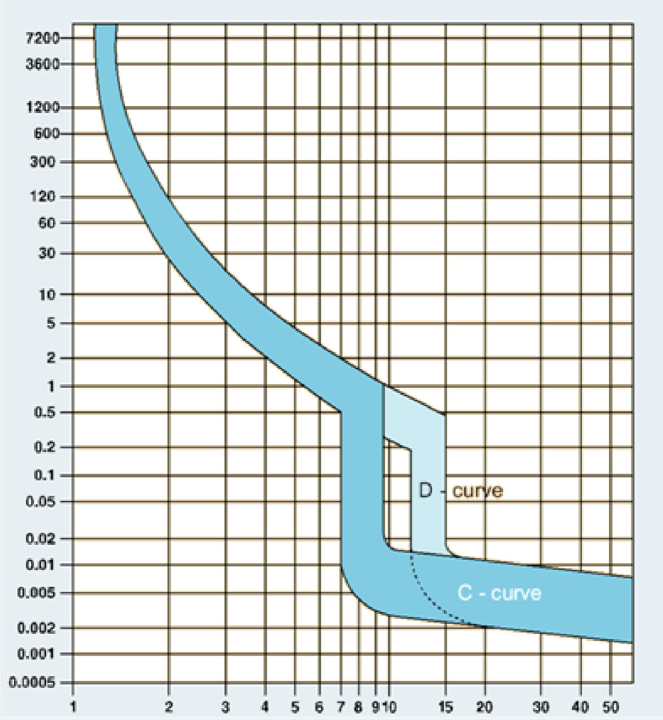
*[Source: Ref **R-3-A** Part 1, Section 2- Review Question 7, P34]*

TQ.3.19 Find the maximum length of a final sub circuit that will permit correct operation of the protective device to provide protection against indirect contact. The circuit consists of a three phase motor protected by an 80 A circuit breaker with a type D curve. The cross section of the actives is 25 mm^2 and that of the earth is 6 mm^2. Assume a nominal supply of 400/230 volts. **Note:** Use the circuit breaker curves given below.

*[Source: Ref **R-3-A** Part 1, Section 2- Review Question 12, P35]*

TQ.3.20 The circuit breaker protecting a 230/400V, sub-main is a 200A type D. The sub-main consists of X-HF-90 four core and earth cable having 70mm^2 copper active and neutral conductors with a 25mm^2 earth conductor. Find the maximum length of the sub-main circuit that will permit correct operation of the protective device. **Note:** Use the circuit breaker curves given below.

*[Source: Ref **R-3-A** Part 1, Section 2- Review Question 13, P35]*



Topic 3.3 Fault Protection Devices

Reading

1. Chapter 8 "*Protection – Earthing and Protective Methods*" from:
   Pethebridge, K & Neeson, I 2009, *Electrical wiring practice. Volume 1*, 7th edn, McGraw Hill, North Ryde, NSW. (**Ref. R-3-B**)
2. Section 2.5 "*Protection Against Overcurrent*" from:
   Standards Australia 2007, *Wiring Rules*, (AS/NZS 3000), Standards Australia, Sydney (**Ref R-3-C**)

Introduction

All electrical circuits have a basic requirement that the conductors of the electric circuit be of adequate size to carry normal and fault current loads without being damaged or degraded by excessive heating. Furthermore all electric current conductors are required to be insulated to prevent unwanted current flow from one conductor to another or from one or more conductors to earth.

The purposes of electric power system protection devices are:

1. To detect excessive current levels in power system conductors
2. To detect excessive current flows to earth due to insulation failure
3. Electrical protection is a primary control for many of the electrical key risk areas and is used to minimise the risk of:
    - Electrocution
    - Death or injury from electric shock (including from secondary causes such as falls as result of an electric shock)
    - Electrical burns (including burns from radiation, current flow, and plasma. It also includes arc blast injuries)
    - Fires
    - Explosions due to gas or catastrophic failure of electrical enclosures.

Protection against Over-Current Overload and Short-Circuit Current

There are many rules that, after consideration of various limiting factors, specify maximum safe working currents for electrical wiring. If these specified current limits are exceeded and there is no protection, or if the protection is either inadequate or ineffective, the resulting abnormal conditions could produce overheating of conductors and subsequent failure of wire insulation.

This insulation failure will be caused by the excessive power loss occurring within the conductors. The heating effect is proportional to the square of the current, so a 100 per cent overload (double the normal circuit current) will result in a heat loss four times higher than that for a normal load over the same time interval:

$$\boxed{H = I^2Rt}$$

Where:

H = heat produced in joules

I = conductor current in amperes

R = resistance of conductor in Ω

T = time for which current flows in seconds

If the overload is large, as would occur with a short circuit of low impedance, the protection must be capable of interrupting the fault current before it can rise to a dangerous value. The protection, be it a fuse or a circuit breaker, must also be able to disconnect the supply to the fault without damage to itself. To achieve this, its design must be such as to possess adequate ‘short-circuit capacity’; that is, ‘breaking capacity’ for circuit breakers and ‘rupturing capacity’ in the case of fuses.

The danger of not complying with this last principle of protection is that the high value of energy dissipated while the fault exists might cause excessive and destructive damage to wiring and equipment. Also, the associated heating and arcing presents a high fire risk. More importantly, a person working close to an arc produced in a high-energy fault could sustain a fatal injury. In addition, there is always the possibility of shock hazard due to leakage current, causing voltages above earth on parts of the installation that are normally at earth potential or isolated from earth.

The requirements for the protection of wiring are:

- The fuse or circuit breaker should be capable of carrying its rated current continuously without overheating or deterioration.
- Small overloads of short duration should not cause the protection to operate.
- The protection must operate, even on a small overload if the overload persists long enough to cause overheating of the circuit conductors.
- The protection must open the circuit before damage caused by fault currents can occur.
- Protection must be ‘discriminative’ in that only the faulty circuit is isolated and other circuits remain operative and unaffected.

Overload protection is achieved by opening the circuit before overheating or deterioration of the protected wiring can occur. This ‘overload’ action is relatively long, the time varying inversely with the square of the current; 2 hours on 125 per cent overload and 3 seconds on 600 per cent overload are typical. The energy dissipated when the fuse element melts or the contacts of a circuit breaker open, due to overload, is relatively low.

Short-circuit fault protection is achieved by:

- The action of the fuse or circuit breaker being fast enough to open the circuit before the let-through energy (I^2t) can attain a value that would cause damage by overheating, arcing or mechanical stress; and
- The protective device being capable of opening the circuit, under these high current conditions, without damage to itself.
- The action in this case is explosive and comparatively violent, when high values of energy must be dissipated in a very short time.

Functions of Over-Current Protection

Circuit protection has two distinct main functions:

- To protect the wiring against overheating and deterioration due to overload; and
- To interrupt quickly the supply and limit the value of energy available in the case of short-circuit.

In designing protective circuits ‘discrimination’ must be one of the design requirements. The purpose of discrimination is to disconnect only the faulty circuit from the distribution network while maintaining the upstream electrical installation active

For more details on general requirements of *Protection Against Overcurrent* see Clause 2.5.1 of **Ref R-3-C**

Overload Protection - Coordination of Protective Devices

Overload currents in circuit conductors must be interrupted by a protective device before the overload currents cause a temperature increase that might damage joints, insulation or other material surrounding the conductor.

Ref R-3-C specifies that the nominal current rating of the device protecting cables against overload current shall not exceed the current-carrying capacity of the protected cables, nor may it be less than the maximum demand of the protected circuit. In this case the current-carrying capacity of a cable is the current that the conductors can carry continuously without overheating the cable. This requirement for the coordination between conductors and protective devices is outlined in Clause 2.5.3 of **Ref R-3-C**, which states:

The operating characteristics of a device protecting a conductor against overload shall satisfy the following two conditions:

$$I_B \le I_N \le I_Z \quad (2.1)$$

and

$$I_2 \le 1.45 \le I_Z \quad (2.2)$$

Where:

I_B	is the current that the circuit conductors would be expected to carry continuously without deterioration that is, the maximum demand
I_N	is the nominal rating of the protective device
I_Z	is the continuous current-carrying capacity of the conductor (see AS/NZS 3008.1 series)
I_2	the current ensuring effective operation of the protective device and may be taken as equal to either: (a) the operating current in conventional time for circuit-breakers ($1.45I_N$); or (b) the fusing current in conventional time for fuses ($1.6\ I_N$ for fuses in accordance with the AS/NZS 60269 series)

To satisfy equation 2.2, the nominal current I_N of a fuse should not exceed 90% of I_Z (1.45/1.6 = 0.9), therefore:

For circuit-breakers….. Equation 2.1 applies

For HRC fuses….. $I_B \le I_N \le 0.9I_Z$ (2.3)

If an overload occurs, a current higher than the normal-rated current is present in both the circuit wiring and the series-connected protective device. Heat generated in the circuit conductor will be proportional to the square of the current and time for which the current flows:

$$\boxed{H = I^2Rt}$$

This results in a rise in temperature (see **Fig. F-3-3-1**). The protective device must operate to open the circuit before the maximum-permitted operating temperature of the cable is exceeded.

The curves in **Fig. F-3-3-1** show that the protection must be temperature-sensitive, the tripping time being less for high ambient temperatures than for low ones, to ensure that the temperature rise in the cable does not exceed safe limits. In Australia, maximum cable temperature is usually based on an ambient temperature maximum of 40°C.

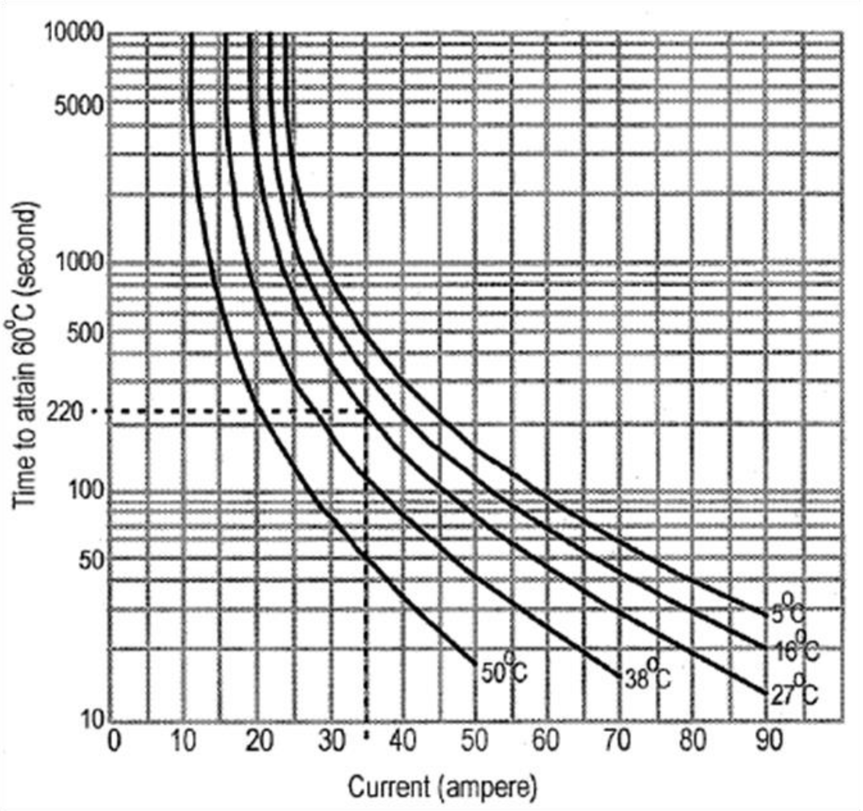


Fig. F-3-3-1 Typical heating curves for cable in conduit

In **Fig. F-3-3-1** the broken line shows that with an ambient temperature of 27°C a current of 35A will cause the cable to attain a temperature of 60°C in 220 seconds.

Circuits should be designed according to all expected operating conditions including immunity to 'nuisance tripping' such as that caused by an overload of short duration.

Short Circuit Protection

Thus far, only overload current has been considered, where a measure of the overload is usually known or assumed, using normal full-load or maximum demand current as the base (for example 'twice rated current' or '150 percent overload').

In the case of a short circuit, however, the only limit to the value of current present is the impedance of the faulty circuit, and the available short-circuit energy. This includes the impedance of the supply source, usually a substation transformer or group of transformers.

Energy distributors will generally advise fault levels. If the short circuit occurs close to the source of supply, the only limit to the current is the source impedance, neglecting the impedance of connections and assuming a short circuit of negligible or zero impedance.

A fault of zero impedance is often referred to as a 'bolted fault', which originates from tests where the short circuit is created by a bolted terminal. The impedance of a transformer is usually stated as the percentage of the primary-rated voltage that is necessary to cause full-load current in the secondary if the load terminals have a short across them. This condition is approaching that of a short circuit between busbars on the low-voltage side of a supply transformer.

A common transformer impedance value is 5%. This %Z represents the amount of voltage needed to make rated current flow in the secondary under short circuit conditions. If 5% cent of supply voltage will produce full load current, then, with a secondary short circuit and normal supply voltage of 100 per cent, twenty times the full load current will be present, i.e. :

$$\text{short circuit current} = (\text{full load current}) \times \frac{100}{5}$$

The increasing current demand of modern installations results in an increase in the capability of the supply source to deliver high values of short-circuit current.

Example

A three-phase, 400V, 500kVA transformer with an impedance of 5 per cent, is located adjacent to and supplying the 400V busbars on a factory switchboard. Determine the short circuit current:

The rated full load current is given by the expression:

$$I_{\text{rated}} = \frac{\text{kVA} \times 1000}{\sqrt{3} \times V_{\text{rated}}} = \frac{500 \times 1000}{\sqrt{3} \times 400} = 722.5\text{A}$$

Available Short-Circuit Current is:

$$I_{S/C} = \frac{I_{F/L} \times 100}{Z\%} = \frac{722.5 \times 100}{5} = 14450\,\text{A}$$

In the above example, at any point in the circuit, other than at the point of supply, the current is less than the above value, due to the impedance of the circuit between the source and the fault. Some impedance is invariably present in the fault itself. The most severe condition is a three-phase fault at the supply terminals, and calculations are usually based on this. A fault between two phases reduces the fault current to about 87 per cent, while current due to a phase to neutral fault is about 50 per cent of that fault current due to the most severe fault.

A short circuit to earth on the multiple earthed neutral (MEN) system is the equivalent of a phase to neutral fault. However, the current is further reduced owing to the impedance of the earthing system between the fault and the neutral link. Note that the current value in the above example (14 450A) neglects any to impedance in the high-voltage supply line and in the transformer primary. In practice, these could be neglected because their contribution is small and error introduced errs on the safe side, i.e. the calculated value is slightly higher than the actual value.

Prospective Short-Circuit Current

The interrupting capacity of the protection must be adequate to enable the interruption of the highest value of current available at the point of installation of the protection.

Clause 2.5.2 of **Ref R-3-C**, stipulates that the protection must be installed at the commencement of the circuit, which is usually at the main switchboard or at a distribution board.

The fault current, usually termed ‘prospective short-circuit current’, must be interrupted before the temperature of conductors reaches the admissible limit. Temperature limits for cables under short-circuit conditions are given in the AS/NZS 3008.1 series Section 5.

Clause 2.5.4.1 of **Ref R-3-C** requires that the prospective short-circuit current be determined at every relevant point of an electrical installation, the relevant points being mainly where a protective device is installed. Any estimation of fault level must commence at the source of supply.

There are various ways estimating fault levels. If the rating of the transformer is known, proceed as in the example given below. If the transformer’s rating is not known, information must be obtained from the energy distributor and is usually stated as amperes per phase or total MVA fault capacity at any point on the line. The fault current can be calculated from known MVA as in the example following

Example 1

An energy distributor gives a fault level of 7 MVA on a 400V line, then the prospective fault current per phase is:

$$\mathrm{I}_{\text{fault}} = \frac{\text{faultlevel}}{\sqrt{3} \times \mathrm{V}_{\text{LINE}}} = \frac{7 \times 10^6}{\sqrt{3} \times 400} = 5833\,\text{A perphase}$$

If the supply source is other than a transformer (an alternator for example), the characteristics of the supply source must be known to permit calculations. As an example a 500kVA 11kV/400V transformer with 5% impedance will have:

Fault capacity of 10MVA

Fault current of 14433A at 400V

Switchboards close to the transformer will absorb nearly all the fault energy available and need to be designed accordingly. There is a reduction of fault levels with switchboards further away from their source of supply due to impedance of feeder cables. Manufacturers need to consider requirements for switchboards to pass ‘type approval’ tests with respect to fault-current capability. Venting and modular design may be used to contain explosions caused by high fault currents.

Example 2

A 500kVA 11000:400/230V 5% impedance transformer connected through a large consumer’s mains to a main switchboard that feeds a distribution board through a submain originating at the main switchboard. The impedance of the consumer mains is given as 0.004Ω and that of the sub-mains as 0.026Ω. Calculate the fault level at the main switchboard and the distribution board

The prospective short-circuit current for a 500kVA transformer is

$$\mathrm{I}_{\text{fault}} = \frac{\text{TX VArating}}{\sqrt{3} \times \mathrm{V}_{\text{LINE}}} \times \frac{100}{\%Z} = \frac{500 \times 10^3}{\sqrt{3} \times 400} \times \frac{100}{5} = 14433\,\mathrm{A}$$

therefore, the impedance/phase of supply (Z_1) is:

$$\mathrm{Z}_1 = \frac{\mathrm{V}}{\mathrm{I}_{\text{SC}}} = \frac{230}{14433} = 0.01594\,\Omega$$

Let impedance of consumer mains be Z_2 and sub-mains Z_3

Then fault level at main switchboard is:

$$\mathrm{I}_{\text{FAULT}} = \frac{\mathrm{V}}{\mathrm{Z}_1 + \mathrm{Z}_2} = \frac{230}{0.01594 + 0.004} = 11435\,A$$

fault level at distribution board is:

$$\mathrm{I}_{\text{FAULT}} = \frac{\mathrm{V}}{\mathrm{Z}_1 + \mathrm{Z}_2 + Z_3} = \frac{230}{0.01594 + 0.004 + 0.026} = 5006\,\mathrm{A}$$

The fault levels calculated above are summarized in the following diagram

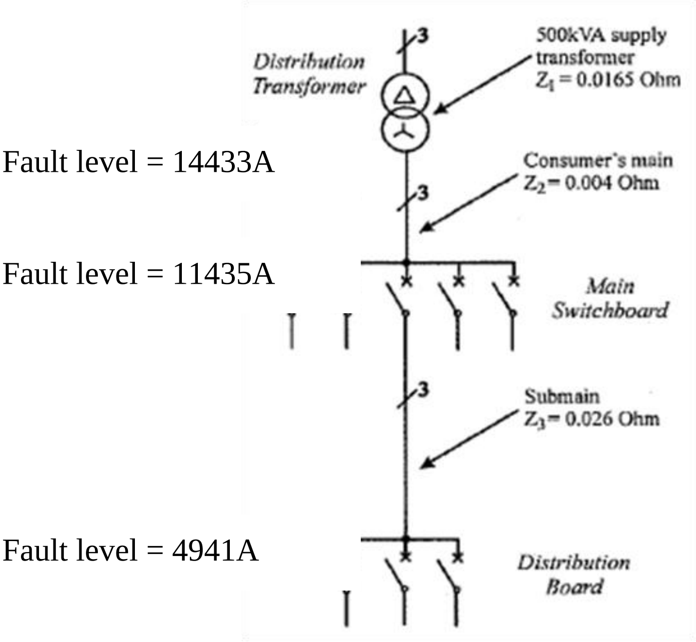


Fig F-3-3-2 Decreasing Fault Levels with Distance from Source

In the above example the protective equipment for the locations at which fault levels were calculated, needs to have a rating sufficient to clear the indicated values of short-circuit current. If, however, the short circuit occurred in subcircuit wiring (at the control panel for an automatic machine for example), the impedance of the circuit wiring between the distribution board and the panel would reduce the available current still further. Note that for the purposes of calculation, any impedances present in connections, terminations, circuit breakers, fuses and similar series connected devices have been ignored. Any busway feed in to the circuit needs to be included and the manufacturers should supply appropriate impedance figures. If the installation comprises many motors, the energy stored in their magnetic fields could also contribute to fault current, to the extent of approximately four times their rated current.

Figure **Fig. F-3-3-2**, shows how the fault level decreases as the impedance of cables increases and is typical of technical information available from manufacturers.

Note: An energy distributor might upgrade a substation supplying existing installations that have been in service for a number of years, in order to allow for load increases. In most cases, the resulting raised fault current levels will not have been allowed for in these existing installations. As a result, they will not be able to cope with the increased fault current available, and this will create a significant safely and fire hazard.

Prospective Fault-Current Levels from Tables and Graphs

In practice, fault levels are usually determined by consulting the appropriate tables and graphs where, by cross-reference, the values can be ‘read off’. Tables and graphs of the like shown in Figures **F-3-3-3** and **F-3-3-4** can be obtained from manufacturers and are useful in conversion from MVA to current(kA) and the determination of prospective short-circuit current levels of transformers and fault levels at the ends of cables, given route length and cable size.

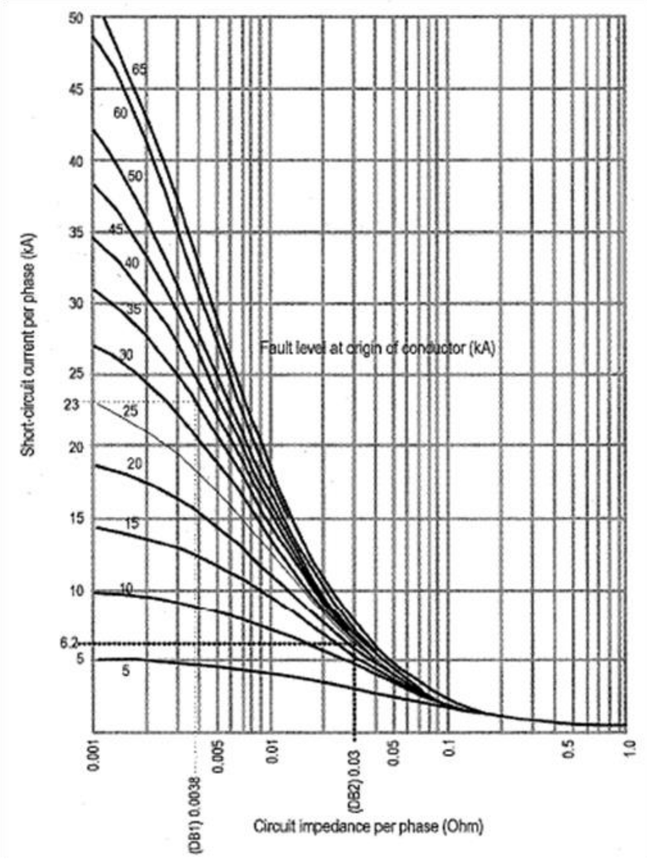
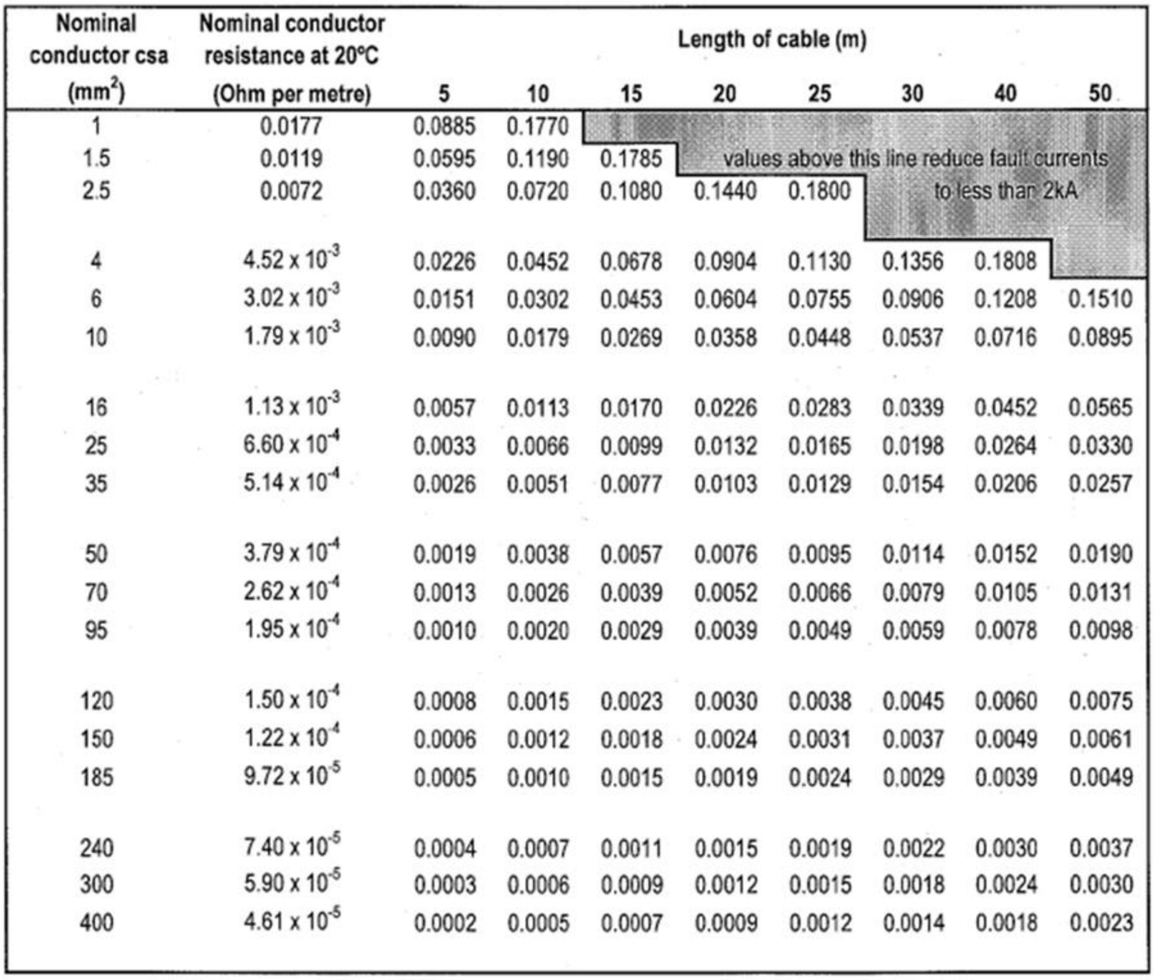


Fig. F-3-3-3 Prospective short-circuit currents



Nominal conductor csa (mm^2)	Nominal conductor resistance at 20°C (Ohm per metre)	Length of cable (m) 5	10	15	20	25	30	40	50
1	0.0177	0.0885	0.1770						
1.5	0.0119	0.0595	0.1190	0.1785					
2.5	0.0072	0.0360	0.0720	0.1080	0.1440	0.1800			
4	4.52×10^{-3}	0.0226	0.0452	0.0678	0.0904	0.1130	0.1356	0.1808	
6	3.02×10^{-3}	0.0151	0.0302	0.0453	0.0604	0.0755	0.0906	0.1208	0.1510
10	1.79×10^{-3}	0.0090	0.0179	0.0269	0.0358	0.0448	0.0537	0.0716	0.0895
16	1.13×10^{-3}	0.0057	0.0113	0.0170	0.0226	0.0283	0.0339	0.0452	0.0565
25	6.60×10^{-4}	0.0033	0.0066	0.0099	0.0132	0.0165	0.0198	0.0264	0.0330
35	5.14×10^{-4}	0.0026	0.0051	0.0077	0.0103	0.0129	0.0154	0.0206	0.0257
50	3.79×10^{-4}	0.0019	0.0038	0.0057	0.0076	0.0095	0.0114	0.0152	0.0190
70	2.62×10^{-4}	0.0013	0.0026	0.0039	0.0052	0.0066	0.0079	0.0105	0.0131
95	1.95×10^{-4}	0.0010	0.0020	0.0029	0.0039	0.0049	0.0059	0.0078	0.0098
120	1.50×10^{-4}	0.0008	0.0015	0.0023	0.0030	0.0038	0.0045	0.0060	0.0075
150	1.22×10^{-4}	0.0006	0.0012	0.0018	0.0024	0.0031	0.0037	0.0049	0.0061
185	9.72×10^{-5}	0.0005	0.0010	0.0015	0.0019	0.0024	0.0029	0.0039	0.0049
240	7.40×10^{-5}	0.0004	0.0007	0.0011	0.0015	0.0019	0.0022	0.0030	0.0037
300	5.90×10^{-5}	0.0003	0.0006	0.0009	0.0012	0.0015	0.0018	0.0024	0.0030
400	4.61×10^{-5}	0.0002	0.0005	0.0007	0.0009	0.0012	0.0014	0.0018	0.0023

values above this line reduce fault currents to less than 2kA

Fig. F-3-3-4 Cable Impedance (Ω) for Copper

Example

An energy distributor states that a prospective short-circuit current of 35kA is to be assumed at a point of supply at a main switchboard, which feeds a main distribution board (DB1) through 25m of 120mm^2 cable. This distribution board supplies another distribution board (DB2) through 45m of 25mm^2 cable. Calculate the fault level at DB2:

Fault level at point of supply = 35kA

Impedance of 25m of 120mm^2 cable (from Table in **Fig. F-3-3-4**) = 0.0038Ω

Fault level at DB1 (from **Fig. F-3-3-3**) = 23 kA

Impedance of 45m of 25 mm^2 cable (from Table in **Fig. F-3-3-4**) = 0.029Ω

Fault level at DB2 (from **Fig. F-3-3-3**) fault level at origin of conductor is 23 kA; a point between the 20 kA and the 25 kA curves is estimated at = 6.2 kA.

Prospective fault-current levels (energy distributor)

The New South Wales Service and Installation Rules (Ref **R-3-F**)provide prospective short-circuit currents at the point of supply as follows:

Suburban residential areas	10 kA
Commercial and industrial areas	25 kA
Installations on railway land	6 kA

Operation Time of Protective Device

The protection provided for short circuits must not be confused with the function of overload protection, where the increase in current is quite moderate compared with the high values that may be present under short-circuit conditions. Also, on overload, the operating time is relatively long, and high-speed operation would be a disadvantage because overloads of short duration are permissible.

In contrast to this, the time taken to clear a short circuit must be such that the stresses due to the heavy currents are kept within safe bounds. These stresses are due to:

- the magnetic forces between current-carrying paths, which can be considerable
- the rapid heating of parts due to the fault energy
- damage caused by arcing at the fault

It follows that; if large values of prospective short-circuit currents are possible, then the fault must be cleared (isolated from the supply) before the current can reach its first maximum or peak value. This same principle applies to either a fuse or circuit breaker. Not only must the device clear the fault but it must also have the capacity to do so (rupturing or breaking capacity) without damage to itself. To achieve this, the operation time must be such as to limit the fault energy to a value that the device is capable of clearing.

Temperature Rise in Conductors During Short Circuit

All short-circuit currents shall be interrupted before the temperature of the conductors reaches the admissible limit. **Section 5 of AS/NZS3008.1.1 table 52 & 53** gives the maximum temperature limits for conductors with varying insulation. The equation defining these limits is:

$$I^2t = K^2S^2$$

Or re-arranging

$$t = \frac{K^2S^2}{I^2}$$

Where:

t = duration in seconds

K = factor dependent on the material of the conductor, the insulation and the initial and the final temperatures (value of K obtained from table 52 of AS/NZS3008.1.1

S = CSA of conductor in mm^2

I = effective short-circuit current

Tutorial 3.3

TQ.3.21 List the conditions short circuit protective devices must meet.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q1 P56]*

TQ.3.22 List the 'recognised' methods of fault protection.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q2 P56]*

TQ.3.23 Can a device used for protection against automatic disconnection of supply be capable of auto reclosing?

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q3 P56]*

TQ.3.24 Under what conditions can a device be of the auto reclose type?

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q4 P56]*

TQ.3.25 Give an example where an auto reclose device may be required.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q5 P57]*

TQ.3.26 List four types of devices that could be employed to provide automatic disconnection of supply.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q6 P57]*

TQ.3.27 Define an overload current and give an example.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q7 P57]*

TQ.3.28 Define short circuit current and give an example.

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q8 P57]*

TQ.3.29 Given a 11kV/400V (Delta-Star), 600kVA transformer has an impedance of 4%, determine the:

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q9 P58]*

- rated current
- fault current at the transformer secondary terminals
- fault level at the transformer secondary terminals
- transformer impedance in ohms.

TQ.3.30 A 11kV/400V (Delta-Star), 500kVA transformer has a nominated fault level of 10MVA, determine:

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q10 P58]*

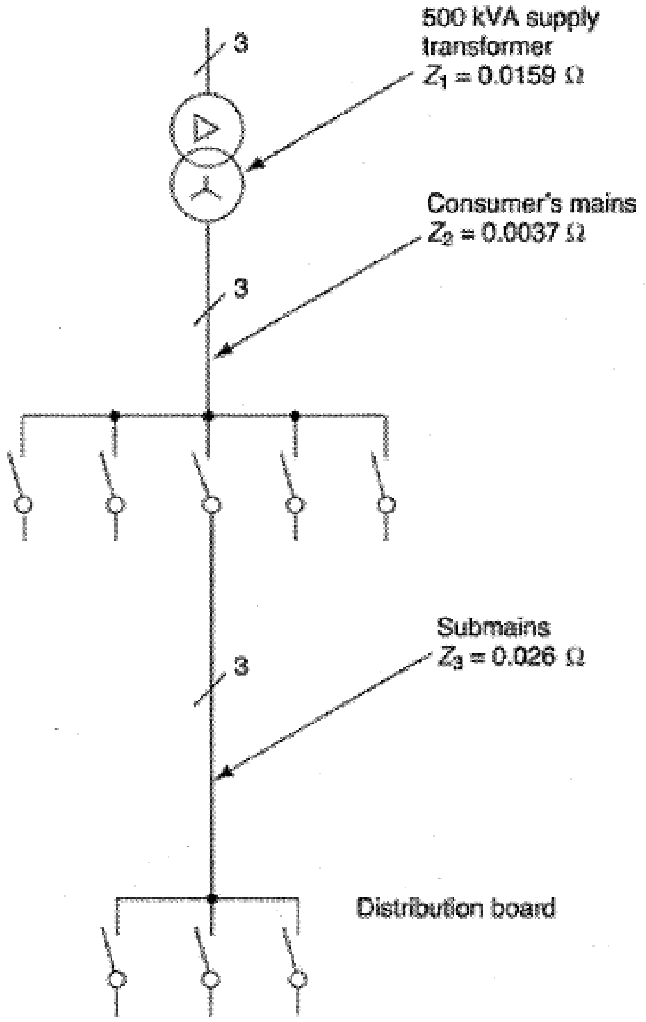
- prospective fault current at the transformer
- transformer impedance in ohms.

TQ.3.31 A 11kV/400V (Delta-Star), 500kVA transformer has a prospective fault current of 14.4kA, what is the impedance per phase of the transformer?

[Source: Ref ***R-3-A*** *Part 1, Section 3- Review Questions Q11 P58]*

TQ.3.32 For the installation shown below determine the prospective fault current at each relevant point within the installation

*[Source: Ref **R-3-A** Part 1, Section 3- Review Questions Q12 P59]*



TQ.3.33 A 3-phase 400/230V service supplies the main switchboard to a block of factory units. The supply authority advises that the fault level at the consumer's terminals is 18kA. The consumer's mains consist of 50mm^2 active conductors and a 35mm^2 neutral conductor having a length of 30 meters. Determine the theoretical fault current at the main switchboard. Use the table from **Fig. F-3-3-4** to determine cable impedances.

*[Source: Ref **R-3-A** Part 1, Section 3- Review Questions Q13 P59]*

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.

A fuse interrupts excessive current (blows) so that further damage by overheating or fire is prevented. Overcurrent protection devices are essential in electrical systems to limit threats to human life and property damage. 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.

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.

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.

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 these paragraphs are 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**

The fuse wire connects the contacts on the wedge, and passes through a hole in a section of the wedge. When the 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.
- 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

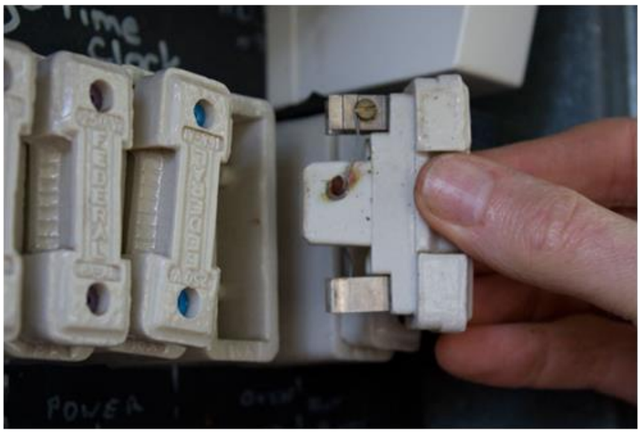


Fig. F-3-4-1 Rewireable Fuses

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**

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

Fig. F-3-4-2 (a) 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

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

There are two basic types of fuses available for appliances and consumer electronics: fast-acting or time-delay. Any replacement fuse must match the one it’s replacing. In general, fast-acting fuses are a single strand of wire or strip of metal. Time-delay fuses usually have a coiled wire, a thick element wrapped in wire, or a spring. Most electronic fuses will have the voltage and amp rating stamped on the end cap. The type of fuse can generally be visually identified. Also, owner’s manuals will have the correct replacement fuse generically identified.

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

High Rupturing Capacity (HRC) Fuses

Another type of fuse is the HRC fuse (high rupturing capacity). 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. It can operate more quickly; interrupt higher values of current than other types of fuses, and completely contains 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 F-3-4-3**, while **Fig F-3-4-4** shows a sectioned view of a HRC fuse cartridge

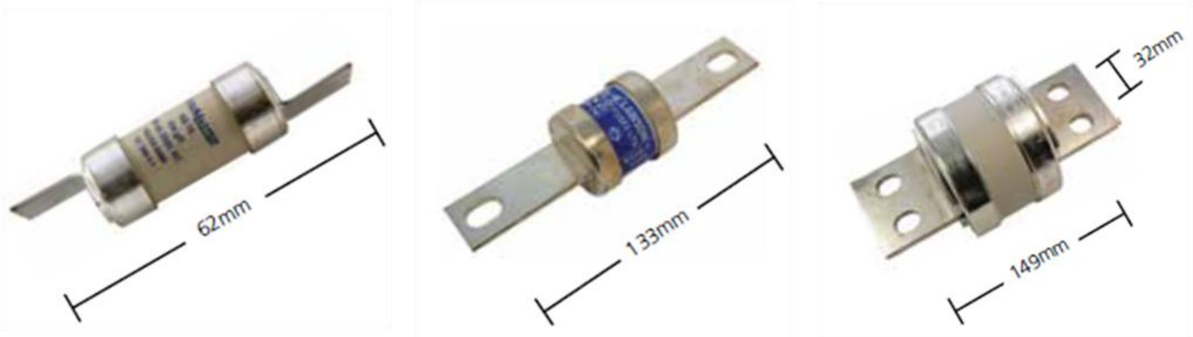


Fig F-3-4-3 (a) Typical HRC Fuse Cartridges

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

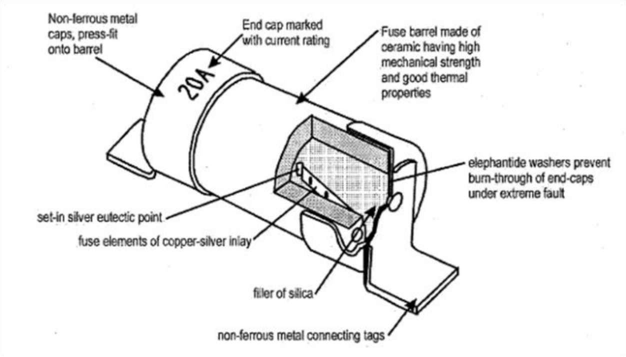


Fig. F-3-4-4 Construction of a HRC fuse

Fuse Links

Fig F-3-4-5 shows the construction of typical fuse elements. Reduced sections (A in **Fig F-3-4-5**)are located along the length of the fuse element creating short circuit zones of high current density, which respond rapidly to high fault currents and quickly produce a multiple arcing condition and subsequent circuit interruption. The center of the fuse link element (B in Fig **F-3-4-5**) has a band of pure silver which is formed into a trough and then filled with tin. At a critical temperature the silver and tin merge together and form a low melting point alloy (around 230°C), which causes the center of the element to melt at this temperature. Without this metallurgical effect the center of this element would need to be raised to 960°C (the melting point of pure silver) under overcurrent conditions.

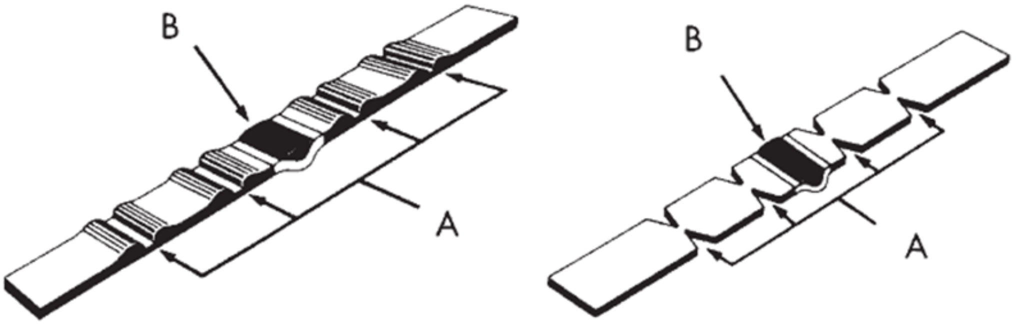


Fig. F-3-4-5 HRC Fuse Links

Filler

The filler which totally surrounds the fusible elements consists of high grade silica sand, which is extremely low in impurities and is of tightly controlled grain size. The purpose of this filler is twofold. Firstly, because of its close proximity to the fuse elements it is able to effectively cool them and therefore, enable less material to be used for a given rated current. More important, however, is the effect of the filler when a fuse link operates on a short circuit fault current. In this instance the fuse element suddenly disintegrates under the effect of such a current, rapidly dispersing it through the adjacent silica sand and forming a high resistance material which rapidly forces the current down to zero, severely restricting the current and energy let through to the fault.

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. 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

Fuses labeled 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

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. The deciding factor in the operation of a HRC fuse is the energy required to melt the fuse element.

Fig F-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.

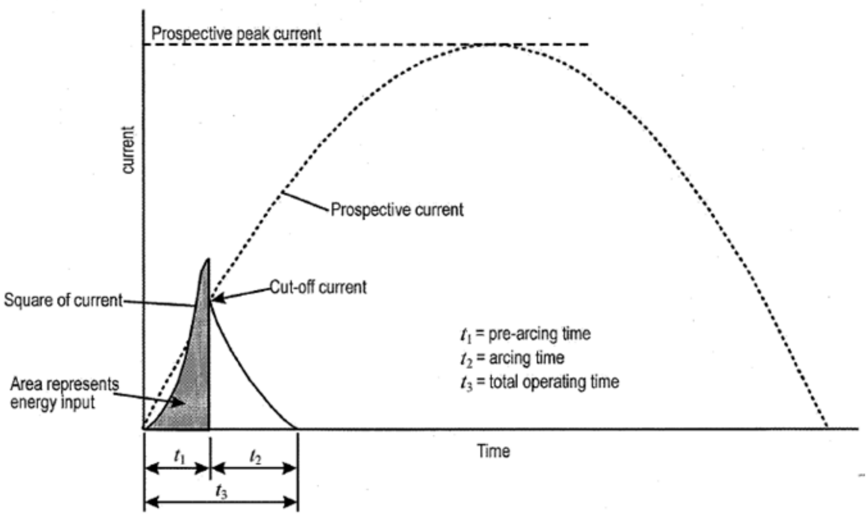
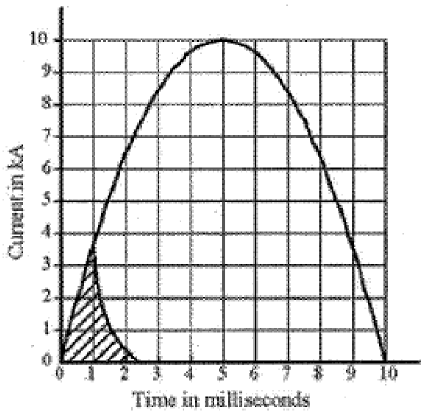


Fig. F-3-4-6 HRC Fusing Characteristic

Example

For the HRC fuse characteristic shown at right:

- 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



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)

Time-Current Characteristics

Fig. F-3-4-7 shows Time verses Current characteristics, of HRC fuses. These are log-log graphs of nominal prospective fault current versus pre-arcing time, i.e. melting curve. These characteristics are the ones most frequently used. They enable the fuse link’s ability to withstand surge currents, such as, motor starting currents, to be assessed. They are also used in discrimination studies.

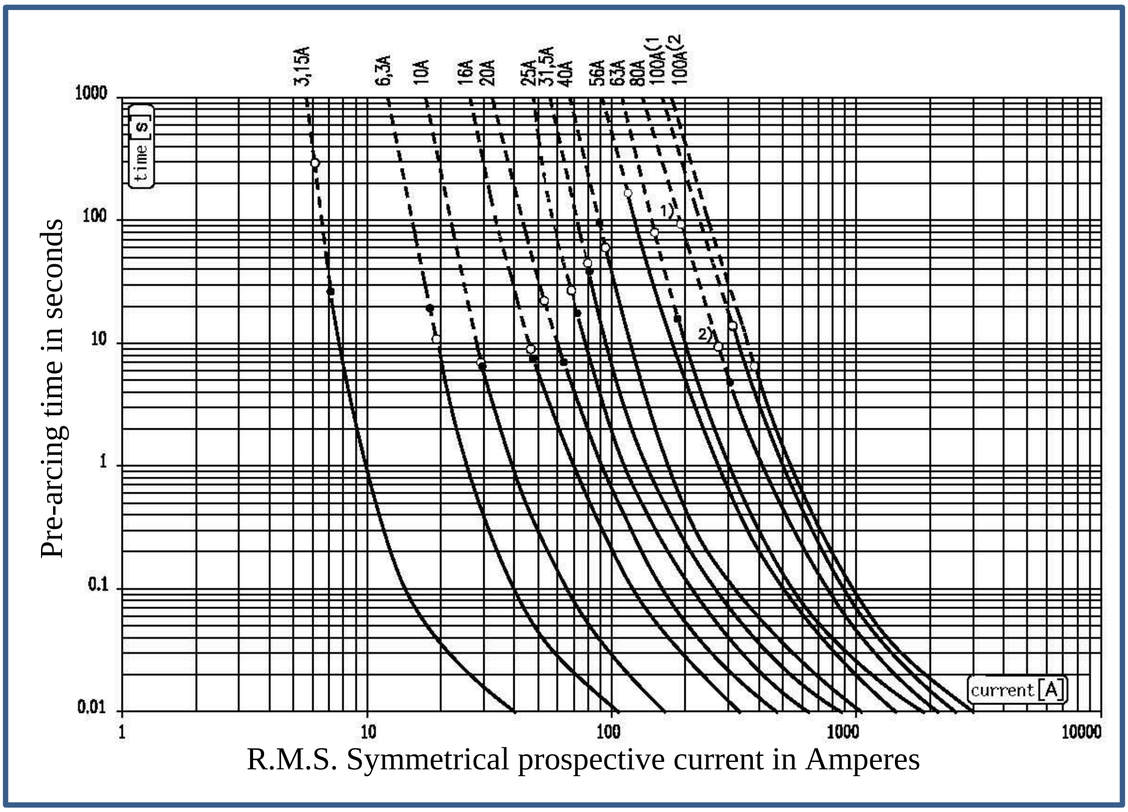


Fig. F-3-4-7 HRC Fuses Time-Current Characteristics

Fuses and Fault Loop Impedance

Table 8.1 of **Ref. R-3-C** 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. The values of Z_s are derived from:

$$Z_s = \frac{U_0}{I_a} \qquad \text{E-3-4-1}$$

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. F-3-4-8** below)

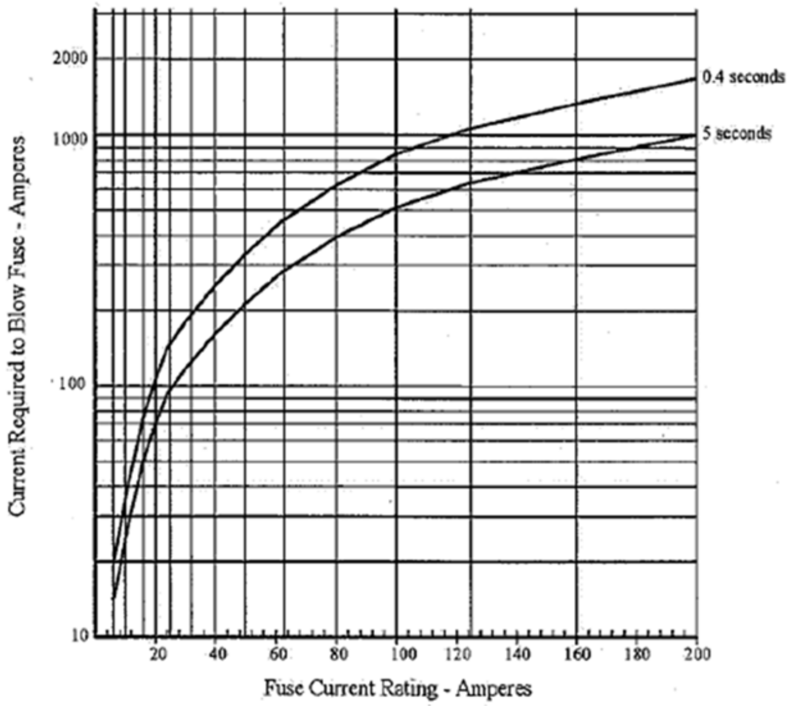


Fig. F-3-4-8 HRC Fuse Current Rating Versus Fusing Current Curves

The following rules for disconnection times are from **Ref. R-3-C**

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.

1.5.5.3 (d) - **Disconnection times.** The maximum disconnection time for 230/400 V supply voltage shall not exceed the following:

- 0.4 s for final sub-circuits that supply—
- socket-outlets having rated currents not exceeding 63 A; or
- hand-held Class I equipment; or

- portable equipment intended for manual movement during use.
- 5 s for other circuits including submains and final subcircuits supplying fixed or stationary equipment

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:

$K^2S^2 > I^2t$ (from clause 2.5.4.5(b) of **Ref. R-3-C**)

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

The time/current curve of **Fig. F-3-4-9** shows the fuse (and circuit breaker) will operate before the I^2t characteristic of the cable is reached i.e. the cable is protected.

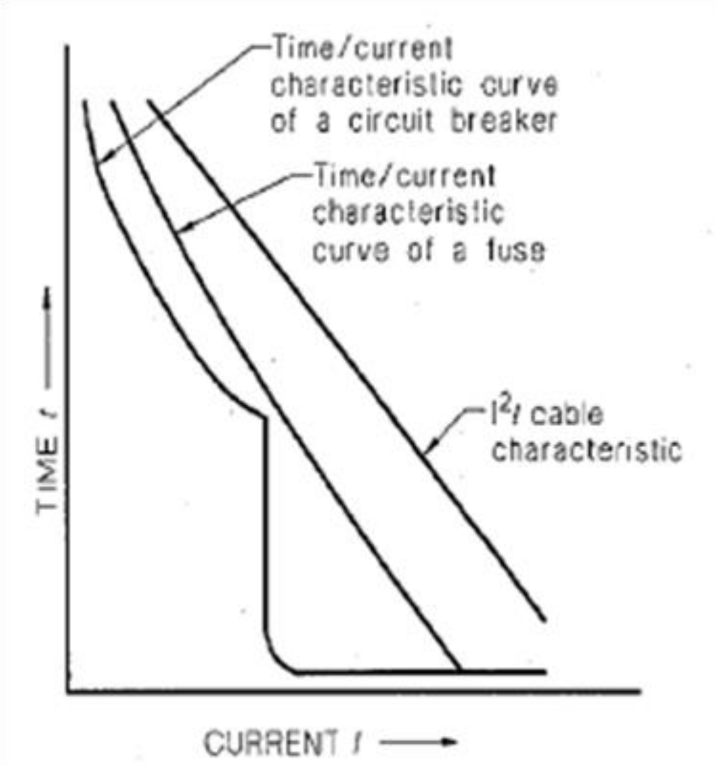


Fig. F-3-4-9 Time-Current characteristics of Fuse and Circuit Breaker.

The cable is protected if the protective device curve falls to the left of the cable curve

Tutorial 3.4

NOTE: Where applicable quote the appropriate Clause No. from the relevant Standard

TQ.3.34 Fuses and circuit breakers are primarily installed to protect:

*[Source: Ref **R-3-A** Part 1, Section 4- Review Questions Q1 P76]*

a. Electrical appliances
b. Electrical cables
c. Electrical loads
d. Persons and livestock

TQ.3.35 The element of a high rating HRC fuse is normally comprised of:

____

TQ.3.36 The purpose of the silica powder filler in a HRC fuse is:

a. For cooling of the fuse element and to form a high resistance material for current interruption when the element fuses
b. For cooling of the fuse element and to provide mechanical shock absorption for the fuse element
c. To form a high resistance material for current interruption when the element fuses and to provide mechanical shock absorption for the fuse element
d. All three of the reasons covered in choices A, B, and C above

TQ.3.37 If a cable supplying a load that is operating at 50% overload, the power dissipated by the cable will be:

*[Source: Ref **R-3-A** Part 1, Section 4- Review Questions Q3 P76]*

a. 25% of its original value
b. 50% of its original value
c. 150% of its original value
d. 225% of its original value

TQ.3.38 When installing fuses in a final sub-circuit, the current carrying capacity of the cables are re-rated by a factor of:

*[Source: Ref **R-3-A** Part 1, Section 4- Review Questions Q4 P76]*

a. 0.7
b. 0.8
c. 0.9
d. 1.25

TQ.3.39 From the curves shown of Fig **F-3-4-7**above and Equation **E-3-4-1** determine:

*[Source: Ref **R-3-A** Part 1, Section 4- Exercise 3a and 3b, P73]*

a. the current required to operate a 40A fuse in 5 seconds and the required fault loop impedance

b. the current required to operate a 40A fuse in 0.4 seconds and the required fault loop impedance

TQ.3.40 From the Table 8.1 of **Ref. R-3-C** determine the maximum value of fault loop impedance to cause the fuses listed below to operate in the nominated times.

*[Source: Ref **R-3-A** Part 1, Section 4- Exercise 3c, P73]*

Fuse Rating (A)	Required Tripping Time (s)	Max. Fault Loop Impedance (Ω)	Current Required to Operate Fuse (A)
10	0.4		
10	5		
25	0.4		
40	0.4		
63	5		
100	5		

TQ.3.41 A final sub circuit supplying 230V, 10A socket outlets is protected by a 20A fuse. If the fault loop impedance of the circuit is 3.1 Ω, will the fuse disconnect the circuit in the required time if there is a fault to earth?.

*[Source: Ref **R-3-A** Part 1, Section 4- Exercise 3d, P74]*

TQ.3.42 A 2.2kW quick recovery water heater is to be installed in the tea room of an existing factory. The nearest distribution board has HRC fuses fitted with spare fuse holders for additional circuits. The TPS cable is to be run through the roof space of the tea room which has thermal insulation installed.

*[Source: Ref **R-3-A** Part 1, Section 4- Exercise "Fuse Selection" , P75]*

a. Determine the maximum demand current

b. Select a fuse to protect the circuit

c. Current carrying capacity of cable from Ref R-3-G, assume cable is partially surrounded.

d. Do the values of current comply with $I_B < I_N < I_Z$?

e. Does the arrangement comply with $I_2 < 1.45 \times I_Z$?

f. What is required to ensure the circuit will comply?

g. Assuming 1.5mm^2 cable is used, will the arrangement provide short circuit protection?

TQ.3.43 The de-rating factor of 90% for a fuse protected cable is derived from what ratio?

*[Source: Ref **R-3-A** Part 1, Section 4- Review Questions Q7 P77]*

TQ.3.44 What is the maximum acceptable fault loop impedance for a 20A fuse to operate in the specified time of 0.4 seconds?

*[Source: Ref **R-3-A** Part 1, Section 4- Review Questions Q8 P77]*

Topic 3.5 Circuit Breakers

Introduction

A circuit breaker (CB) is a type of switch that opens automatically if the current through the CB 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. 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

To achieve tripping, a bimetallic strip is heated either by the load current (or a fixed proportion of the load current) passing through it, or indirectly by a heater (See **Fig. F-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.

If the circuit breaker 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. The time lag of the thermal strip ensures that overloads of short duration do not cause tripping; but should these continue, the cumulative heating effect will eventually trip the CB in time to avoid exceeding the temperature rise limits of the cable.

In practice, if this type of CB is operated in an ambient temperature higher than its rating or even in an enclosure or grouped with other equipment where the temperature will exceed its ‘free air’ temperature rating, it must be de-rated. 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.

The time-lag characteristic, however, is a disadvantage if, for example, a low impedance short circuit occurs and it is necessary to open the circuit quickly before damage can occur due to the high prospective currents. Thermal tripping is therefore close to ideal for overload protection, but is unsatisfactory against short circuits. This type of circuit breaker is often backed up with a fuse that provides short-circuit protection.

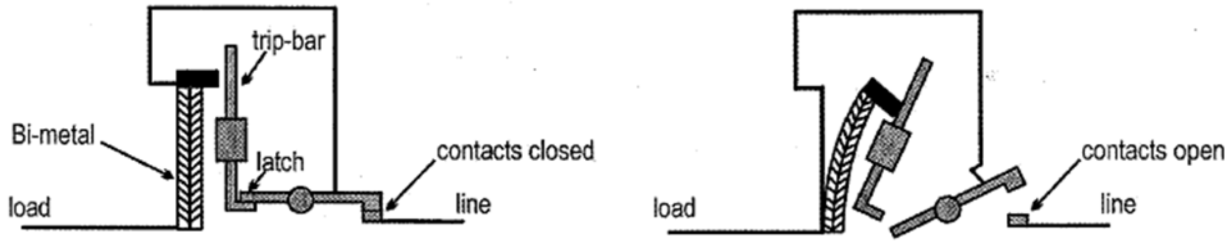


Fig. F-3-5-1 Thermal Circuit Breaker Trip Mechanism

Magnetic Circuit Breaker

In this type of 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 of the trip mechanism with normal load current, the iron armature is restrained in its movement by some opposing force, which must first be overcome before movement can take place; this is usually in the form of a spring. Some type of time-delay device must also be incorporated and this is often in the form of an oil filled dashpot. The operating principle of a magnetic-only CB is shown in Figure **Fig. F-3-5-2(a) to (e). Fig. F-3-5-2(a)** shows the basic principle of the magnetic trip mechanism while Figs. **Fig. F-3-5-2(b) to (e)** summarise the operation of the instantaneous and time delay trip operation.

The magnetic CB will provide a near instantaneous trip on heavy overloads (usually ten times the full load) or on a short circuit. This is because the magnetic field is strong enough to pull in the armature without it being necessary for the plunger to move. Magnetic trip-type CBs may also be designed or adjusted to provide short-circuit protection and to provide the inverse time characteristic necessary for overload protection. The magnetic trip action is independent of ambient-temperature conditions, its adjustment being made for a fixed ambient temperature.

Protection is not complete at temperatures above that for which the CB is calibrated. Both types of CB, thermal and magnetic, are in use for protection, but their protective characteristics are complementary. This led to the development of a third type of CB, in which the characteristics are combined.

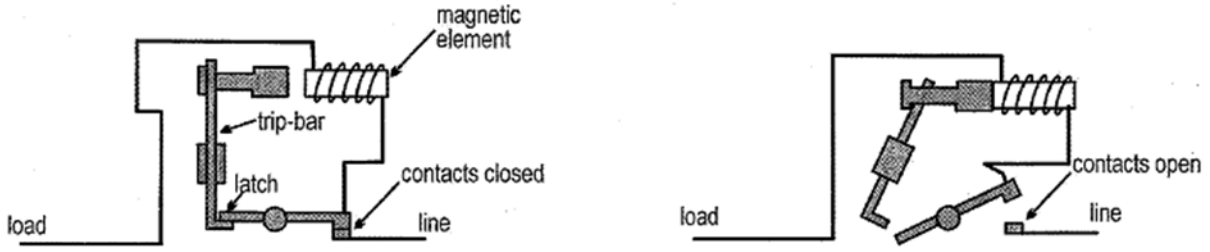


Fig. F-3-5-2(a) Magnetic Circuit Breaker Trip Mechanism

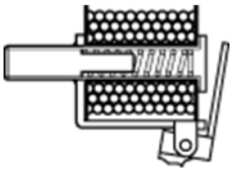


Fig. F-3-5-2(b) Current within rating – magnetic field insufficient to attract tripping armature or to move core

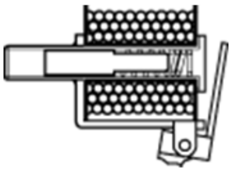


Fig. F-3-5-2(c) Moderate overload - magnetic field insufficient to attract tripping armature but is strong enough start moving core

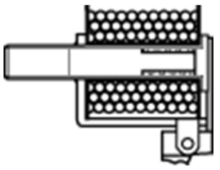


Fig. F-3-5-2(d) Moderate overload persists – core continues its movement until it reaches the pole piece reducing the reluctance of the magnetic circuit attracting the armature and tripping the CB

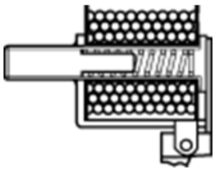


Fig. F-3-5-2(e) Short Circuit Fault - magnetic field generated is strong enough to instantly attract the armature without the aid of the core, thus tripping the CB instantly

Thermal-Magnetic Circuit Breaker

This type of CB utilizes a thermal element to provide the time - delay characteristic and the ambient temperature facility, while short-circuit protection is provided by magnetic action. When overloads occur, time delay is provided by the time taken to heat the bimetallic element. With large overload or on short circuit the magnetic element influences the tripping time and is so adjusted that with ten times the rated current it takes over completely to provide almost instantaneous tripping, with a typical interrupting time of 0.01 seconds.

When a CB trips, it is important to remove the cause of the overload before closing the circuit breaker and restoring the power. Therefore, to be able to tell if a circuit breaker tripped rather than turned off some circuit breakers have three toggle positions — off/tripped/on. The ‘on’ position is with the toggle up, (the opposite to a light switch). When the toggle is in the center position, the circuit breaker has tripped. The ‘off’ position has the toggle down.

Another important feature of a CB is the trip-free mechanism. With this type of mechanism, if a fault is still present in the circuit, it is not possible to reset the circuit breaker and switch back on even if toggle is held in the ‘on’ position. Most circuit breakers have this feature.

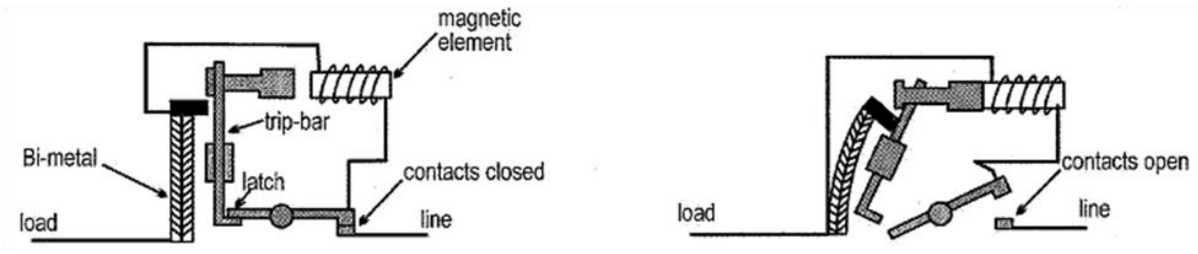


Fig. F-3-5-3 Thermal-Magnetic Circuit Breaker Trip Mechanism

Arc Suppression

When circuit breakers interrupt high fault currents, an arc is drawn between the contacts. In large circuit breakers, blasts of air or oil extinguish the arc. For general wiring, arc extinction is assisted by the use an arc suppression grid as shown in **Fig. F-3-5-4** .

Arc extinction relies on the fact that the arc drawn between the contacts is a current carrying conductor and as such, surrounded by a magnetic field the strength of which is proportional to the magnitude of the current. 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.

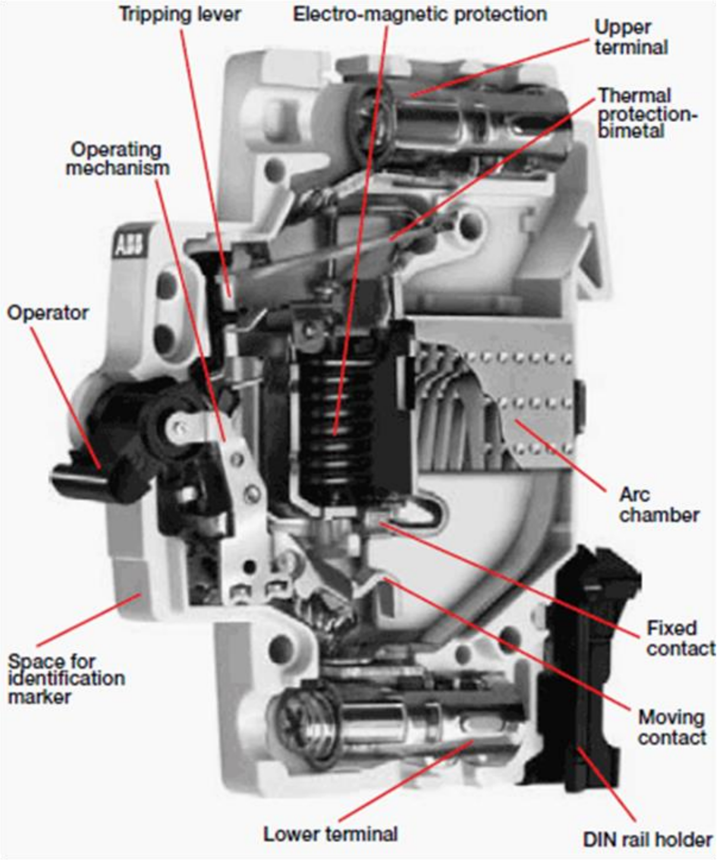
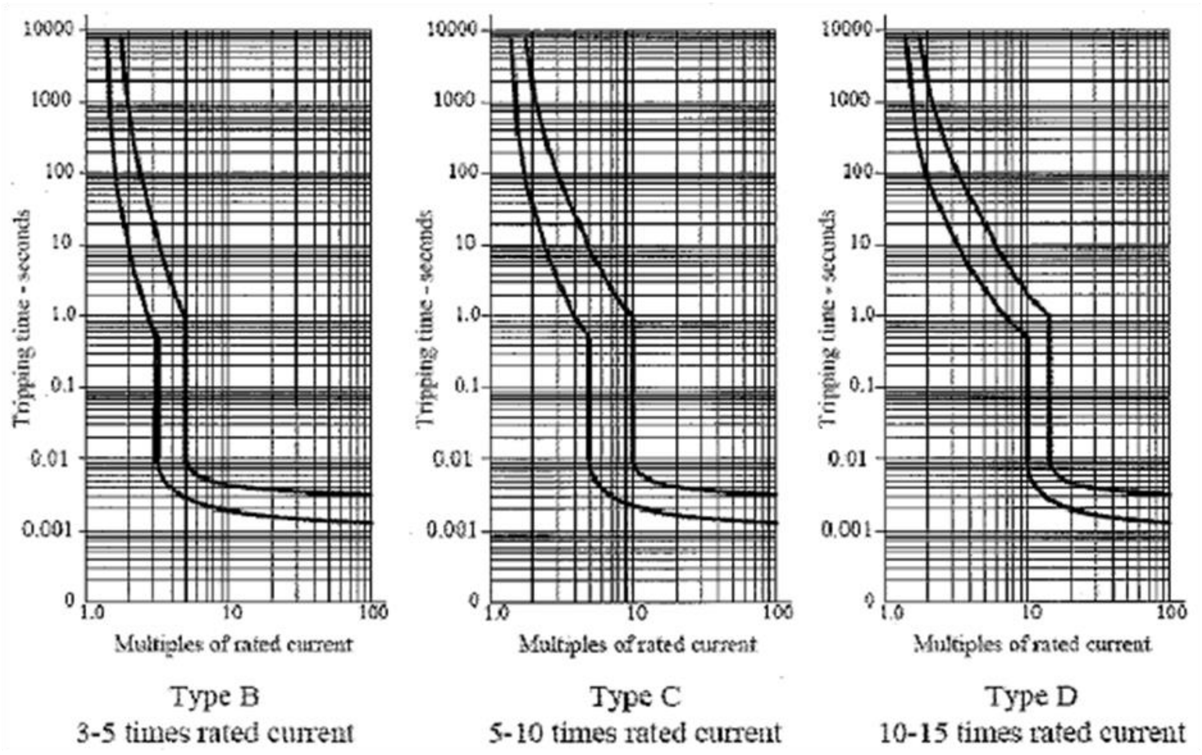


Fig. F-3-5-4 Thermal-Magnetic Circuit breaker showing the arc suppression grid (Arc Chamber)

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)
- 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. F-3-5-5**.



Type B
3-5 times rated current

Type C
5-10 times rated current

Type D
10-15 times rated current

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

Tutorial 3.5

NOTE: Where applicable quote the appropriate Clause No. from the relevant Standard

TQ.3.45 Explain what is meant by the term discrimination as applied to circuit protection:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q4, P87]*

TQ.3.46 Explain what is meant by the term trip free as applied to circuit protection:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q5, P87]*

TQ.3.47 Explain what is meant by the term prospective fault current:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q9, P88]*

TQ.3.48 Explain what is meant by the term inverse time characteristic:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q10, P88]*

TQ.3.49 Explain the action of a magnetic circuit breaker

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q16, P90]*

TQ.3.50 A final sub-circuit supplying 230V, 10A socket outlets is protected by a 20A type C circuit breaker. If the fault-loop impedance of the circuit is 2.12 Ω, will the circuit breaker disconnect the circuit in the required time if there is a fault to earth?

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q18, P90]*

TQ.3.51 A 230V installation is arranged in the following manner:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q19, P91]*

consumer's mains = 16mm^2, length 25 meters

final sub-circuit:

cable = 1.5mm^2,2-core + earth, length 15 meters, current rating 13A
load = 2.2kW quick recovery water heater, taking 9.6A
protection = 10A type C circuit breaker
external fault-loop impedance = unknown

Does the circuit arrangement satisfy the requirements of the Rules in terms of:

- coordination between the cable and circuit protective device?
- overload protection?
- protection against indirect contact?

TQ.3.52 Using Table 8.1 of AS/NZS 3000:2007 determine the maximum value of fault-loop impedance to cause the circuit breakers listed in the following table to trip in the nominated times. Also determine the current required to operate the circuit breaker.

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q17, P90]*

Circuit Breaker Rating (A)	Circuit Breaker Type	Maximum Fault-Loop Impedance (Ω)	Fault Current Required to Operate Circuit Breaker (A) (show range)
20	C		to
20	D		to
25	B		to
40	C		to
63	D		to
100	C		to

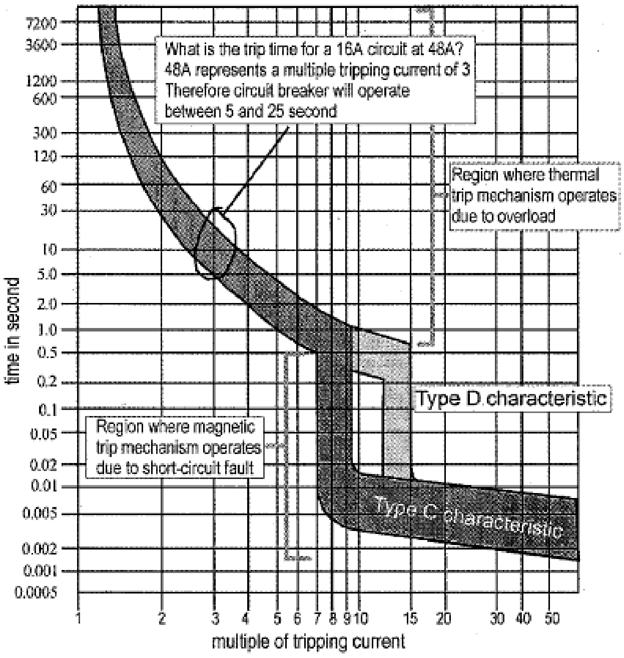
TQ.3.53 Use the circuit breaker tripping curves shown below to answer the following:

*[Source: Ref **R-3-A** Part 1, Section 5- Review Questions Q15, P89]*

a. Under fault condition a type C, 20A circuit breaker is exposed to 400A.
How long will it take to operate?

b. A 10A type C circuit breaker is exposed to 12A.
How long will it take to operate?

c. A 160A type D circuit breaker is exposed to 960A.
How long will it take to operate?



Topic 3.6 Residual Current Devices

Introduction

Residual Current Devices (RCDs), commonly called ‘safety switches’, are protective devices that isolate supply to a circuit if an earth fault causes a fault current above a predetermined value (Clause 1.4.80 of **Ref R-3-C**). 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 **Ref R-3-C** requires RCD’s to be installed for the protection of persons and livestock. They provide protection against indirect contact but cannot be the sole means of protection against direct contact.

Accidents that result in electrocution come suddenly and unexpectedly. They can be caused by a number of factors:

- faults in tools, appliances, leads or any electrical equipment
- damp conditions
- improper use of electrical equipment

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

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 level of protection, however, does not offer protection from direct or indirect contact with live parts in the event of insulation breakdown, damage to the barriers or enclosures, or deterioration of these materials due to ageing.

To give protection against indirect contact with live parts, earthing systems were introduced. 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 failing RCDs are used as additional protection to the earthing system.

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. These devices have also been known as ‘core balance units’ or ‘current-operated earth-leakage circuit breakers’. More recently, through electrical-safety promotion programs particularly aimed at the domestic consumer, they have been referred to as ‘safety switches’. Use of these is mandatory in all new domestic installations.

Irrespective of the terms used to describe this type of protection, the purpose is the same: to rapidly cut off the power to a circuit when measured conditions in the circuit indicate that a current, at a level likely to cause physical harm, is leaking to earth. RCDs can also provide protection against leakage currents likely to cause damage or start a fire.

Early electrical systems only provided limited protection against electric shock, as little was known about the causes of death from electrocution and the factors involved. Research into the physiological effects of electricity has been parallel with the development of electrotechnology (and medical science) since the late 18th century.

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. Since that time, research shows that specific factors relate to electric shock:

- human body impedance
- harmful effects of increasing current levels
- duration of current flow

Much of this research has been carried out by the International Electrotechnical Commission (IEC) and is documented in *EC Report 479: Effects of Current Passing Through the Human Body*. This information was essential to the development of effective techniques of protection against electric shock.

The 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 upset the normal heart function, causing it to fibrillate. Ventricular fibrillation is the disruption of the normally coordinated rhythmic contraction and relaxation activity of the heart muscles, so that pumping action becomes ineffective, and the circulation of blood ceases.

Under these conditions, permanent brain damage occurs within a few minutes, followed by death within several minutes. 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.

Figure F-3-6-1 shows the time-current effects on the human. These are accepted as the international standard for the development of techniques of protection against electric shock. The curves show 4 zones (1 to 4) with zone 4 further subdivided into sub-zones a, b and c. The curves represent the various time-current effects on the human body as follows:

- 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%):
- A further increase in current and time is likely to cause a complete stoppage of heart activity (cardiac arrest) and breathing; burning might also occur. If the duration of current flow is below 200 millisecond, ventricular fibrillation is likely only within what is known as the ‘vulnerable period’ of heart activity, if the relevant threshold current is exceeded.

This information on current effects on the human body has served as the basis for determining the operating characteristic for effective RCDs.

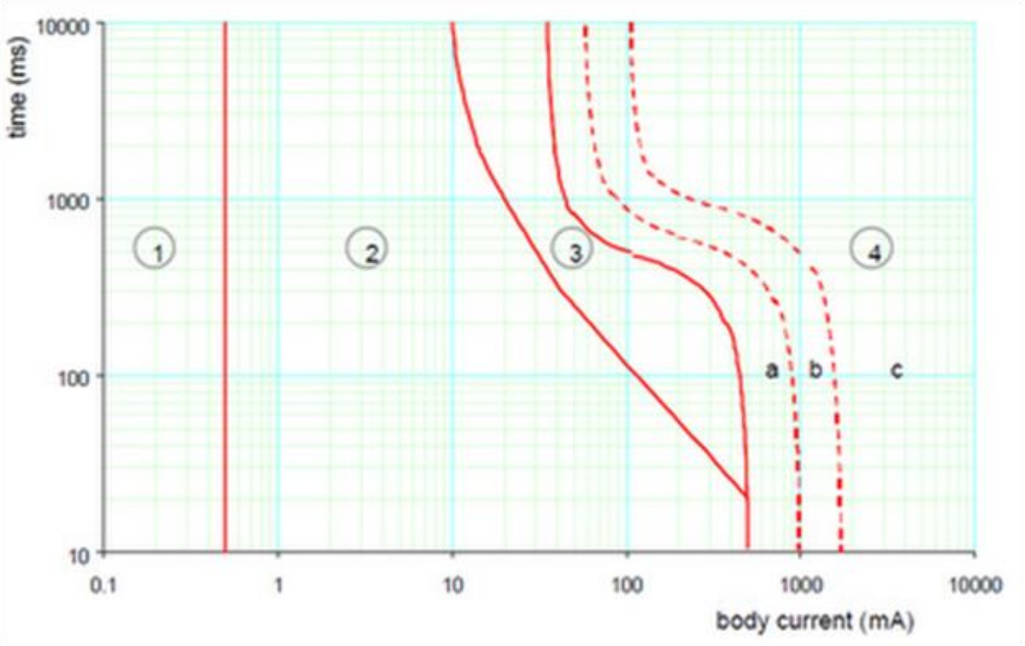


Figure F-3-6-1 Time-current zone effects on humans

As an illustration, a Type II RCD (30 mA) must operate as required by AS 3190:*Approval of Test Specifications- Residual Current Devices* and will trip the circuit that it is protecting well below the threshold of the probability of ventricular fibrillation (that is no greater than zone 3).

Note: The information in this chapter 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. Each Standard meets the compliance requirements of the Wiring Rules (**Ref R-3-C**).

Operating Principle

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. F-3-6-2** shows.

In the case of a single-phase circuit, the current that flows in the active conductor is normally equal to and opposite to the current flowing in the neutral conductor. Magnetic fluxes, related to currents in each conductor, are established in the toroidal core. Under normal conditions, the phasor sum of these currents is zero; the fluxes cancel each other, and so the resultant flux in the core is zero as **Fig. F-3-6-3** shows.

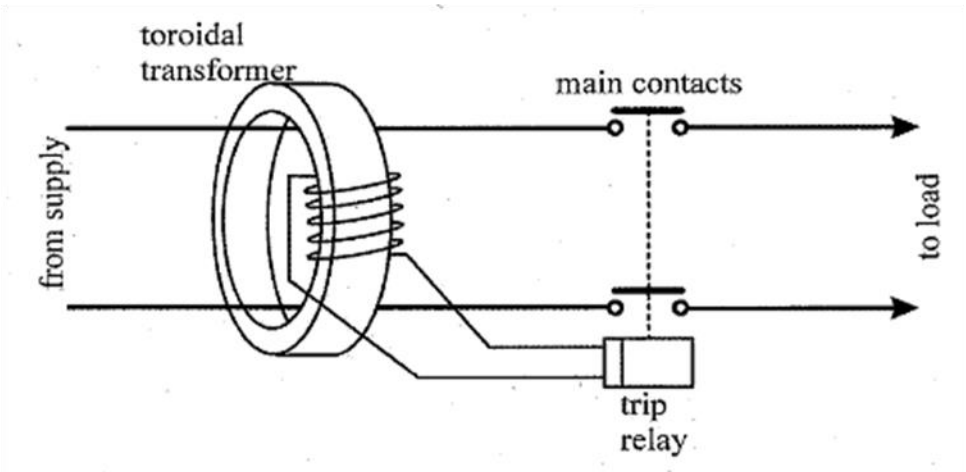


Figure F-3-6-2 Operating principle of an RCD

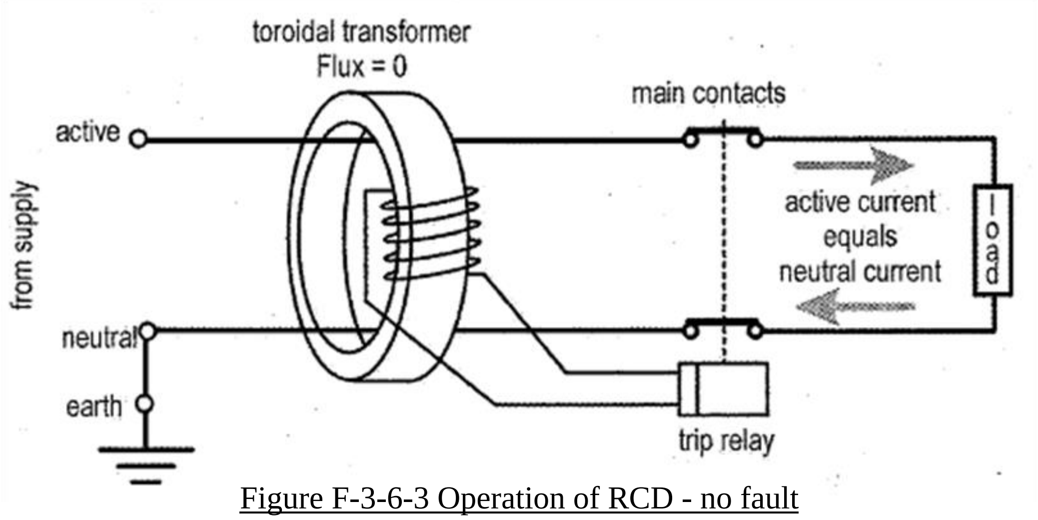


Figure F-3-6-3 Operation of RCD - no fault

Tracing out the path of the earth fault current in **Figure F-3-6-4**, it can be seen that there is a second current path from the active to the source, which bypasses the toroidal core. 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.

Under these conditions, the phasor sum of the currents in the active and neutral conductors passing through the toroidal core will be equal to the earth fault current. A net resultant magnetic flux is established in the toroidal core by this fault current (that is a residual current).

Due to transformer action, 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 is normally zero. This is the case even when some phases are loaded more than others are, because the neutral conductor carries the out-of-balance current.

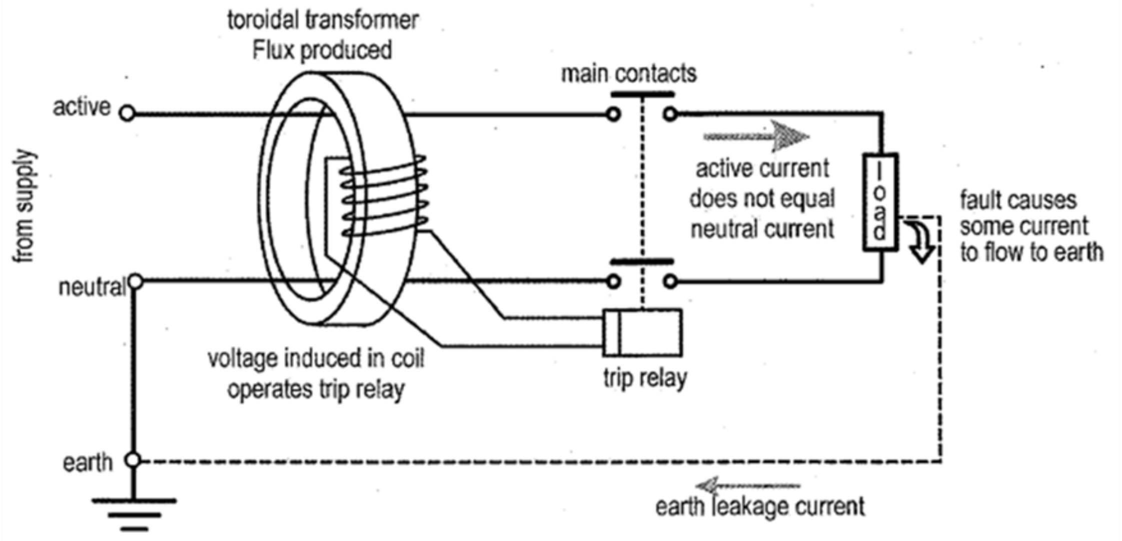


Figure F-6-6-4 Operation of RCD - earth fault

If all the conductors supplying a load are passed through a toroidal core transformer, any earth fault current will be detected by the sensing winding. Therefore the same operating principle applies as described for single-phase AC circuits.

It is obvious from Figs. **F-3-6-3** and **F-3-6-4** that, to detect earth fault current, all the live conductors supplying a circuit (actives and neutral) must pass through the device, from supply to load, in the same direction. The term ‘residual’, meaning ‘left over’, refers to the current left over as a result of the phasor sum of the currents in all the conductors passing through the toroidal core. The terms ‘earth fault current’, ‘earth leakage current’ and ‘residual current’ are interchangeable.

The basic operating principle applies to all RCDs, and all use a toroidal current transformer to sense residual current. However, in practice there are variations in the other operating mechanisms, and these variations are mainly related to reliability and manufacturing cost.

All RCDs must be provided with an accessible testing facility. This allows the user to test periodically the tripping operation of the device by pressing a test button located on the RCD. When the button is pressed, an artificial earth fault is created such that all of the components of the device are tested.

The three main types of operating mechanism are:

- Magnetically held trip relay
- Electronic relay
- Magnetically held relay with electronic time delay

Magnetically Held Trip Relay

The trip relay includes a permanent magnet, which 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. No connection between the trip circuit and the supply is required.

There are two types of trip relays that use this same principle. One type is a polarized-type relay that only responds to the positive half-cycle of a fault current. The other is 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.

Electronic Relay

The small output signal of the toroidal transformer is used to trigger a silicon-controlled rectifier (SCR) or is amplified to operate a relay or shunt trip circuit to trip the main contacts. These types derive their operating energy from the mains supply.

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

The Australian Standard *Approval and Test Specifications—Residual Current Devices* (AS 3190) classifies four types of RCDs or residual current relays. The Standard also covers portable RCDs.

Under this Standard, a 'residual current device' is defined as containing a toroidal transformer for detecting residual current, a circuit-tripping mechanism and test facilities constructed in one unit.

On the other hand, a 'residual current relay' contains a toroidal transformer, test facilities and circuitry necessary to provide an output. The output can be connected to operate an external contactor or shunt-trip circuit breaker. Generally, throughout this text, the term 'RCD' will include both of these devices, unless otherwise stated.

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.

As well as having a tripping sensitivity rating, an RCD has a maximum load-current rating. So, when selecting an RCD for a particular application, both the trip sensitivity rating and maximum load-current rating need to be specified (e.g. 30 mA/20 A). AS 3190 classifies RCDs by their sensitivity rating as follows:

- Type I: residual current rating not exceeding 10mA
- Type II: residual current rating exceeding 10mA but not exceeding 30 mA
- Type III: residual current rating exceeding 30mA but not exceeding 300mA without selective tripping-time delay
- Type IV: residual current rating exceeding 30mA but not exceeding 300mA with selective tripping-time delay.

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. This can interfere with the effective operation of the RCD. As a consequence 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

Applications

Type I RCD is specified for use in patient treatment areas by AS/NZS 3003: *Electrical Installations—Patient Treatment Areas of Hospitals and Medical and Dental Practices*. This type is also suitable for use in research and educational laboratories. In hospital use, the RCD must trip on a leakage current of no more than 10mA in a time of not more than 40 milliseconds. Because medical equipment might also contain rectifying components, the Type I RCD must also respond to DC pulses. The device must not trip on leakage currents less than 5mA.

Medical treatment quite often requires the patient to be connected to electro-medical equipment, and some procedures might involve the insertion of electrodes into the body. Under these conditions, body resistance is lowered and the probability of fibrillation is greatly increased. The maximum trip time for Type I devices is derived from the duration of the vulnerable period of heart activity.

Type II RCD is required to operate within 300 milliseconds (250 milliseconds for residual current relays) at 30mA-leakage current and within 40 milliseconds at 150mA-leakage current. This operating characteristic is well below the probability of ventricular fibrillation, and therefore this type of RCD will protect against direct contact with live parts. The device must not trip at leakage currents below 15 mA. In practice, a typical design point would be 22.5mA to trip in less than 40 milliseconds.

Ref R-3-C 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

Ref R-3-C Clause 2.6.3.2 requires RCD protection of socket-outlets with ratings up to 20A in installations other than residential. Lighting and directly connected hand held equipment also require RCD protection.

Types I and II are available in an RCD/circuit breaker combination providing circuit protection and residual current protection in one unit.

RCDs incorporated in a standard combination outlet assembly provide a convenient and economical method of installing residual current protection, however, these devices are not suitable for residential installations where the RCD protection must be at a switchboard (see Note 2 to Clause 2.6.3.1 of **Ref R-3-C**).

Type III RCDs are manufactured with residual current ratings of 100mA and 300mA, with a maximum tripping time of 300 milliseconds (250 milliseconds for residual current relays) at the rated tripping current. Although the maximum operating characteristics show the 100mA device to be below the fibrillation zone, a 300mA device would be in the zone of probability of fibrillation. Therefore, 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.

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. Fault current is independent of the RCD and is the result of the voltage and the fault-path resistance:

Type IV RCDs (also known as **S-type** because they have selective tripping-time delay). These are RCDs with a residual current rating greater than 30 milliamps but not exceeding 300 milliamps with selective tripping between 50 and 150 milliseconds. These are 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. Type IV may not be suitable for personal protection.

Portable RCDs 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. For example, a supply flexible cord with 1.0 mm^2 conductors and protected by a portable RCD with a load current not exceeding 10A is limited to a length of 25 meters. The Standard stipulates maximum lengths for supply flexible cords with conductors up to 4.0 mm^2.

Australian Standard 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. 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 unwanted or nuisance tripping include:

- Standing leakage currents
- Electrical disturbances
- Installation practices and faults

RCD and Testing

Before installing an RCD on an existing circuit it is essential to locate and rectify any source of unacceptable leakage current. The procedure when testing for leakage current in a circuit is:

- Supply is turned off
- The main earth and main neutral from the neutral link is disconnected Appliances can remain connected or disconnected and tested separately.
- An insulation resistance tester set to 500V DC is used to test between the load side of the main switch and the main earth and between the neutral link and main earth.

If a low reading is obtained, the circuits not intended for RCD protection are isolated and the circuit is tested again. A reading of 1MΩ means there is a leakage current of 0.24mA for a voltage of 240V to earth.

The above method of testing requires the installation to be isolated from the supply, which can be disruptive normal running of the establishment. A more convenient method of testing for leakage currents is by using a clamp-on ammeter. The ammeter is clamped around the active and neutral conductors of a circuit and the reading will indicate the phasor sum of the currents in these conductors. The ammeter indicates the leakage current as seen by the RCD. Any standing leakage current not eliminated from a circuit to be earth fault protected, increases the apparent sensitivity of the RCD. For example, a circuit having a standing leakage current of 10 mA, will cause a 30mA trip RCD to operate on a fault current of 15mA.

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. Domestic installations require the residual current protection device to be installed on the main switchboard (**Ref R-3-C** clause 2.6,2.4). 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.

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

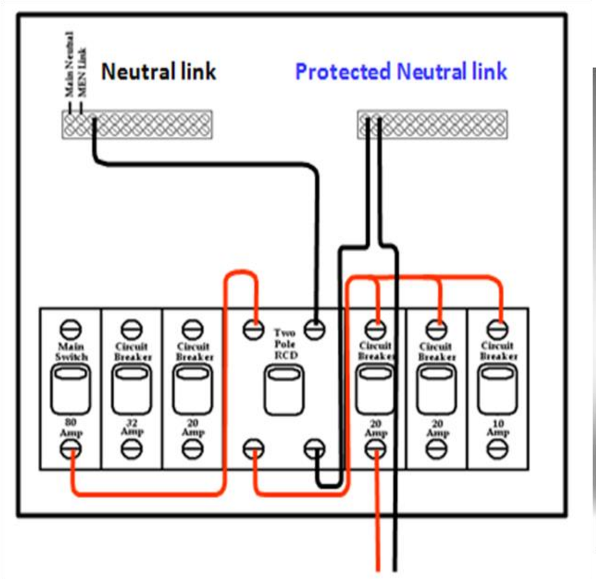


Figure F-3-6-6 Connecting a 2-pole RCD

Figure F-3-6-7 RCD Power


Output Used to supply Trip Coil on a Circuit breaker

Figure F-3-6-8 Toroidal RCD

Tutorial 3.6

NOTE: Where applicable quote the appropriate Clause No. from the relevant Standard

TQ.3.54 In a domestic installation, nominate which circuits require RCD protection.

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q3, P113]*

TQ.3.55 What is the maximum rated residual current of an RCD protecting socket outlets and lighting circuits in a domestic installation?

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q5, P113]*

TQ.3.56 Using a voltmeter with an internal resistance of 1000 Ω/volt set to the 250VAC range, calculate the current that would flow if connected between active and earth on a 230V circuit.

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q8, P114]*

TQ.3.57 Using a voltmeter with an internal resistance of 10 MΩ/volt, calculate the current that would flow if connected between active and earth on a 230V circuit.

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q9, P115]*

TQ.3.58 From the results of the calculations of TQ.3.56 and TQ.3.57, above, which test instrument would be more suitable for testing the operation of a RCD?

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q10, P115]*

TQ.3.59 What don't RCDs provide protection against?

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q13, P115]*

TQ.3.60 Where are RCD's with a sensitivity of 10mA used?

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q14, P115]*

TQ.3.61 How is the load current rating of an RCD determined?

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q15, P115]*

TQ.3.62 Do earthing conductors pass through an RCD? Explain

*[Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q16, P116]*

TQ.3.63 [What is a type S RCD used for?

*Source: Ref **R-3-A** Part 1, Section 6- Review Questions Q18, P116]*

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 Ref. **R-3-C** , 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 VAC or 1500 VDC.
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/Distortion to Supply

Clause 1.10.2 of **R-3-F**, 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** – 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.
- **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 **Ref R-3-C** 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. An example of this might be process machinery that is attended by operators e.g. punches presses, conveyor belts etc.

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.

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

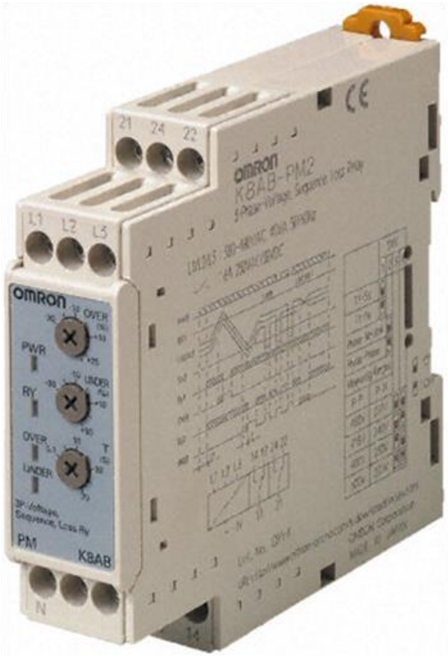


Fig. F-3-7-1 Undervoltage relay

Overvoltage

Clause 2.1.2 of **Ref R-3-C** 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 in an electrical installation include the following:

- An insulation fault between the electrical installation and a circuit of higher voltage.
- Switching operations.
- Lightning.
- Resonant phenomena.

Clause 2.7.3 of **Ref R-3-C** 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

Sudden increases (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.

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

These high voltages are variously known as:

- voltage surges
- overvoltage
- voltage transients
- voltage spikes.
- Switching of electrical equipment inside the installation such as lights and motors can also cause voltage surges.

If adequate protection is not installed, voltage surges may damage sensitive electronic equipment such as computers, televisions and videos. Appendix F of **Ref R-3-C** supplies guidelines for the installation of Surge Protective Devices (SPD's)

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 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. However, the resistance drops to only 2.3 Ω at 700 volts peak (See Fig. F-3-7-2(a)).

Fine protection is provided by socket outlet type surge diverters that limit peak voltages to approximately 800V (See Fig. F-3-7-2(b)).

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

Tutorial 3.7

NOTE: Where applicable quote the appropriate Clause No. from the relevant Standard

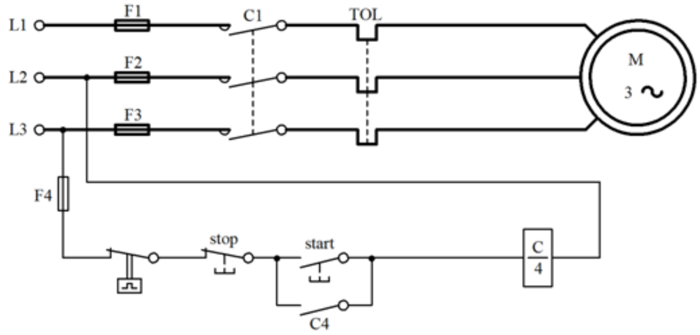
TQ.3.64 For each of the items of equipment listed in the table below, identify if they would be suitable or unsuitable for automatic re-closure of the supply.

*[Source: Ref **R-3-A** Part 1, Section 7-Example 5, P120]*

Equipment	**Automatic Re-closure**	
	Suitable	**Unsuitable**
Lathe in a fabricating shop		
Conveyor in a mail handling center		
Air conditioning system		
Refrigeration plant for a cool room		
Power hacksaw		
Sump pump		
Fire hydrant booster pump		
Lifts in a multi-storey building		

TQ.3.65 Explain how the DOL starter shown below prevents automatic re-closure of the supply to the motor, following a loss of supply.

*[Source: Ref **R-3-A** Part 1, Section 7-Example 6, P121]*



TQ.3.66 What conditions could warrant the installation of SPD's?

*[Source: Ref **R-3-A** Part 1, Section 7- Review Questions Q1, P124]*

TQ.3.67 What is the best primary location for the installation of SPD's

*[Source: Ref **R-3-A** Part 1, Section 7- Review Questions Q2, P124]*

TQ.3.68 How should SPD's be installed?

*[Source: Ref **R-3-A** Part 1, Section 7- Review Questions Q3, P124]*

References for Chapter 3

R-3-A TAFE Manufacturing and Engineering Division 2011, *Resource Manual - Electrical Installation Practice 2*, TAFE Electrical Trades Section, Mt Druitt.

R-3-B Pethebridge, K & Neeson, I 2009, *Electrical wiring practice. Volume 1*, 7th edn, McGraw Hill, North Ryde, NSW.

R-3-C Standards Australia 2007, *AS/NZS 3000:2007 Electrical installations,* Standards Australia, Sydney

R-3-D TAFE Training & Education Support Industry Skills Unit 2009, *UEENEEGOO7B - Select and arrange equipment for general electrical installations*, Industry Skills Unit, Meadowbank.

R-3-E NSW Department Of Primary Industries 2006 *Electrical Protection and Earthing,* viewed 27 Nov 2012, http://www.resources.nsw.gov.au/__data/assets/pdf_file/0016/101743/EES005-Electrical-Protection-and-Earthing-Guideline.pdf

R-3-F NSW Trade and Investment 2011, *Service and Installation Rules of New South Wales*, Dept. of Energy, Utilities and Sustainability, Sydney.

R-3-G Standards Australia 2009, *AS/NZS 3008.1.2:2010 - Electrical installations - Selection of cables*, Standards Australia, Sydney.