NAT10809004

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1.1Safety principles

Introduction

In order to reduce the risks of electrical accidents, the Australian/New Zealand Wiring Rules (AS/NZS 3000:2018) specifies fundamental safety principles to which all electrical installations must adhere. These safety principles provide an overview of the minimum protective measures necessary to protect the public from risks such as electric shock and electrical fires.

Fundamental Safety Principles

Part 1 (Section 1) of the Wiring Rules specifies the fundamental safety principles necessary to ensure the safety of persons, livestock and property against dangers and damage that may arise whilst the installation is being used.

AS/NZS 3000:2018 specifies three main risks posed by electrical installations:

- Shock current
- Excessive temperatures
- Explosive atmospheres

In order to protect against these risks, Part 1 specifies safety principles relating to the following three aspects of an electrical installation:

- Design
- Installation
- Verification

In order to understand the intention and application of the safety principles laid out in AS/NZS 3000:2018, it is important to first become familiar with several terms and definitions.

Safety Principles – Terms and Definitions		
Term	**Definition**	**Example**
Direct Contact	Contact with a conductor that is live under normal operating conditions.	Receiving an electric shock from touching an energised busbar in a switchboard.
Indirect Contact	Contact with a conductor that is not normally live but has become live due to a fault.	Receiving an electric shock from touching the metal frame of a faulty stove.
Basic Protection	Protection against direct contact.	Insulation on cables and busbars is one method of preventing direct contact.
Fault Protection	Protection against indirect contact.	Typically provided by using circuit breakers and connecting exposed metal parts to an earthing system.

Touch Voltage	Any voltage appearing between simultaneously accessible parts.	The voltage between the frame of a faulty stove and the ground (earth).
Touch Current	The current that flows through a person or animal when direct or indirect contact occurs.	The current that flows through a person when they touch the energised metal frame of a faulty stove.

Electrical Current Definitions

The following table explains the terms used to describe undesired current conditions throughout AS/NZS 3000:2018.

Electrical Current – Terms and Definitions		
Term	**Definition**	**Example**
Overcurrent	Any current exceeding the rated value.	Overload currents, fault currents and short-circuit currents are all different types of overcurrent.
Overload Current	An overcurrent occurring in a circuit that is electrically sound.	An excessive current that is drawn when a motor is used to drive a mechanical load that is beyond its design capability.
Fault Current	A current resulting from an insulation failure or from the bridging of insulation.	Current that flows when unintended contact occurs between any two conductors, e.g. active and earth.
Short-Circuit Current	A fault current resulting from a fault of negligible impedance between live conductors.	Current that flows when unintended contact occurs between phases, or between phase and neutral conductors.

1.2 Methods of Compliance

Protection Against Shock Current

To protect against shock current, AS/NZS 3000:2018 states that electrical installations must be provided with the following:

- Control and isolation devices
- Basic protection
- Fault protection

These protection methods are described in the following table:

Protection Against Shock Current

Type	Function	Permissible Methods
Control and Isolation Devices	To prevent or remove hazards and allow maintenance of electrical equipment.	Control and isolation devices consist of: • Isolation devices. • Emergency switching devices (e.g. an emergency stop button). • Shut-down devices. • Functional switches (e.g. a light switch).
Basic Protection	Protects against contact with live parts under normal operating conditions.	Basic protection may be provided by: • Insulating live parts. • Placing live parts behind barriers or in enclosures. • Using obstacles to prevent contact with live parts. • Placing live parts out of reach. Residual current devices (RCDs) may be used as an *additional* method of providing basic protection.
Fault Protection	Protects against contact with live parts under fault conditions.	Fault protection may be provided by: • Automatic disconnection of supply (ADS). • Use of class II equipment. • Electrical separation. • Limiting the possible fault current to a safe value. ADS is the most common method of fault protection.

Protection Against Excessive Temperatures

Whenever current flows in a conductor, heat is produced. To protect against excessive temperatures that could result in an electrical fire, electrical installations must be provided with:

- Protection against thermal effects under normal operating conditions.
- Overcurrent protection.
- Protection against earth fault currents.
- Protection against unwanted voltages.
- Protection against the spread of fire.

Protection Against Excessive Temperatures	
Type of Protection	**Permissible Methods**
Protection Against Thermal Effects Under Normal Operating Conditions	Protection against thermal effects under normal operating conditions is provided by both of the following: • Selecting and installing suitably rated equipment. • Ensuring adequate ventilation where required.
Overcurrent Protection	Overcurrent protection may be provided by either of the following: • Automatic disconnection of supply (ADS). • Limiting the overcurrent to a safe value. ADS is the most common method of overcurrent protection.
Protection Against Earth Fault Currents	Protection against earth fault currents is achieved by providing both of the following: • An earthing system. • Devices for automatic disconnection of supply (ADS).
Protection Against Unwanted Voltages	Protection against unwanted voltages may be provided by either of the following: • Segregation. • Overvoltage protective devices.
Protection Against the Spread of Fire	Protection against the spread of fire is achieved by both of

	the following: • Correct selection and installation of equipment. • Maintenance of fire barriers.

Explosive Atmospheres

Due to the nature of some electrical installations, additional risks posed by explosive atmospheres may exist. Petrol stations, mines and industrial plants, for example, typically contain areas in which explosive gases or dusts are, or may become, present. These areas are classed as "Hazardous Areas (HA)".

Electrical equipment installed in hazardous areas poses a significant ignition risk due to sparks or arcs that may occur. For this reason, the Wiring Rules states that only specialised equipment may be installed in hazardous areas, and that these installations must comply with the AS/NZS 60079 series of Australian Standards.

Other Protection Requirements

In addition to the protection requirements above, all electrical installations must:

- Provide protection against injury from mechanical movement, by providing isolation devices.
- Be protected against external influences.

1.3 Installation Design and Equipment

Installation Design and Equipment Selection

Part 1 of AS/NZS 3000:2018 states that electrical installations must be designed to ensure that minimum levels of safety and performance are achieved, as shown in the following table.

Installation Design and Equipment Selection	
Design Requirements	**Details**
Persons, livestock and property are adequately protected.	All necessary protective measures are implemented to ensure protection against: • Shock current. • Excessive temperatures. • Explosive atmospheres.
The installation functions as intended.	The 'maximum demand' of an installation is determined, and equipment designed and installed to meet that maximum demand. Electrical installations are arranged to ensure

	that the voltage at the terminals of connected appliances and equipment is suitable for the appliances and equipment.
The installation is compatible with the supply.	The installation must be compatible with the following supply characteristics: • a.c. or d.c. current type • Number of conductors / phases • Voltage • Frequency • Maximum available supply current • Prospective short-circuit current • Earthing system • Limits on the use of equipment • Harmonics
Inconvenience caused by faults is minimised.	The installation is divided into separate circuits, and each circuit is provided with protection equipment, such that the effect of a fault in one part of the installation (e.g. a circuit) will not have a negative impact on other parts.
The installation can be safely operated, inspected, tested and maintained.	The installation is divided into separate circuits, and each circuit is provided with control equipment, such that the different parts of the installation can be controlled and isolated independently.

1.1 Electrical Installation Circuits

Introduction

The purpose of an electrical installation is to supply electricity to various items of equipment. To achieve this, electrical equipment is connected to the supply with circuits, each of which must be provided with adequate protection and controls. In this topic, you will learn about the factors that need to be considered when arranging an electrical installation into circuits.

Electrical Installation Circuits

AS/NZS 3000:2018 states that electrical installations shall be divided into circuits to:

- Avoid danger and minimize inconvenience in the event of a fault.
- Allow for safe operation, inspection, testing and maintenance.

Circuit Arrangements

It is the role of the electrical installation designer to determine the number and type of circuits needed for a given installation. Factors that should be considered when dividing installations into circuits include:

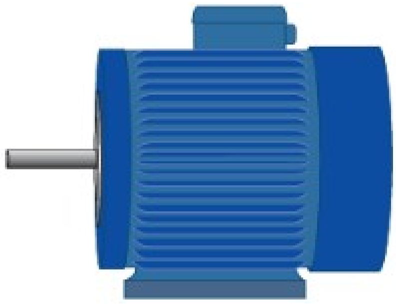
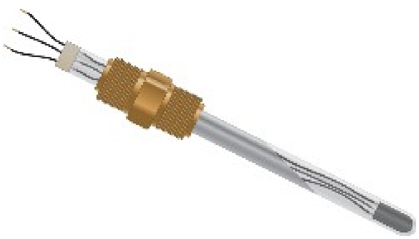
- The relationships between the items of electrical equipment to be connected.
- The loads, operating characteristics and ratings of the equipment to be connected.
- Limiting the consequences of a fault or overload in a section of the installation.
- The ability to perform maintenance, alterations and additions with minimal interruption to other parts of the installation.

AS/NZS 3000:2018 Appendix C provides guidance on how to arrange circuits in electrical installations.

Types of Circuits

The following table shows the circuit groupings typically used in electrical installations.

Circuit Groups		
Group	**Example**	**About**
Lighting		Primarily used to supply luminaires, but may also have the following equipment connected: • Small exhaust fans. • Ceiling fans. • Smoke detectors. A single lighting circuit generally supplies several luminaires of a similar type, ratings and purpose.
Socket Outlets		Used to supply portable appliances through provision for the connection of a plug. Several 10 A socket-outlets can be supplied from a single circuit. Socket outlets with higher ratings (e.g. 15 A, 20 A, 25 A, 32 A) are generally supplied individually.

Heating and/or Air-Conditioning Appliances		Used to supply electrical appliances such as: • Fixed cooking appliances (stoves, ovens and cooktops). • Heating, ventilation and air-conditioning (HVAC) systems. Each appliance is typically supplied on its own circuit.
Motors		Used to supply motor-driven plant, such as: • Hoists • Conveyor systems Each item of motor-driven plant is typically supplied on its own circuit.
Auxiliary Services		Used to supply instrumentation, control and indication equipment such as: • Sensing devices (pictured) • Metering equipment • Indicator lamps
Safety Services		Used to supply safety services, including: • Fire detection, smoke control, extinguishing and warning systems • Evacuation systems (emergency lighting and exit signs) • Lift systems • Emergency power supplies Circuits supplying safety

		services must be supplied separately from the other circuits in the installation.

2.2 Electrical Circuit Design

Load Requirements

The load requirements in electrical installations vary over the course of each day, and will be different at different times of the year, for example:

- In a domestic home, the load is increased in the morning when residents are making breakfast, and in the evening when they are making dinner.
- Load requirements are generally at their lowest during the hours after midnight, as most people are asleep and therefore the majority of lighting and appliances are not in use.
- The load requirements of heating circuits increase during the winter months, and the load requirements of air-conditioning circuits increase during the summer months.
- Load requirements can increase at certain festive times of the year such as Christmas.

Electrical Circuit Design

The methods for determining the number and types of circuits suitable for an installation are shown in the following table.

Electrical Circuit Design	
Design Factor	**Requirements**
Maximum Demand	The 'maximum demand' is the amount of current that is needed to supply a given circuit. The Wiring Rules states that maximum demand may be determined by calculation, assessment, measurement or limitation. When designing electrical installations: • The maximum demand of mains and submains is typically determined by calculation. • The maximum demand of final subcircuits is determined by either assessment or limitation. Assessment is used for final subcircuits supplying a single item of equipment. The 'assessed' maximum demand is typically the full load current. However a lower value can be used for domestic cooking appliances in accordance with Table C5.

	In general, an item of equipment with a full load current of 20 A or more should be supplied on its own circuit. ‘Limitation’ is used for final subcircuits supplying multiple items of equipment. In this situation the maximum demand is equal to the nominal current rating of the protection device (i.e. it is limited by the device). For example, a socket outlets circuit protected by a 20 A circuit breaker has a maximum demand of 20 A. What needs to be determined in this case is how many items of equipment can be supplied by a circuit for a given protection device rating. Table C9 provides guidance on the appropriate loading of these circuits.
Voltage Drop Limitations	The ‘voltage drop’ of a circuit is the amount of voltage that drops across the length of the circuit conductors. The Wiring Rules specifies that the voltage drop at any point in an installation must not exceed 5 % of the nominal supply voltage. The voltage drop in a circuit is directly proportional to the route length and circuit current, and is inversely proportional to conductor size. In order to reduce excessive voltage drop: • Long circuits may need to be rearranged into several shorter circuits. • Cable sizes may need to be increased. Comprehensive methods of determining voltage drop are provided in AS/NZS 3008.1.1:2017, and a simplified method is given in AS/NZS 3000:2018 Appendix C.
Fault Loop Impedance Limitations	The ‘fault loop impedance’ of a circuit is the total impedance of the circuit conductors that make up the fault loop (i.e. active and protective earthing conductors). The Wiring Rules specifies maximum values of fault loop impedance for circuits, depending on their size and type of protection. In order to address excessive fault loop impedance:

	• Long circuits may need to be rearranged into several shorter circuits. • Cable sizes may need to be increased. Requirements for the limitation of fault loop impedance are provided in AS/NZS 3000:2018 Section 8 and Appendix B.
Characteristics of Equipment	The characteristics of equipment are evaluated so that equipment having widely varying requirements can be supplied on different circuits. Factors to evaluate include: • Voltage ratings. • Current ratings. • Required supply frequency. • Power ratings. • Intended use. For example, it would be impractical to supply a 10 kW, 400 V motor, from the same circuit as a 230 V light fitting, as the current and voltage requirements are completely different.

Circuit Drawings and Schedules

After the number and type of circuits for an installation have been finalised, circuit drawings and schedules are developed to indicate the operation and relationships between electrical circuits:

- Installation diagrams are used to indicate the locations of cable runs, particularly in the case of underground cables.
- Wiring diagrams are used to indicate the connection of circuit conductors.
- Schedules are used to indicate the number, type and protection of circuits in an electrical installation.

2.3 Special Circuit Arrangements

Isolated Supply (Separated Circuits)

An isolated supply can be used to provide fault protection to an individual circuit. The output side of the isolated supply is electrically separated from the input side by double insulation. The effect is that it is highly unlikely for a voltage to appear between the output terminals of the isolated supply and earth.

An isolated supply can be provided by:

- An isolating transformer.
- A generator (e.g. the output of a motor/generator set).
- An isolated inverter.

Requirements for separated circuits include the following:

- The nominal circuit voltage must not exceed 500 V.
- Live parts of the circuit must NOT be connected to any other circuit or to earth.
- Any exposed conductive parts or bonding conductors associated with the circuit must NOT be connected to any other circuit or to earth.
- Circuit wiring must be provided with mechanical protection.

Requirements for the arrangement of separated circuits are provided in Section 7 of AS/NZS 3000:2018.

Extra-Low Voltage (ELV) Circuits

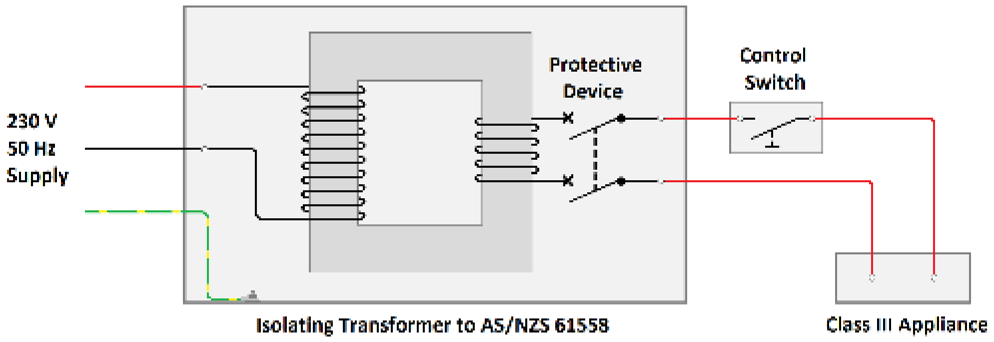
There are two commonly used ELV circuit arrangements that can be used to provide both basic and fault protection, these are:

- Separated Extra-Low Voltage (SELV).
- Protected Extra-Low Voltage (PELV).

The circuits are arranged so that it is not possible for the nominal voltage to exceed the touch voltage limits (specified in Part 1 of the Wiring Rules).

Separated Extra-Low Voltage (SELV)

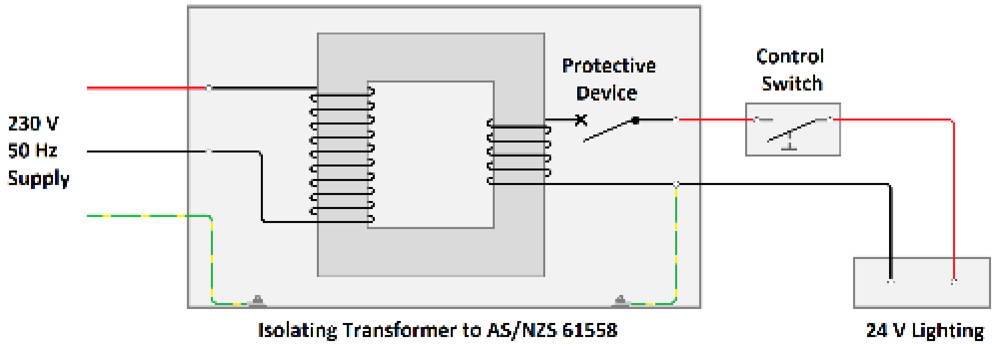
The following table explains the arrangement and requirements for SELV circuits used for basic and fault protection.

<table>
<tr><th colspan="3">Separated Extra-Low Voltage (SELV)</th></tr>
<tr><td colspan="3">
</td></tr>
<tr><th>Definition</th><th>Requirements</th><th>Typical Applications</th></tr>
<tr><td>An extra-low voltage system that is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock.</td><td>Nominal circuit voltage must not exceed:
• 50 V a.c.
• 120 V d.c.
Live parts must not be connected to any other circuit or to earth.
Any protective bonding conductor associated with the circuit must not be connected to earth.
Circuit protective equipment must operate in all unearthed conductors.
Must be electrically segregated from other circuits.</td><td>Examples of where SELV circuits are used include:
• ELV downlights
• Underwater pool lights
• Mobile phone chargers</td></tr>
</table>

Protected Extra-Low Voltage (PELV)

The following table explains the arrangement and requirements for PELV circuits used for basic and fault protection.

Protected Extra-Low Voltage (PELV)



Definition	Requirements	Typical Applications
An extra-low voltage system that is not electrically separated from earth, but that otherwise satisfies all the requirements for SELV.	Nominal circuit voltage must not exceed: • 50 V a.c. • 120 V d.c. Must be protected by the use of insulation or barriers, unless the circuit voltage does not exceed: • 25 V a.c. or 60 V d.c. in dry areas. • 6 V a.c. or 15 V d.c. in other areas. Circuit protective equipment must operate in all unearthed conductors. Must be electrically segregated from other circuits.	Examples of where PELV circuits are used include: • Lighting circuits • Control circuits • Electronic devices (e.g. a laptop power supply)

Requirements for the arrangement of SELV and PELV circuits are provided in Section 7 of AS/NZS 3000:2018.

3.1 Electric Current Effects on the Body

Introduction

Electric current poses a serious risk to the health and safety of people using and working around electrical installations. The current used to boil an electric jug for a cup of tea or coffee could easily kill if it passed through a human being. In addition, the heating effect of electric current has the potential to cause fires, sparking from electric equipment could potentially ignite explosive materials, and the moving parts of electrically actuated equipment can cause severe impact and crush injuries.

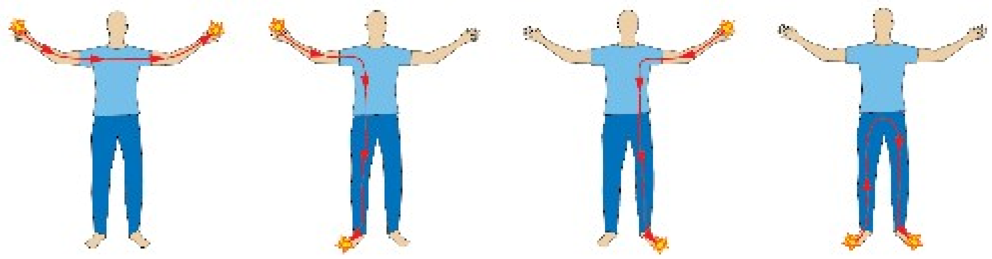
This topic will explore these risks and the protective measures and requirements necessary to control them. Understanding these risks and protection methods is essential to remaining safe and ensuring the safety of the public.

Physiological Effects of Current

The physiological effects of electric current on the human body depends on:

- The magnitude of the shock current.
- The duration of exposure.
- The path of the shock current through the body.
- Whether the shock current is alternating (a.c.) or direct (d.c.).

In general, the higher the shock current and the longer the duration of the shock, the more serious the injuries will be. An electric shock is also more likely to be fatal if the shock current passes through the heart or head.

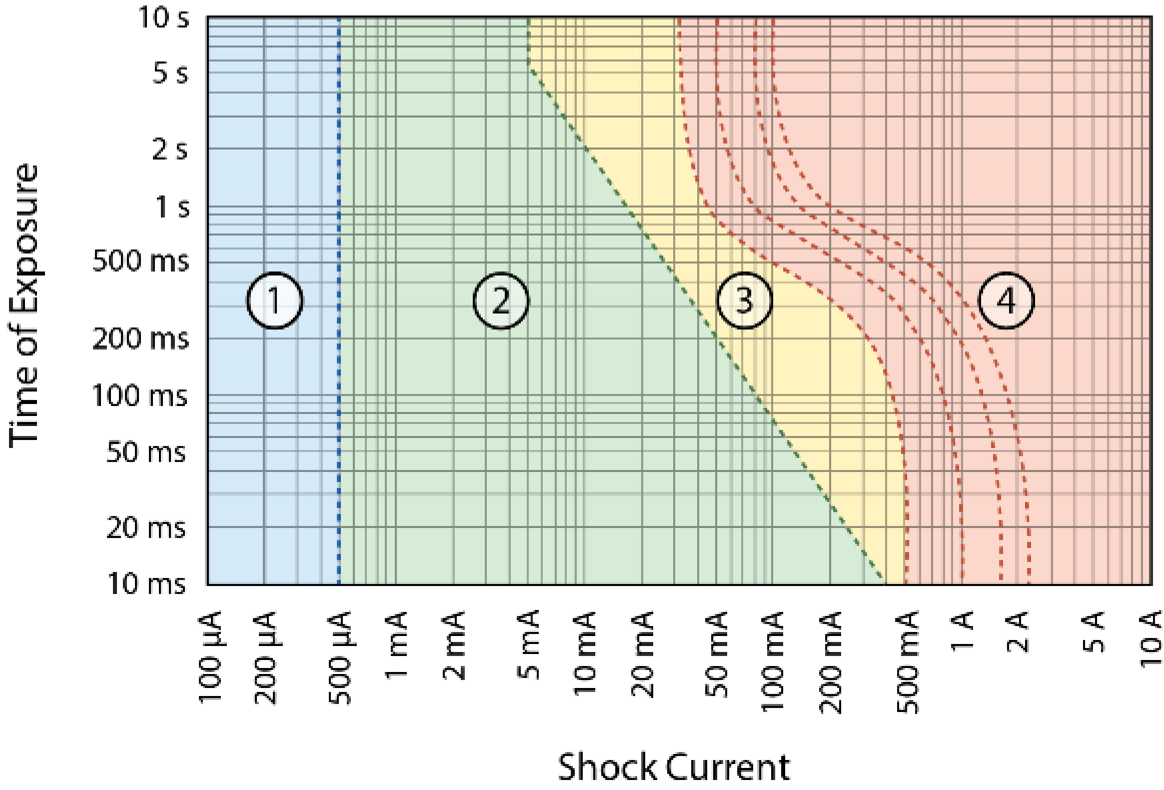


Examples of Shock Current Paths

Direct current (d.c.) has an increased effect of causing muscles in the body to tense resulting in the inability to let go, and the stopping of the heart due to continual contraction.

The magnitude of voltage indirectly affects the severity of an electric shock as the higher the voltage, the higher the current flow through a given impedance (such as the human body). High voltages also increase the risk of electric arcs and may cause explosive damage at points of contact. The effects of electric current will remain for as long as the shock current flows through the body.

A guide to the physiological effects of current is provided in the following chart.



Zone	Typical Physiological Effects
1 (blue)	• Usually below the level of perception. • No noticeable physiological effects on the body.
2 (green)	• May startle a person causing them to pull away. • Minor discomfort. • No serious physiological effects on the body.
3 (yellow)	• Muscular tensing and the inability to let go. • Increased discomfort to severe pain. • Difficulty breathing. • Disturbance to heart rhythms. • Burns.
4 (red)	• Cardiac arrest. • Asphyxiation. • Ventricular fibrillation. • Severe burns.

Electric Shock Injuries

The after effects of electric shock can include:

- Burns
- Difficulty breathing
- Metallic taste in the mouth
- Unconsciousness
- Cardiac arrest
- Death

Other injuries may also be caused depending on the scenario. For example if a shock is sustained whilst working from a ladder, then injuries may result due to falling from a height.

3.2 Ignition Risk

Heat is generated by current flow, and large amounts of heat may be dissipated as a result of electrical arcing. This can cause burns and is a severe fire hazard where flammable materials are present.

Thermal Effects in Normal Service

To protect against the thermal effects of current that will occur during the normal operation of the installation, the Wiring Rules specifies that electrical equipment must be suitably rated and installed to ensure adequate ventilation. Voltage and current ratings of equipment must be sufficient for the circuit parameters, as insufficient ratings will likely result in insulation failure, arcing, and melting or burning of equipment.

Care must also be taken when installing equipment to ensure that any heat produced by the equipment will be able to sufficiently dissipate without causing damage to the surrounding materials. Luminaires for example, can produce significant quantities of heat that could ignite flammable building materials that are in close proximity. For this reason, it is necessary to maintain minimum clearances between recessed luminaires and thermal insulation.

In some cases, equipment may need to be mounted in such a way that air can flow freely around the casing, and it may be necessary to 'de-rate' equipment that is installed in direct sunlight.

Thermal Effects Under Fault Conditions

Very large currents can flow in the event of a fault, and therefore very high temperatures can result if the fault is allowed to continue. To prevent damage in these circumstances, the usual method of protection is to provide a device that will automatically disconnect the supply in the event of a fault. Circuit breakers and fuses are examples of these devices.

Arc faults can occur due to short-circuits, buildup of dust or moisture between energised parts, or as the result of degraded or damaged insulation.

Spread of Fire

In the event that a fire does occur (due to any cause), AS/NZS 3000:2018 requires that the electrical installation must not:

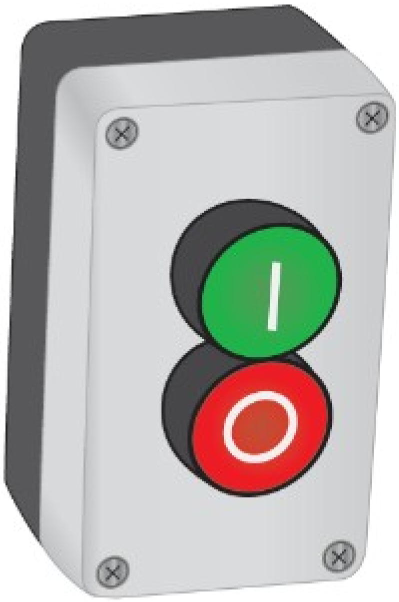
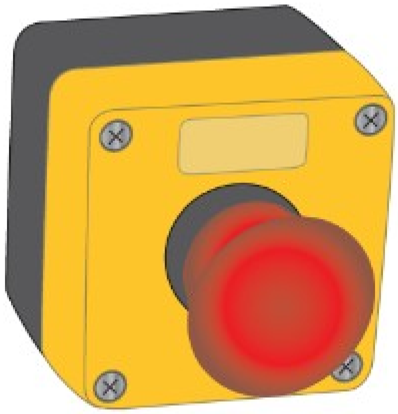
- Obstruct escape routes.
- Propagate fire.
- Attain a temperature high enough to ignite adjacent materials.
- Adversely affect means of egress from a structure.

3.3 Risk of Injury

Electrical equipment with moving mechanical parts poses the risk of physical injury from coming into contact with the moving parts. The mechanical forces acting on electrically actuated arms and rotors can easily be sufficient to cut, crush, puncture or dismember the human body.

Electrical Equipment Controls

To control the risks associated with electrically actuated equipment, various control equipment must be provided as necessary. Types of controls required are shown in the following table.

Electrical Equipment Controls		
Start/Stop Control Switches	**Emergency Stop Switches**	**Isolator**
		
"Functional" switches must be provided to allow electrical equipment to be started, stopped and otherwise controlled safely.	Emergency stopping devices must be positioned at every point where the risk of injury due to moving parts exists.	An isolator must be provided that completely disconnects the equipment from all supply conductors.

All switches controlling electrical equipment with moving mechanical parts must be arranged to prevent automatic restarting after stopping.

3.4 Protection Against Direct Contact

Basic Protection

Basic protection must be provided in an electrical installation to protect against coming into contact with parts of an installation that are live under normal operating conditions (direct contact).

Acceptable methods of providing basic protection are described in the following table.

Basic Protection

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Acceptable methods of providing basic protection are described in the following table.

Basic Protection	
Method	**Requirements**
Insulation	Where insulation is used as a method of basic protection, live parts must be covered with insulation that is suitably rated for the operating conditions of the circuit(s). Insulation should only be able to be removable by destruction.
Barriers or Enclosures	Barriers or enclosures providing basic protection must have a suitable IP rating, be fixed in position, and should generally have covers, lids or doors that are not removable without the use of a tool or key.
Obstacles	Basic protection by the use of obstacles or placing out of reach is only permitted in installations that are restricted to competent persons, or those under their supervision. Obstacles should prevent unintentional contact with live parts, and not be removable without the use of a tool or key.
Placing Out Of Reach	Placing out of reach means that accessible parts at different voltages are placed more than 2.5 m apart, and is intended to prevent unintentional

	contact.

SELV and PELV as Basic Protection

Basic protection may also be achieved by supplying circuits at SELV or PELV, as discussed on Content Page 2.3. The use of SELV or PELV acts to limit the possible touch voltage and shock current to safe values. In order to use SELV or PELV as a method of basic protection, the nominal circuit voltage must not exceed the following values.

For separated extra-low voltage (SELV):

- 25 V a.c. or 60 V d.c.

For protected extra-low voltage (PELV):

- 25 V a.c. or 60 V d.c. in dry areas.
- 6 V a.c. or 15 V d.c. in other areas.

Comprehensive requirements for the arrangement of SELV and PELV circuits are provided in Section 7 of AS/NZS 3000:2018.

4.1 Indirect Protection

Introduction

There are a number of reasons for faults arising in electrical installations. Insulation on equipment degrades over time, which can be accelerated by high temperatures and insufficient ventilation. Mechanical impact, friction and sustained overloads can cause immediate damage, resulting in hazardous fault conditions. The Wiring Rules requires that measures are put in place to protect against the hazards associated with electrical faults and overloads. This type of protection is referred to as 'Fault Protection', and intended to protect against electric shocks resulting from indirect contact.

Indirect Contact

"Indirect contact" means contact with conductive parts that are not live under normal operating conditions, but have become live due to a fault condition, for example the conductive frame of a refrigerator.

Fault Protection

In order to protect against electric shocks from indirect contact AS/NZS 3000:2018 requires an acceptable method of "Fault Protection" is provided in electrical installations. Fault protection may be achieved by using one of the following three methods:

- Automatic disconnection of supply (ADS).
- Use of class II equipment.
- Electrical separation.

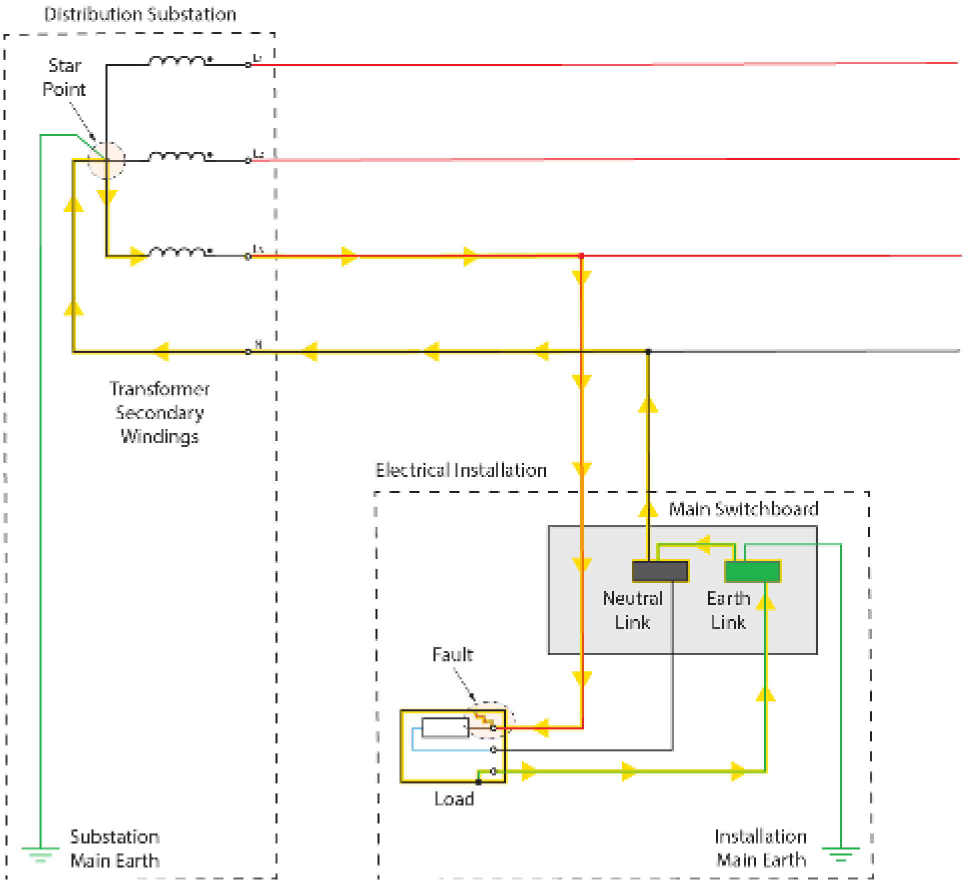
Fault Protection Concepts

In order to understand the principles of fault protection, it is important to understand the concepts of ‘touch voltage’, ‘touch current’ and the ‘earth fault loop’.

Fault Protection Concepts	
Term	**Definition**
Touch Voltage	Any voltage appearing between simultaneously accessible parts.
Touch Current	The current that flows through a person or animal when direct or indirect contact occurs.
Earth Fault Loop	The current path when a short circuit fault occurs between an energised circuit conductor and an exposed conductive part of electrical equipment (e.g. the frame).

Earth Fault Loop

The following diagram illustrates the earth fault loop in a distribution system.

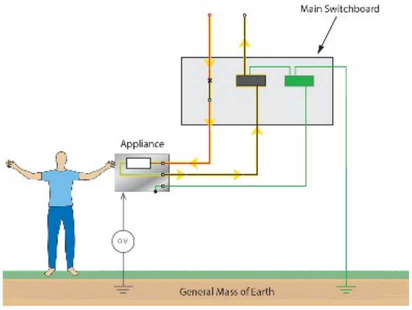
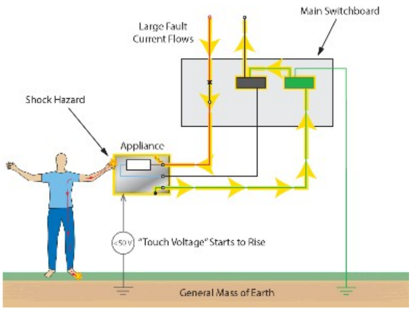


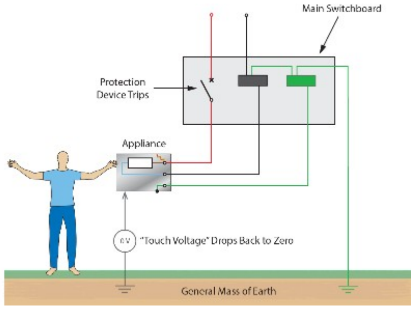
The earth fault loop consists of:

- The active conductor from the supply transformer to the point of supply.
- The active conductor of the consumer's mains.
- The submain active conductor (where applicable).
- The final sub-circuit active conductor.
- The active to earth fault path in the appliance.
- The final sub-circuit protective earthing conductor.
- The submain earthing conductor (where applicable).
- The MEN link.
- The neutral conductor of the consumer's mains.
- The neutral conductor from the point of supply to the supply transformer.

Fault Protection in an Electrical Installation

The following table illustrates the concepts of touch voltage, touch current and the earth fault loop in the context of an electrical installation under normal and fault conditions.

Fault Protection in an Electrical Installation		
State	**Illustration**	**Description**
Normal Circuit Operation		• The load current flows out through the active conductor, through the load and back through the neutral conductor. • The touch voltage is zero volts, and so there is no risk of receiving an electric shock through indirect contact.
Earth Fault Condition		• A large fault current flows out through the active conductor and back through the protective earthing conductor. • The current path illustrated is known as the earth fault loop. • A touch voltage appears between the frame of the appliance and the earth. • If a person contacts the exposed conductive parts of the appliance and the earth (indirect contact), then a touch current will flow through the person.

<table>
<tr>
<td>Automatic Disconnection of the Supply</td>
<td>
</td>
<td>

- Due to the very high fault current, the protection device operates quickly to disconnect the faulty circuit.
- Current stops flowing and the risk of receiving an electric shock through indirect contact is eliminated.

</td>
</tr>
</table>

4.2 Indirect Protection Methods

The acceptable methods of providing fault protection are described in the following table.

Fault Protection	
Method	**Requirements**
Automatic Disconnection of Supply (ADS)	The purpose of ADS is to limit the possibility of a touch voltage arising that is greater than 50 V a.c. or 120 V d.c. ADS is the most common method of fault protection, and requires the installation of two main components: • An earthing system. • A protection device. The earthing system provides a path of low impedance through which a fault current can flow. The protective device automatically disconnects the circuit when a fault current flows. Protective devices providing fault protection by ADS must operate in: • 0.4 s for circuits supplying socket outlets rated up to 63 A, hand held class I equipment or portable equipment. • 5 s for other circuits. The impedance of the earthing system must be very low to ensure that a very large current flows in the event of a fault. If the value of fault current is too low, the protection device may not disconnect the circuit in the required time, potentially resulting in hazardous levels of touch voltage.
Class II Equipment	Class II equipment is provided with either double or

	reinforced insulation, and is not earthed. This double/reinforced insulation is relied upon to prevent short-circuits arising between energised conductors and exposed conductive parts.
Electrical Separation	Electrical separation (isolated supply) can be used to provide fault protection to an individual circuit. The output side of the isolated supply is electrically separated from the input side by double insulation. The effect is that it is highly unlikely for a voltage to appear between the output terminals of the isolated supply and earth. Requirements for separated circuits include the following: • The nominal circuit voltage must not exceed 500 V. • Live parts of the circuit must **NOT** be connected to any other circuit or to earth. • Any exposed conductive parts or bonding conductors associated with the circuit must **NOT** be connected to any other circuit or to earth. • Circuit wiring must be provided with mechanical protection. Electrical separation is usually achieved by the use of an isolation transformer, but may also be achieved by using a generator or isolated invertor.

SELV and PELV as Fault Protection

Fault protection may also be achieved by supplying circuits at SELV or PELV, as discussed on Content Page 2.3. The use of SELV or PELV acts to limit the possible touch voltage and touch current to safe values. Comprehensive requirements for the arrangement of SELV and PELV circuits are provided in Section 7 of AS/NZS 3000:2018.

RCD Protection

Residual Current Devices (RCDs) are used as a method of providing additional protection against electric shock in certain circumstances where the risk of contact with energised parts is increased.

The following table explains where additional protection by the use of a 30 mA RCD is required.

Additional Protection Requirements*	
Residential Installations	30 mA RCD protection required on all final subcircuits.
Other Installations	30 mA RCD protection required on all final subcircuits rated up to and including 32 A, supplying:

	• Socket outlets. • Lighting. • Hand-held equipment. • Any other equipment that may pose an increased risk of electric shock
*Some exceptions apply –See Section 2 of AS/NZS 3000:2018.	

RCDs with a rated residual current in the range of 100 mA to 300 mA are also sometimes used in installations as a protective measure against the initiation of fire.

4.3 Damp Situations

Protection in Damp Situations

Certain situations which are inherently prone to moisture are classified in the Wiring Rules as ‘damp situations’, including:

- Baths, showers and fixed water containers.
- Swimming pools, paddling pools and spa pools.
- Fountains and water features.
- Saunas.
- Refrigeration rooms.
- Areas used for sanitization and hosing-down operations.

The presence of moisture in damp situations increases the risk of electric shock, therefore certain restrictions and enhanced protective measures apply to the selection and arrangement of equipment in these areas.

Typical enhanced protective measures include:

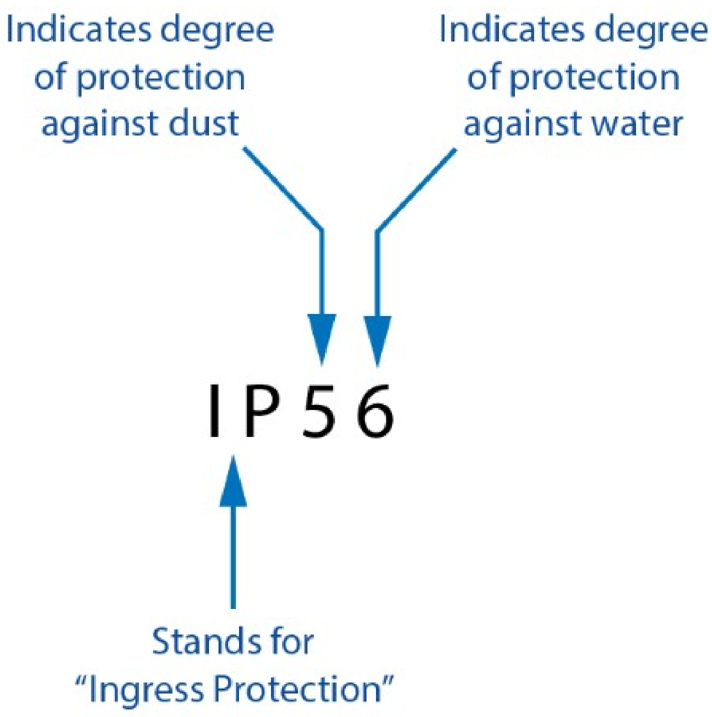
- Use of IP rated enclosures.
- Supply at SELV and PELV.
- Electrical separation.
- Provision of RCDs.

Section 6 of AS/NZS 3000:2018 specifies the protective measures required in the different zones of various damp situations.

Ingress Protection (IP) Ratings

The IP rating system is an internationally recognised system classifies enclosed equipment based on the degree of protection provided against the ingress of solid objects (e.g. dust) and water. An IP rating is expressed as the letters “IP” followed by two numbers, and may also contain an additional and/or supplementary letter at the end. The following table shows how to interpret IP ratings.

Ingress Protection (IP) Ratings



Letter/Number	Interpretation
IP	Indicates that the rating is an Ingress Protection rating.
First Numeral	Indicates the degree of protection against the ingress of solids. Ratings are from zero (no protection) to six (totally protected against the ingress of dust). If no specific degree of protection is designated, an "X" is used instead of a number.
Second Numeral	Indicates the degree of protection against the ingress of water. Ratings are from zero (no protection) to eight (rated for continuous immersion). If no specific degree of protection is designated, an "X" is used instead of a number.
Additional Letter (optional)	l) Can be used to indicate a degree of protection of persons against access to hazardous parts. Ratings are from A (protection against access

	with the back of the hand) to D (protection against access with a 1 mm^2 wire).
Supplementary Letter (optional)	(optional) Can be used to indicate a special class of equipment (e.g. high voltage equipment). Ratings include H, M, S and W.

Appendix G of AS/NZS 3000:2018 provides further details about how to interpret IP ratings.

5.1 Overload and Short Circuit Protection

Introduction

Overcurrent in an electrical installation poses a serious risk due to the temperature rise that occurs in the circuit conductors. If an overcurrent condition is allowed to persist, it is likely that equipment will melt, catch on fire, and/or ignite other nearby materials. In this topic, you will learn how to select and arrange overcurrent protection equipment to suit the installation conditions and load requirements.

Overcurrent

AS/NZS 3000:2018 defines ‘overcurrent’ as any current exceeding the rated value. There are two main types of overcurrent that can occur in a circuit, these are:

- Overload current.
- Short-circuit current.

An overload is an overcurrent occurring in a circuit that is electrically sound (i.e. not electrically faulty). An example of when this might occur is when a motor is used to drive a mechanical load that is beyond the motor’s design capability. Overload currents are usually only moderately higher than the rated current, but will cause damage if sustained for extended periods.

A short-circuit current is an overcurrent resulting from insulation failure (i.e. an electrical fault). When insulation fails, a current path of very low impedance can arise between the circuit conductors, which can result in very high currents – many times greater than the rated current.

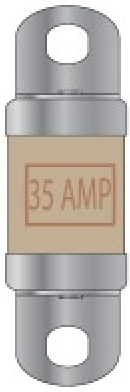
A short-circuit can occur between live conductors (e.g. between two phases) or between live conductors and earth (i.e. an earth fault).

Overcurrent Protection

The Wiring Rules stipulates that overcurrent protection must consist of:

- Overload protection.
- Short-circuit protection.

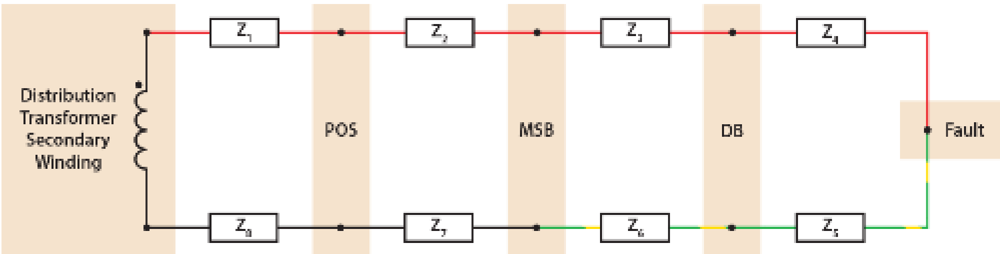
Permissible methods of overcurrent protection are described in the following table.

Overcurrent Protection Methods	
Circuit Breakers	**Fuses**
	
Circuit breakers used as the sole overcurrent protection device must have both overload (thermal) and short-circuit (magnetic) release mechanisms.	May be either: • High Rupturing Capacity (HRC) Fuses. • Fuse-Combination (CFS) Units.
Combinations of circuit breakers and fuses may be used, where one device provides overload protection and the other device provides short-circuit protection.	

Note: Fault protection, as discussed in Topic 4 is intended to protect against *electric shock* from indirect contact, whilst overcurrent protection is intended to protect against *excessive temperatures* caused by overcurrent.

Earth Fault Loop – Equivalent Circuit

The path of an earth fault current is known as the ‘earth fault loop’. The following diagram shows the equivalent circuit of an earth fault loop.



Abbreviations	
POS	Point of Supply
MSB	Main Switchboard
DB	Distribution Board
Impedances	
Z_1	Service lines active conductor
Z_2	Consumer’s mains active conductor
Z_3	Submain active conductor

Z_4	Final subcircuit active conductor
Z_5	Final subcircuit protective earthing conductor
Z_6	Submain protective earthing conductor
Z_7	Consumer's mains PEN conductor
Z_8	Service lines PEN conductor

It is important to be able to determine the value of fault loop impedance, as this value must be sufficiently low to cause a large enough fault current to cause automatic operation of the protection device.

Note: the operating characteristics of overcurrent protection devices will be explored in the next topic.

Worked Example – Earth Faults

The diagram above shows a 400 V three phase electrical installation. The circuit conductors in the installation have the following impedances.

Conductor	Size	Length	Impedance at 50 Hz
Supply Impedance (distribution transformer to the point of supply)	N/A	N/A	
Consumer's Mains (CM) • Phase Conductor • Neutral Conductor	185 mm2 185 mm2	21 m 21 m	0.003 Ω 0.003 Ω
Submains (SM) • Phase Conductor • Neutral Conductor • PE Conductor	70 mm2 70 mm2 25 mm2	36 m 36 m 36 m	0.013 Ω 0.013 Ω 0.034 Ω
Final Subcircuit (FSC) • Phase Conductor • Neutral Conductor • PE Conductor	4 mm2 4 mm2 2.5 mm2	42 m 42 m 42 m	0.247 Ω 0.247 Ω 0.397 Ω

Calculate the earth fault loop impedance and earth fault current (I_F) that would flow in the event of an earth fault at the appliance.

(a) Earth fault loop impedance

$$Z = 0.028 + 0.003 + 0.003 + 0.013 + 0.034 + 0.247 + 0.397$$

$$Z = 0.725\ \Omega$$

(b) Earth fault current

$$I_F = \frac{230}{0.725}$$

$$I_F = 317.24\ \text{A}$$

Prospective Short-Circuit Current

The prospective short-circuit current (I_{SC}) is the maximum current that would flow in the event of a ‘worst-case scenario’ fault at a given point, typically expressed in kA.

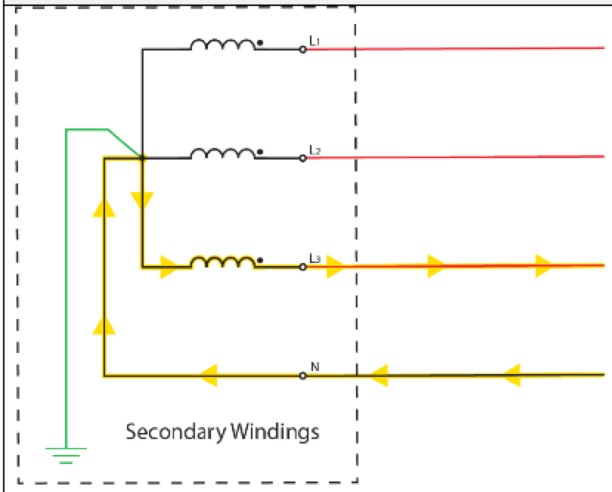
The type of fault that creates the worst-case scenario varies depending on a number of factors, including the location of the fault within the installation, and the impedance of the distribution transformer.

For example, consider the comparison between an earth fault, and a short-circuit between two phases, at a 400/230 V distribution board:

- The voltage across the earth fault impedance will be 230 V (phase to earth), but the voltage across the short-circuit impedance will be 400 V (phase to phase).
- The impedance of the short-circuit path within the installation will generally be lower, as it involves only phase conductors, whereas the earth fault path consists of phase conductors and protective earthing conductors (which have a smaller cross-sectional area, and therefore a higher impedance).
- However, the impedance of the fault path at the star-connected distribution transformer will be higher, as the path will include two transformer windings, whereas the path for an earth fault or phase to neutral fault will include just one winding.

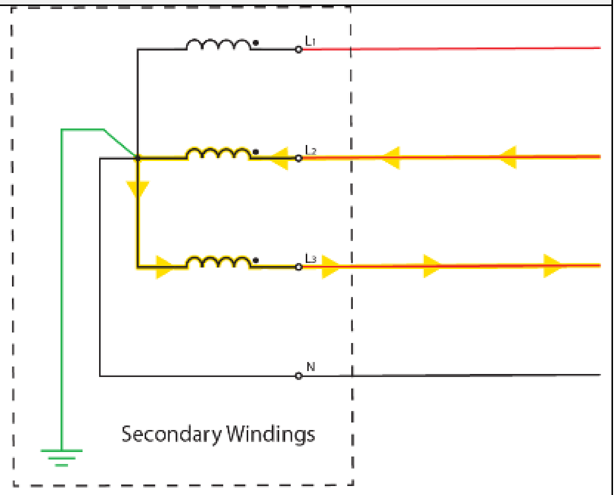
The following diagrams show the different current paths back at the distribution transformer secondary windings for a fault between phases and a fault between active and earth/neutral.

230 V Fault Path



For a fault between active and earth or neutral, the fault path only includes the impedance of one winding.

400 V Fault Path



For a fault between two phases, the fault path only includes the impedance of two windings.

In a single phase installation, the worst-case scenario is generally a short between active and neutral conductors rather than an earth fault. This is because the size of the neutral conductor is usually (but not always) slightly larger than the associated protective earthing conductor, resulting in a slightly lower return path impedance. However the voltage across each type of fault, and the current path back at the distribution transformer will be the same in each case.

The prospective short-circuit current must be determined at various points in an installation so that protection devices with adequate ratings can be selected. Short-circuit protection devices must have the ability to stop, or 'break' the prospective short-circuit current. This ability is known as the 'breaking capacity' of the protection device, sometimes referred to as the 'kA rating'.

The breaking capacity of a protection device must be equal to or greater than the prospective short-circuit current for the point at which the device is installed.

Fault Level

The 'fault level' at a given point in an installation is the maximum apparent power (volt-amperes) that would be present in the event of a 'worst-case-scenario' fault.

Fault level is typically expressed in MVA, and can be determined for a particular point in an installation by multiplying the prospective fault current by the maximum voltage that may appear across the fault.

5.2 Protection Methods Requirements

Terms and Definitions

The following table explains some of the terms and definitions associated with overcurrent protection.

Overcurrent Protection – Terms and Definitions		
Protection Device	**Symbol**	**Explanation**
Nominal Current	I_N	The maximum current that the protection device will permit to flow indefinitely.
Instantaneous Trip Current	I_2	The current that will cause the automatic operation of the protection device in the required time.
Circuit Equipment	**Symbol**	**Explanation**
Maximum Demand	I_B	The maximum current required to supply the circuit equipment.
Current Carrying Capacity	I_z	The maximum current that the conductors can carry continuously without sustaining damage.

Coordination

In order to ensure circuit equipment is adequately protected, overcurrent protection devices must be correctly ‘coordinated’ with circuit cables and equipment. When correctly coordinated, the protection device will permit the circuit design current to flow indefinitely, but will disconnect an overcurrent prior to any cables or equipment sustaining damage.

To achieve this, overcurrent protection devices must satisfy the following equations:

For circuit breakers:

$$I_B \leq \mathbf{I_n} \leq \mathbf{I_z}$$

For HRC fuses:

$$I_B \leq \mathbf{I_n} \leq 0.9 * \mathbf{I_z}$$

For both circuit breakers and fuses:

$$I_2 \leq 1.45 * \mathbf{I_z}$$

Where:

IB = the maximum demand for the circuit

IN = the nominal current of the protective device

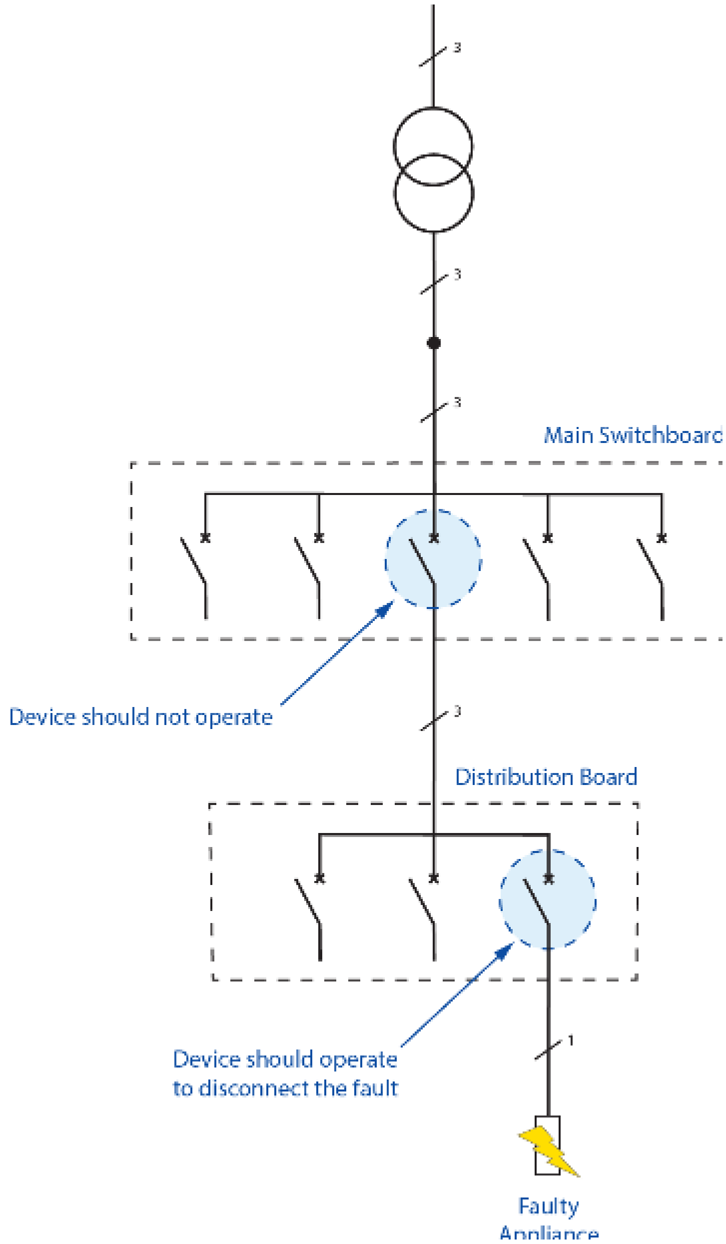
IZ = the continuous current carrying capacity of the circuit conductors

I2 = the current causing operation of the protective device in the required time

Discrimination

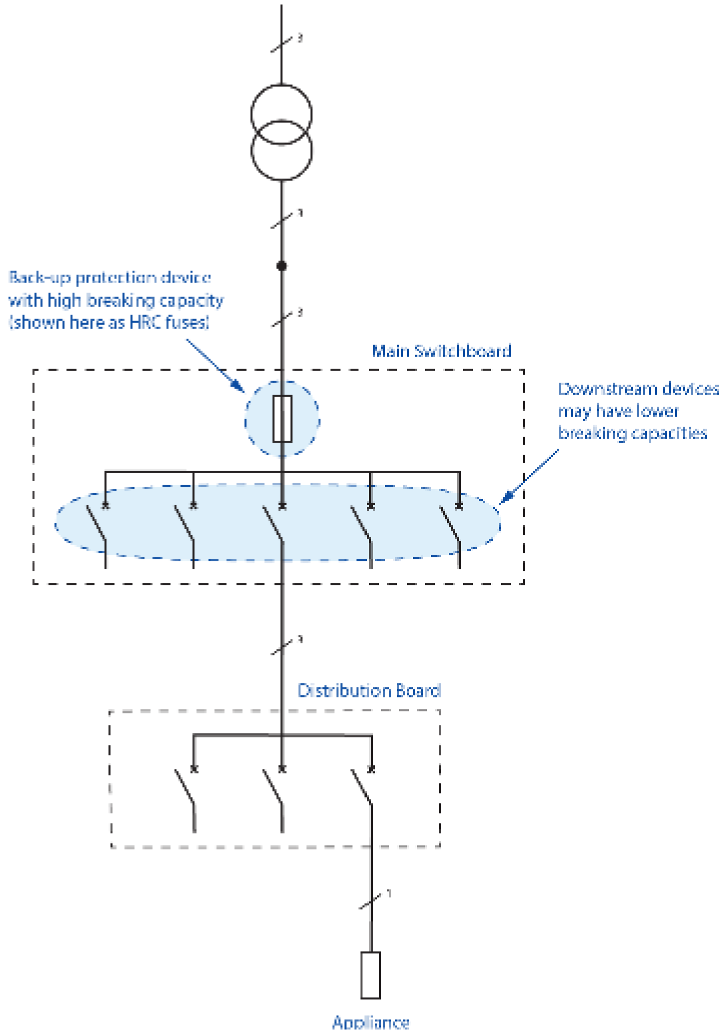
Where two or more protection devices are connected in series, such as in a main switchboard and a downstream distribution board, the devices must be selected to ensure that only the intended device operates in the event of a fault. This is referred to as ‘discrimination’ or ‘selectivity’.

Usually, it should be the first device upstream of a fault that operates to disconnect the fault. Proper discrimination can be achieved, in a general sense, by selecting downstream protection devices that have lower nominal current ratings than those devices immediately upstream.


3
3
3
Main Switchboard
Device should not operate
3
Distribution Board
Device should operate
to disconnect the fault
1
Faulty
Appliance

Back-Up Protection (Cascading)

Back-up protection or ‘cascading’ is when an upstream protective device is installed to assist a downstream device in clearing a fault. Cascading allows downstream devices to have smaller breaking capacities, reducing installation costs.



Introduction

As discussed in the previous topics of this unit, automatic disconnection of the supply (ADS) is a common method of providing protection against both electric shock and excessive temperatures. In this topic, you will learn about the different types of protection devices used for ADS, including their operating principles, characteristics and applications.

Devices for Automatic Disconnection of Supply (ADS)

There are three types of devices used for ADS, these are:

- Circuit breakers.
- Fuses.
- Residual current devices (RCDs).

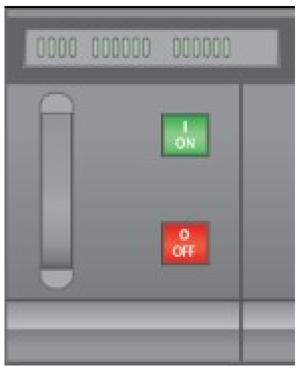
RCDs are sometimes called ‘residual current circuit breakers’ (RCCBs). Combination RCDs are also available, known as a ‘residual current circuit breaker with overcurrent protection’, or RCBO. For example, a 20 A Type C 30 mA RCBO provides protection against overload, short circuit and earth leakage, all in the one device.

ADS devices are classified by the following features and ratings:

Features of ADS Devices	
Features	**Description**
Tripping mechanism	The tripping mechanism is the method by which the device disconnects the circuit.
Nominal current and voltage	The nominal current and voltage represent the normal operating values the device is designed for.
Instantaneous tripping current	The instantaneous tripping current is the current that will cause operation of the device in the specified time.
Breaking capacity	The breaking capacity is a value in kA, and indicates the capability of a protective device to stop (break) a fault current. The protective device will not be able to break currents above the breaking capacity, so it is important to select devices with breaking capacities greater than the prospective short-circuit current at the point of installation.
I^2t (energy let-through) characteristics	The I^2t characteristics, or energy let-through, is the amount of, potentially damaging, energy the device will allow through prior to disconnecting a fault current. I^2t values are measured in ampere squared seconds (A^2s).

Circuit Breakers

There is a wide variety of circuit breakers available for different situations. The three main types of circuit breaker are shown in the following table.

Circuit Breakers		
		
Miniature Circuit Breaker (MCB)	Molded-Case Circuit Breaker (MCCB)	Air Circuit Breaker (ACB)

Tripping Mechanisms

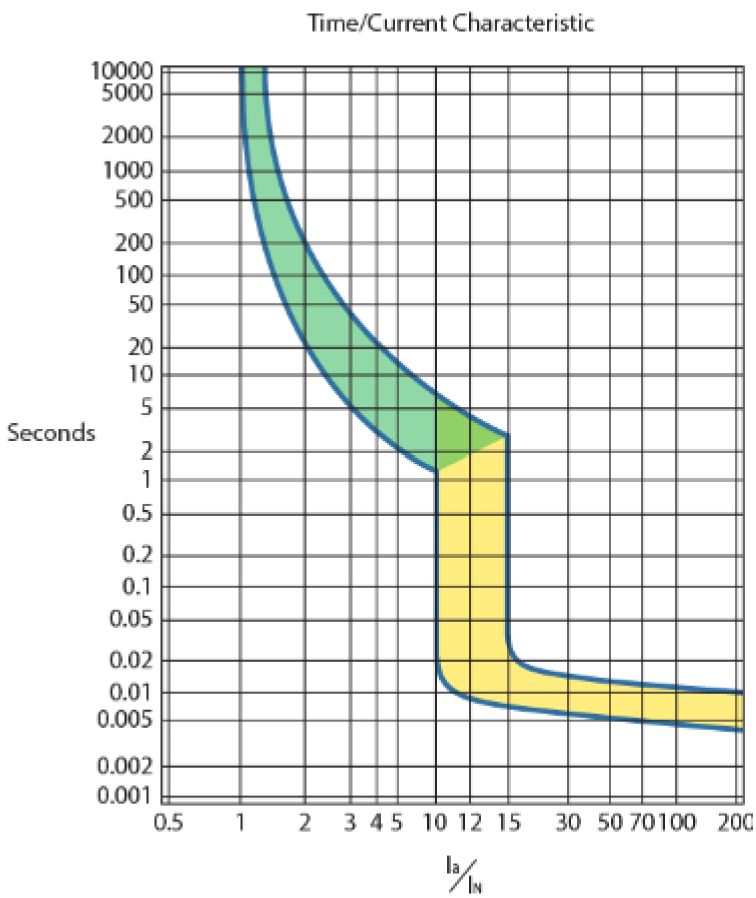
There are four types of tripping mechanisms used in different circuit breakers, as described in the following table.

Tripping Mechanisms	
Type	**Operation and Features**
Thermal	• Operate due to the bi-metal principle. • • Suitable to be used as overload protection.
Magnetic	• Operate due to electromagnetism • • Operate very quickly in the event of sudden fault currents. • • Suitable to be used as short-circuit protection.
Thermal-Magnetic	• Have both thermal and magnetic mechanisms. • • Suitable for use as both overload and short-circuit protection. • • Most commonly used circuit breakers
Electronic	• Consist of an external current sensor that feeds information back to the breaker. • • Adjustable tripping characteristics. • • Used in special applications, generally involving large currents.

Operating Characteristics

Circuit breakers have an ‘inverse time/current characteristic’. This means that the time it takes for a circuit breaker to operate decreases as the value of overcurrent increases. The time/current characteristic curve of a circuit breaker indicates the time taken to clear an overload or fault. A typical thermal-magnetic characteristic curve is shown below, in which:

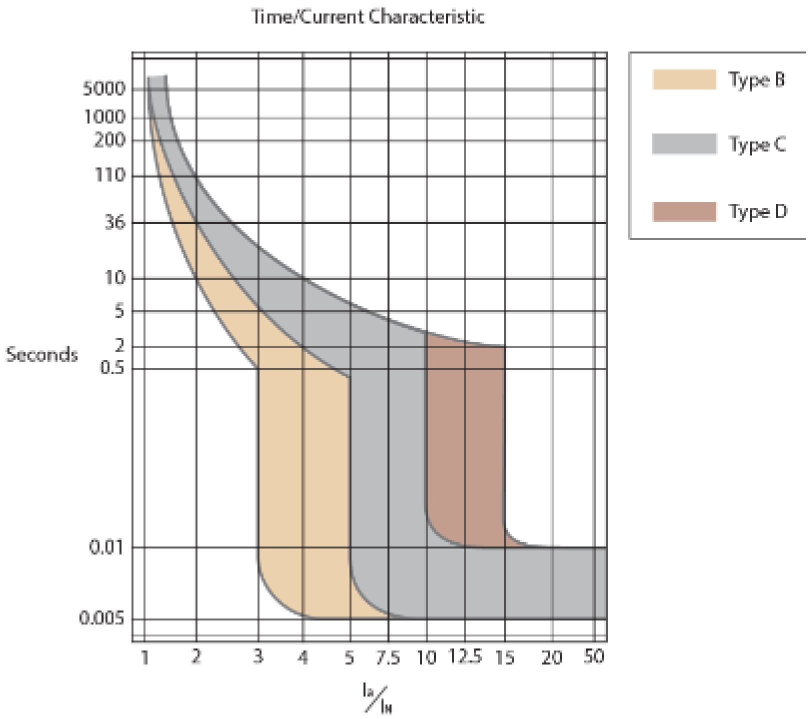
- The thermal portion of the curve is highlighted in green.
- The magnetic portion of the curve is highlighted in yellow.



Instantaneous Tripping Characteristics

There are three circuit breaker instantaneous tripping characteristic types, as shown in the following table:

Instantaneous Tripping Characteristics



Circuit Breaker Type	Instantaneous (0.4 s) Tripping Current (I_a)	I_a for a 20 A Circuit Breaker	Typical Application
B	4 times the nominal current	80A	Resistive heating loads
C	7.5 times the nominal current	150A	Socket-outlets and lighting
D	12.5 times the nominal current	250A	Motors

6.2 Fuses

A fuse operates by having a sacrificial low resistance element that melts when an overcurrent flows, thereby opening the circuit. There are three types of fuses commonly found in low voltage electrical installations:

Fuses

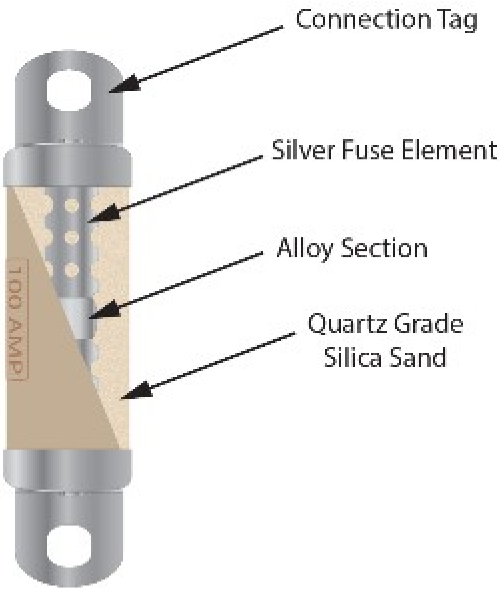
Type	Description
High Rupturing Capacity (HRC) Fuse	• Available in a range of current ratings for both high and low voltage circuits. • Suitable for use as both overload and short-circuit protection. • High breaking capacity and low energy let through.
Combination Fuse Switch (CFS) Unit	• Contain HRC fuses that can be pulled in and out of the circuit by operating a switch lever. • Functions as both a fuse and a switch.
Semi-Enclosed Rewireable Fuse	• No longer permitted by AS/NZS 3000:2018. • Many are still in service in existing installations.

HRC Fuses

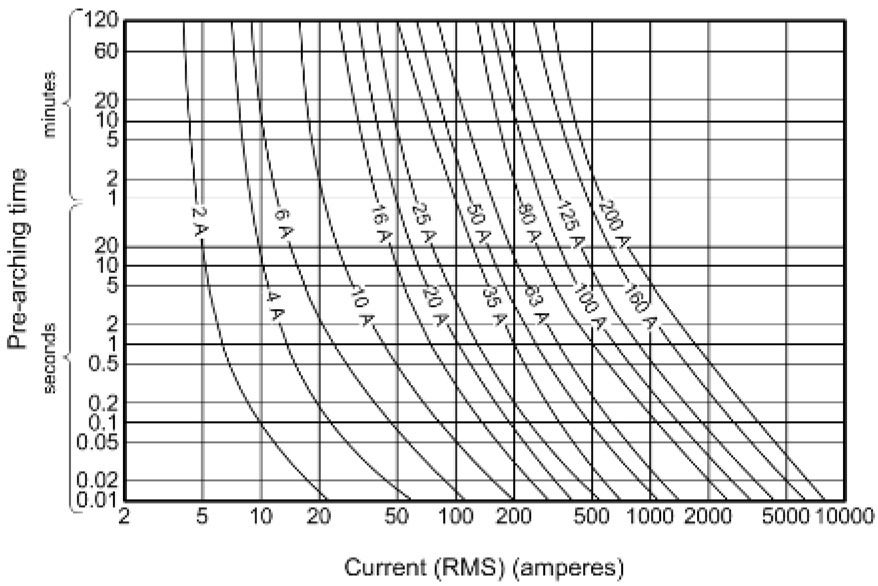
An HRC fuse consists of one or more silver fuse elements encased in a ceramic tube that is filled with quartz grade sand. A copper contact at each end of the tube allows for connection into the circuit via the fuse holder. The quartz sand cools the fuse element during normal operation, and acts as a high resistance material during a fault, resulting in a high breaking capacity. HRC fuse elements also have several reduced sections along their length to provide multiple arcing points in the event of a fault. The high breaking capacity of HRC fuses make them suitable for use as fault current limiting (FCL) devices.

To provide overload protection, fuse elements are constructed with an alloy section in the middle with a much lower melting point than the remaining silver construction. This allows the element to open due to small overloads of long durations.

The following diagram shows the basic parts of a HRC fuse.



Fuses have an 'inverse time/current characteristic'. This means that the time it takes for a fuse to operate decreases as the value of overcurrent increases. Typical time/current characteristic curves of various HRC fuses can be seen in the following diagram.



HRC Fuse Ratings

There are a number of ratings and operating parameters that need to be considered when selecting HRC fuses for a given application. The following table explains the main ratings and features of HRC fuses.

Fuse Ratings	
Rating	**Description**
Voltage	The maximum normal operating voltage for which the fuse is designed.
Nominal Current	The current that the fuse is designed to carry continuously without damage to the element.
Duty	The maximum fault current that the fuse can interrupt without causing damage to the fuse carrier and holder.
Pre-Arcing Time	The time taken from when a fault current starts to flow, until the fuse element begins to melt.
Arc Time	The time taken from when the fuse element begins to melt until the interruption of the fault current is complete.
Arc Voltage	The surge in voltage that occurs during the time it takes for the fuse element to melt.
Let-Through Energy (I^2t)	The amount of energy a fuse will allow to pass through in the event of a fault, measured in A^2s.

Some loads have specific current characteristics that need to be accounted for. Induction motors can draw very large currents during starting and braking operations, and even very short durations of overcurrent can cause significant damage to semiconductor devices, such as soft starters and uninterruptible power supplies. .For this reason, various different classes/categories of HRC fuse are available, each specifically designed for different operating scenarios and applications.

The category/class of a HRC fuse is a two letter code.

- The first letter is lowercase, and indicates the type of protection provided by the fuse:
  - ‘a’ indicates the fuse is suitable to provide short circuit protection only.
  - ‘g’ indicates the fuse is suitable to provide both short circuit and overload protection.
- The second letter is uppercase and indicates the application for which the fuse is designed. Common types include:
  - ‘G’ type is designed for general purpose applications.
  - ‘M’ type is suitable for motor protection.
  - ‘R’ and ‘S’ types are suitable for protecting semiconductor devices.

For example, a Class gM HRC fuse is suitable to provide both overload and short circuit protection to a motor circuit.

Class R and S HRC fuses are designed to have very fast response times, therefore providing very low I^2t characteristics to prevent damage to sensitive semiconductor devices.

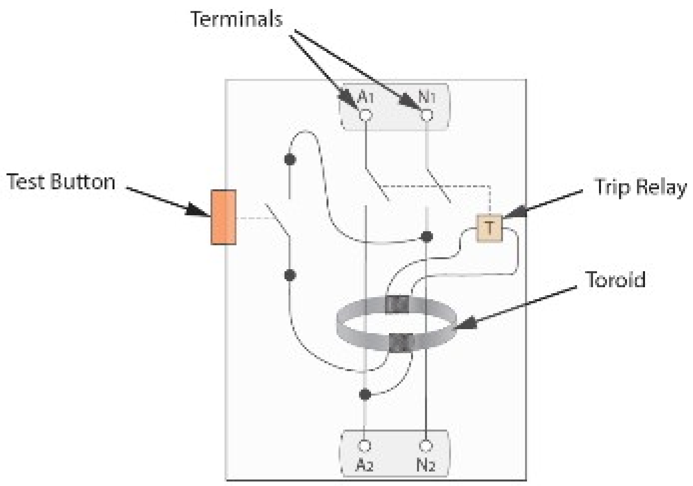
Conventional Tripping Current

The conventional tripping current of fuses is slightly higher than that for circuit breakers (1.6 x I_N as opposed to 1.45 x I_N for circuit breakers). Due to this, circuit conductors that are protected by fuses must be de-rated by a factor of 0.9 (1.45 / 1.6 = 0.9). So for example, a 20 A HRC fuse will not provide adequate protection to a cable with a current carrying capacity (CCC) of 20 A – due to the higher conventional tripping current, the CCC of the conductors must be de-rated to 18 A (i.e. 20 x 0.9 = 18).

6.3 Residual Current Devices (RCDs)

Residual current devices (RCDs) are used to provide additional protection against electric shock, as required by AS/NZS 3000:2018, and can also be used to reduce the chance of an electrical fire. They operate by comparing the current in the active and neutral conductors of a circuit, and disconnecting the circuit when an imbalance is detected. The following table indicates the internal arrangement and operation of RCDs.

Residual Current Devices (RCDs)



Operation

- The active and neutral conductors of the protected circuit pass through a toroid in the RCD.
- When there is no leakage, the magnetic fields caused by the current flow in the conductors cancel each other out, due to being equal and opposite.
- When there is leakage to earth, the outgoing current in the active conductor is greater than the returning current in the neutral conductor, and so the magnetic fields become unequal.
- This means that a residual magnetic field appears that is proportional to the leakage current.
- The magnetic field induces a voltage into the toroid coil, in turn causing a current to flow to the trip device.
- When the trip device current (which is proportional to the leakage current) reaches a pre-determined value, the RCD disconnects the circuit.
-

Selecting RCDs

The following factors need to be considered when selecting RCDs for a given application:

- Rated voltage
- Nominal current (I_N)
- Residual current (ΔI)
- Trip time

RCDs are placed into one of four categories based on their rated residual current, as described in the following table.

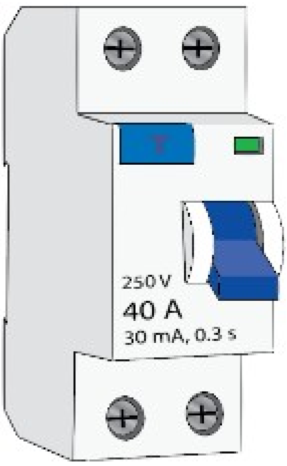
RCD Categories	
Category	**Description**
Category I	Rated residual current up to and including 10 mA
Category II	Rated residual current greater than 10 mA, up to and including 30 mA
Category III	Rated residual current greater than 30 mA, up to and including 300 mA
Category VI	As per Category III but with increased tripping times

Further features and capabilities of a RCD are indicated by the 'Type', as shown in the following table.

RCD Types	
Type	**Description**
Type AC	Detects a.c. leakage currents.
Type A	Detects a.c. and pulsating d.c. leakage currents.
Type B	Detects a.c. leakage currents up to 1000 Hz, and a wider range of d.c. leakage currents.
Type S	djustable time and current settings

Domestic and Residential Installations

AS/NZS 3000:2018 states that all final subcircuits in residential installations must be protected by RCDs having residual current rating not greater than 30 mA, and a trip time no greater than 0.3 s. The RCD shown below, for example, would be suitable for protecting a 230 V socket-outlets circuit in a house.



Note however, that the circuit would still require overcurrent protection, which would typically be provided by a suitably rated circuit breaker.

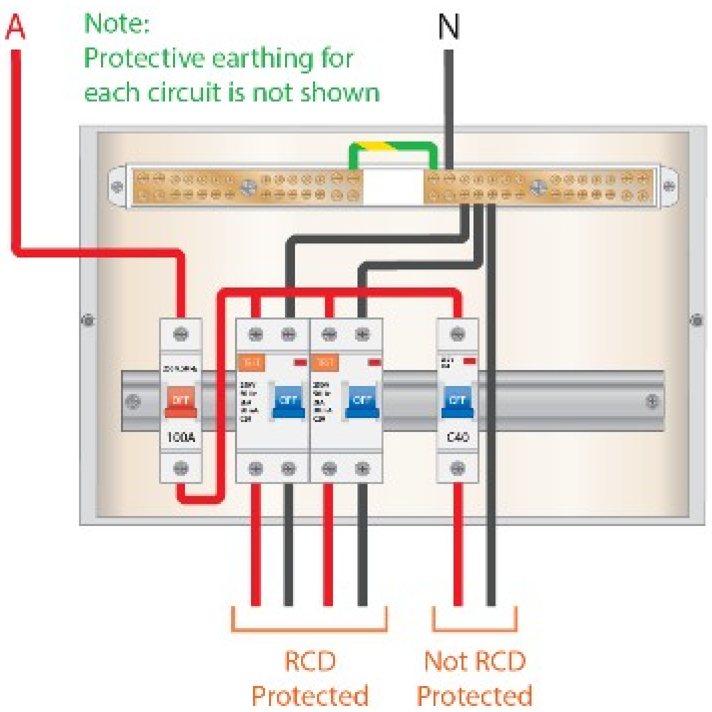
Residual Current Circuit Breakers with Overcurrent Protection (RCBOs) incorporate the protective features of both a RCD and a thermal-magnetic circuit breaker into the one device. This means that a RCBO can be used to provide overload, short-circuit and earth leakage protection.

Non-Domestic and Non-Residential Installations

In non-residential installations, essentially all final subcircuits rated up to and including 32 A are also required to be 30 mA (max) RCD protected. Some exceptions to this rule can apply in certain circumstances – refer to Clause 2.6.3.2.3 of AS/NZS 3000:2018.

RCD Wiring Arrangements

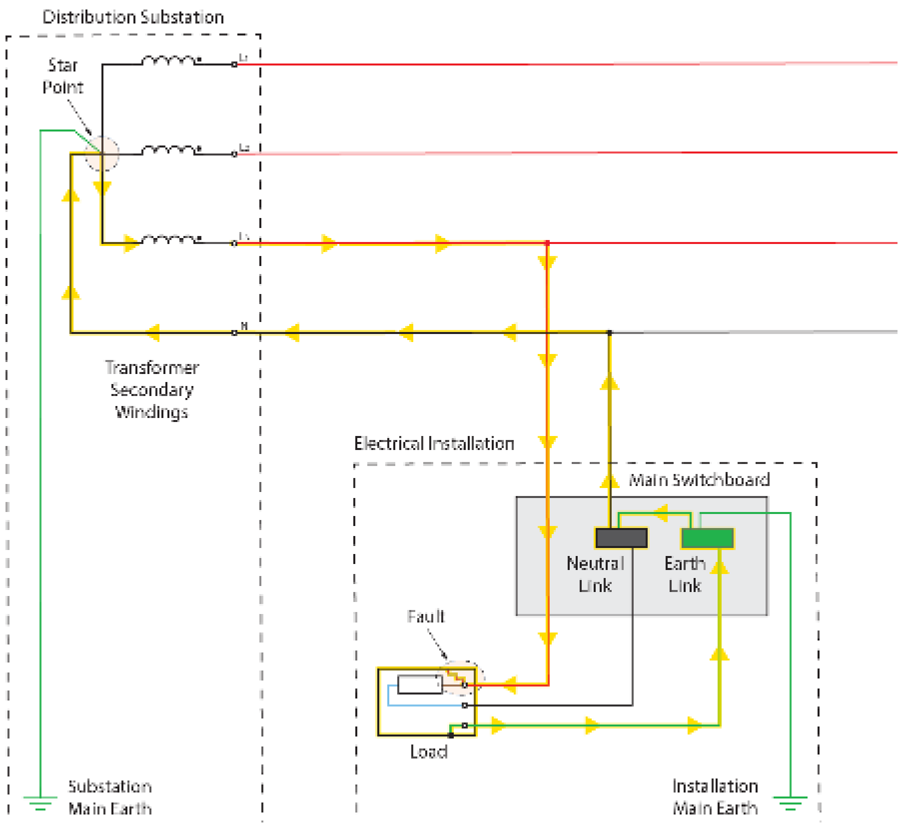
The following diagram shows an example of a non-residential switchboard wiring arrangement for two RCBO protected circuits and one non-RCD protected 40 A circuits. For clarity, protective earthing conductors and connections have not been shown.



Try searching the manufacturer websites provided in the further learning resources on this page to find real world examples of RCDs.

6.4 Earth Fault Loop Impedance

In order for a fault current protective device to operate, a large fault current must flow. For this reason, it is fundamentally important that the impedance of the earth fault loop is sufficiently low to allow the required fault current to flow. The following diagram shows the earth fault loop.



Factors Affecting Earth Fault Loop Impedance

The following table explains the factors that affect the impedance of the earth fault loop.

Factors Affecting Earth Fault Loop Impedance	
Factor	**Factor**
Length of the earth fault loop conductors	• Increasing the length of the conductors will increase the fault loop impedance. • Reducing the length of the conductors will reduce the fault loop impedance.
Cross-sectional area of the earth fault loop conductors	• Increasing the cross-sectional area of the conductors will reduce the fault loop impedance. • Reducing the cross-sectional area of the conductors will increase the fault loop impedance.

Wiring Rules Requirements

AS/NZS 3000:2018 states that the impedance of the earth fault loop must be low enough to ensure if a fault occurs at any point in the installation, automatic disconnection of the supply will occur in the required time.

To ensure that this occurs, the following equation must be satisfied:

$Z_s \times I_a \leq U_o$

Where:

Z_s = the total impedance of the earth fault loop

I_a = the instantaneous (0.4 s) tripping current of the protection device

U_o = the nominal circuit voltage to earth (230 V a.c.)

Worked Examples – Fault Loop Impedance

(a) Calculate the maximum permissible earth fault loop impedance for a 230 V socket-outlets circuit that is protected by a 20 A Type C circuit breaker.

Ia = 7.5 * 20 = 150A

Z_s = 230/150 = 1.53Ω

(b) Calculate the maximum permissible earth fault loop impedance for a 400 V three phase motor circuit that is protected by a 50 A Type D circuit breaker.

Ia = 12.5 * 50 = 625A
Z_s = 230/625 = 0.37Ω

The values calculated in the worked examples above can also be found in the Wiring Rules. The following Tables in AS/NZS 3000:2018 provide maximum parameters to ensure the instantaneous tripping of different circuit protection devices in the event of a fault:

- Table 8.1 provides maximum values of fault loop impedance.
- Table 8.2 provides maximum values of circuit conductor (active and earth) resistance.
- Table B1 provides the maximum route lengths for different combinations of circuit conductor sizes and protection devices.

7.1 Overvoltage Protection

Introduction

Abnormal voltages can result in damage to equipment and hazardous situations arising in electrical installations. The Wiring Rules stipulates that appropriate equipment must be provided to protect electrical installations against failure from overvoltage and undervoltage conditions. In this topic you will learn about overvoltage and undervoltage conditions, including causes, effects and associated methods of protection.

Overvoltage

Overvoltage is defined as a condition in which the voltage is increased by 10 % or more above the nominal supply voltage for one or more cycles. There are three main types of overvoltage, these are power surges, voltage spikes and swells.

Overvoltage Causes and Effects	
Causes	**Effects**
• Nearby switching of high voltage circuits. • Nearby switching of heavy loads. • Nearby switching of inductive or capacitive circuits. • Lightning. • Resonant phenomena.	• Breakdown of insulation. • Damage to equipment and appliances. • Unbalanced voltages in multiphase systems.

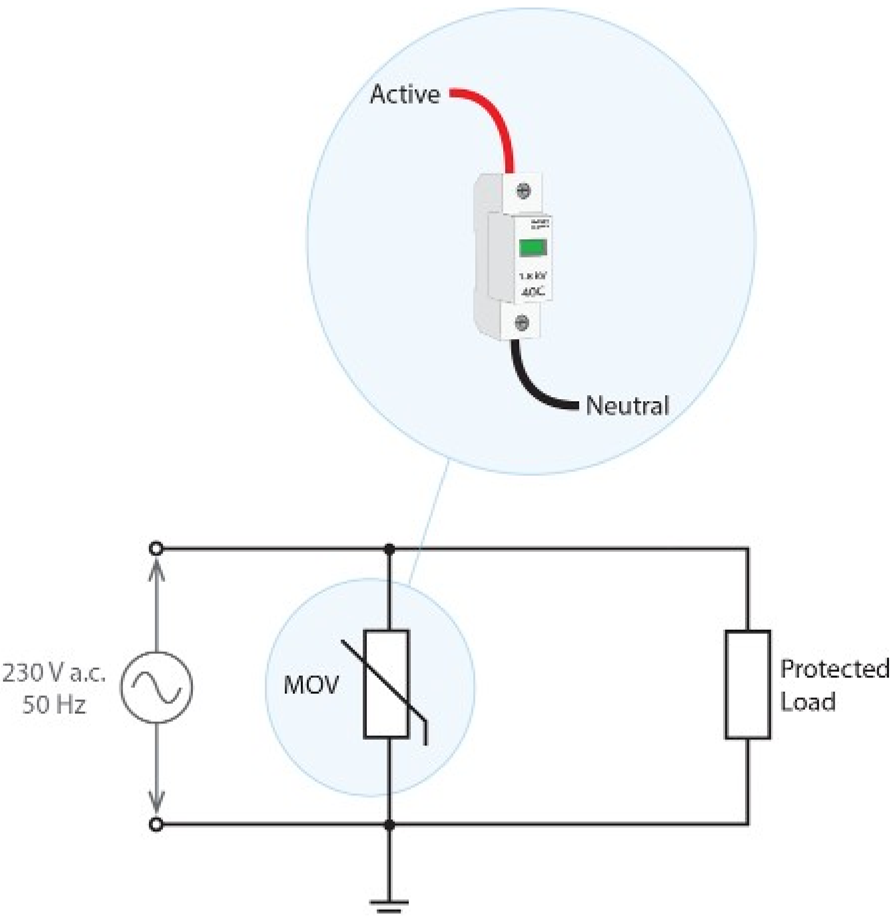
Protection Methods

Surge protective devices (SPDs), commonly known as surge arrestors or surge diverters, are used to protect against overvoltage conditions that may result from lightning or switching operations. The following diagram shows a basic DIN mountable SPD that could be used to protect a small 230 V electrical installation.

SPDs consist of a voltage dependent path to earth, connected in parallel with the supply. When an overvoltage occurs, a short circuit to earth is automatically created, preventing the overvoltage from appearing across the terminals of installation equipment. There are four main types of SPD, as described in the following table.

<table>
<tr><th colspan="2">Surge Protective Devices (SPDs)</th></tr>
<tr><th>Type</th><th>Operating Principle</th></tr>
<tr><td>Mercury-Oxide Varistors (MOV)</td><td rowspan="2">Use voltage dependent resistors that have a very high resistance under normal voltage conditions.
In the event of an overvoltage condition, the resistance drops sharply providing a short to earth.</td></tr>
<tr><td>Valve Type Arrestors</td></tr>
<tr><td>Gas-Filled Arrestors</td><td>Use an argon/hydrogen gas that requires a large striking voltage to ionise.
When an overvoltage appears, the gas ionises, providing a short to earth.</td></tr>
<tr><td>Suppression Diodes (Solid State)</td><td>Use Zener diodes that will only conduct when a pre-determined voltage is reached.
In the event of an overvoltage condition, the Zener diode conducts, providing a short to earth.</td></tr>
</table>

The following diagram shows the arrangement of an SPD to protect a load.



Other protective measures include the provision of insulation, screening, segregation and separation. In this context, these measures are intended to prevent faults occurring between circuits operating at different voltage levels.

7.2 Undervoltage Protection

Undervoltage

The term ‘under voltage’ is used to describe a number of conditions including:

- Blackout – a complete loss of supply.
- Interruption – a brief loss of supply.
- Brownout – an extended period of decreased supply voltage.
- Sag – a brief period of decreased supply voltage.

Undervoltage Causes and Effects	
Causes	**Effects**
• Power grid overloads and faults. • Lightning. • General overloads. • High impedances on supply conductors. • Nearby switching of heavy loads, particularly those requiring large startup currents.	• Hazardous conditions caused by unexpected stopping and starting of moving machinery. • Damage to electronic equipment. • Loss of electronic data. • Dimming of lights.

Protection Methods

Methods of protecting against undervoltage include:

- Undervoltage relays
- The use of automatic voltage regulators (AVR).
- The use of uninterruptible power supplies (UPS).
- The use of shunt capacitors or static VAr compensators.
- The use of series capacitors.
- Upsizing transformers and/or conductors to reduce impedance.

To avoid hazardous re-starting of equipment after an under voltage condition, under voltage release devices can be fitted to circuit breakers and RCDs. These devices disconnect the supply when the voltage drops below a pre-determined level (e.g. 10 %), and can only be re-set manually.

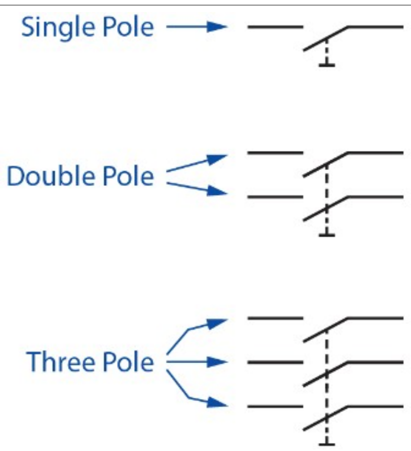
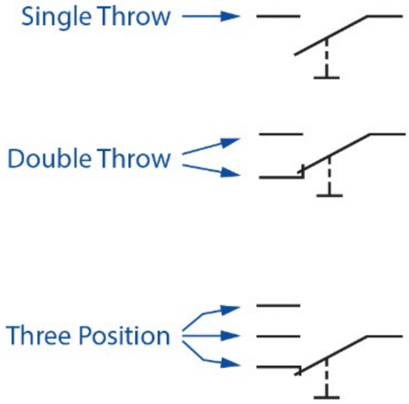
8.1 Switch Types

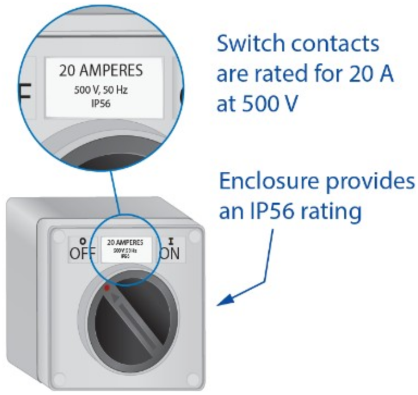
Introduction

In addition to providing protection devices, the Wiring Rules requires that electrical installations are provided with adequate control equipment to ensure the installation can be operated and maintained safely. In this topic, you will learn about the various types and requirements for control devices in electrical installations.

Switch Types

There is a huge variety of switches available from electrical wholesalers, each having features designed for different purposes, scenarios and environments. Switches can be broadly defined by the following features, as shown in the following table.

Characteristics of Electrical Switches		
Features	**Illustration**	**Details**
Number of Poles		Refers to the number of individual paths in and out of the switch. E.g. to switch the three phases and neutral of a circuit, a four pole switch is required.
Throw		Refers to how many different paths the switch can alternate between. A single throw is either closed or open, whereas a double throw has two possible output paths for each input path.

Switching Mechanism		Switching mechanisms may be either permanent or momentary. A permanent mechanism has two or more positions, and remains in a selected position until operated. A momentary mechanism generally has only two positions, and only changes position for the duration that it is being physically operated. E.g. a normally closed push button opens when pressed, and closes again when released.
Ratings		Main ratings are voltage, current and Ingress Protection (IP) ratings. Voltage and current ratings indicate the maximum voltage and current for which the switch is designed. IP ratings indicate the degree of protection afforded against the ingress of dust and moisture.

8.2 Switching Requirements

Electrical Installation Switching

The Wiring Rules states that electrical installations must be provided with control and isolation devices:

- To prevent or remove hazards.
- To allow maintenance of electrical equipment.

There are four categories of control and isolation devices specified in AS/NZS 3000:2018, these are:

- Isolation devices.
- Emergency switching devices.
- Shut-down devices for mechanical maintenance.
- Functional control switches.

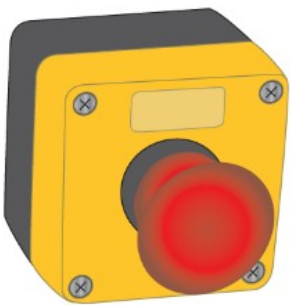
Isolation Devices	
Example Illustration	**Details**
	• The purpose of an isolation device is to de-energize a circuit by disconnecting all active supply conductors. • Isolators are usually single throw switches with a permanent mechanism. • ‘Load break’ isolators are capable of breaking the full load current of the circuit. • ‘Off-load disconnectors’ are not capable of breaking the full load current, and so the circuit must be isolated prior to operating an off load disconnector. • Examples include main switches and isolators for fixed motors and appliances.

Requirements for Isolation Devices

AS/NZS 3000:2018 requires that isolation devices must:

- Operate in all active conductors.
- Not operate in an earthing conductor or a PEN conductor.
- Be rated for any voltages likely to occur.
- Have a suitable IP rating for the installation environment.
- Not be able to falsely indicate that the contacts are open.
- Have clearly labelled ‘ON’ and ‘OFF’ positions.
- Be designed to prevent unintentional operation.
- Be lockable in the ‘OFF’ position.
- Be clearly labelled to indicate the equipment they control.

It is not permitted to use an electronic device (i.e. a programmable relay) as an isolator.

Emergency Switching Devices	
Example Illustration	**Details**
	• The purpose of an emergency switching device is to provide a means of removing unexpected danger. • Emergency switches are commonly normally closed pushbutton (momentary) type switches. • An example is an emergency stop button (pictured). • The push button of an emergency switch must be coloured red.

Requirements for Emergency Switching Devices

AS/NZS 3000:2018 requires that emergency switching devices must:

- Not operate in an earthing conductor or a PEN conductor.
- Be rated for any voltages likely to occur at that point in the installation.
- Have a suitable IP rating for the installation environment.
- Be manually operated by a single action.
- Be capable of breaking the full load current of the circuit.
- Not re-energize the circuit upon release of the device.
- Require manual re-setting where danger is present.
- Be readily accessible for convenient operation.
- Be identifiable for their intended purpose.

Shut-Down Devices for Mechanical Maintenance	
Example Illustration	**Details**
	• The purpose of a mechanical maintenance shut-down device is to disconnect the supply where mechanical maintenance work might involve the risk of physical injury. • They are usually of a similar type to an isolator.

Requirements for Shut-Down Devices

AS/NZS 3000:2018 requires that shut-down devices for mechanical maintenance must:

- Not operate in an earthing conductor or a PEN conductor.
- Be rated for any voltages likely to occur at that point in the installation.
- Have a suitable IP rating for the installation environment.
- Be manually operated.
- Be capable of breaking the full load current of the circuit.
- Have a clearly labelled 'OFF' position.
- Be designed to prevent unintentional operation.

Shut-down devices need not operate in all active circuit conductors.

Functional Control Devices	
Example Illustration	**Details**
	• The purpose of a functional control device is to control the operation of a circuit. • A wide variety of switch types are used for functional switching. • Functional switches are required for each part of a circuit that needs to be controlled independently of another part. • Functional switches may directly make and break connections, or send signals to activate more complex control systems. • Examples include a light switch and a motor STOP-START station (pictured).

Requirements for functional control devices

AS/NZS 3000:2018 requires that functional control devices must:

- Not operate in an earthing conductor or a PEN conductor.
- Be suitable for the harshest operating conditions that can be reasonably anticipated.

Functional switches need not operate in all active conductors or be labelled to identify the 'ON' or 'OFF' positions (unless otherwise required). It is not permitted to use disconnectors, fuses or links for functional switching purposes.

8.3 Control Arrangements

Electrical Installation Main Switches

Main switches are intended to provide a means of controlling an entire electrical installation. The Wiring Rules requires that one or more main switches are installed on the main switchboard to control each individual supply that is available.

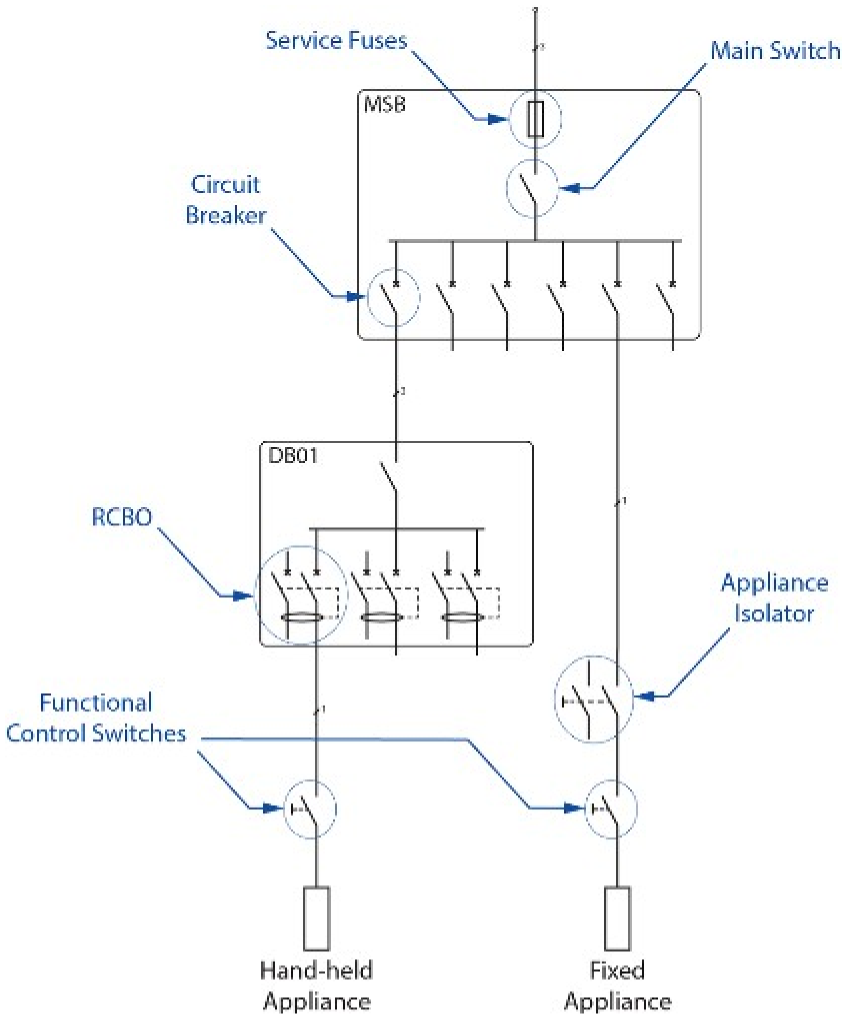
Subcircuit Control Arrangements

Distribution boards are also generally provided with an isolating switch that can be used to control the supply to the distribution board. Isolation switches are also required on the following fixed appliances and accessories:

- Socket outlets.
- Cooking appliances.
- Water heaters.
- Room heaters.
- Heating cables.
- Electricity convertors.
- Motors.
- Capacitors.
- Safety services.
- Generation systems.

Functional switches are often incorporated into electrical appliances and equipment, however additional wiring and arrangement of functional controls is also commonly required for many circuits, such as for those supplying motors and lighting.

The following diagram shows some typical control arrangements for a basic electrical installation.

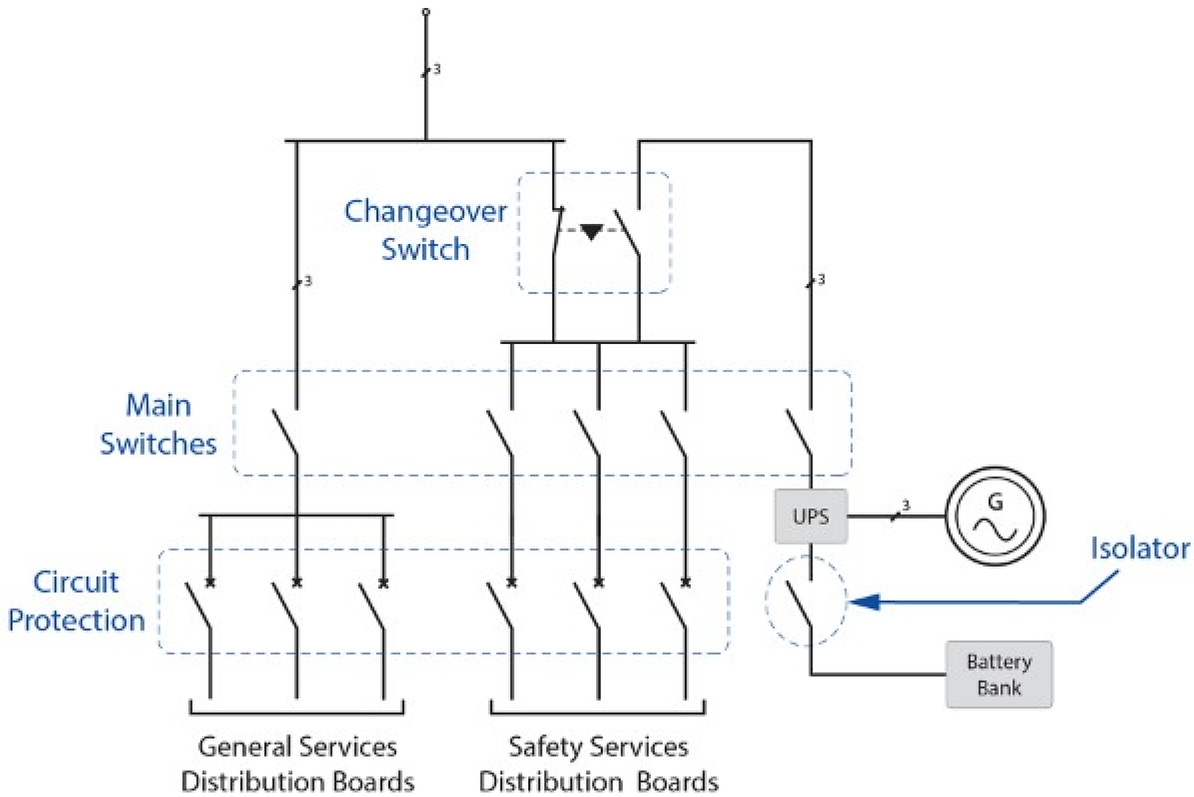

Service Fuses
Main Switch
MSB
Circuit
Breaker
DB01
RCBO
Appliance
Isolator
Functional
Control Switches
Hand-held
Appliance
Fixed
Appliance

Electrical Installations with Safety Services

Where an installation has safety services such as lifts or evacuation equipment, the supply to each safety service must be controlled by one or more main switches that are separate from the remainder of the installation. All safety service main switches must not be controlled by any other main switches in the installation.

Where an alternative supply is provided, a changeover switch is required at the main switchboard to switch between the main and alternative supplies as necessary. Some exceptions apply to the location requirements for changeover switches, for example in the case of lift equipment, the changeover switch may be installed in the lift motor room.

The following diagram shows the arrangement of main switches, circuit protection and changeover switching in an electrical installation with safety services and an alternative supply.



9.1 Switchboards and Distribution Boards

Introduction

The majority of protection, control and metering equipment in an electrical installation are housed in switchboards and distribution boards. They also provide points at which the installation is divided into circuits. In this topic, you will learn about the basic types, requirements, and arrangement of electrical switchboards.

Types of Switchboards

Switchboards are used to house electrical control, protection and metering equipment in electrical installations. They are generally in the form of a panel or enclosed box, constructed from metal or hard plastic, typically with a lockable door or cover to prevent unauthorised access. The internal equipment is usually directly fixed onto a metal or insulated back plane, or onto DIN rails.

There are a number of different types of switchboards that are used for different purposes, but the general functions of switchboards are to:

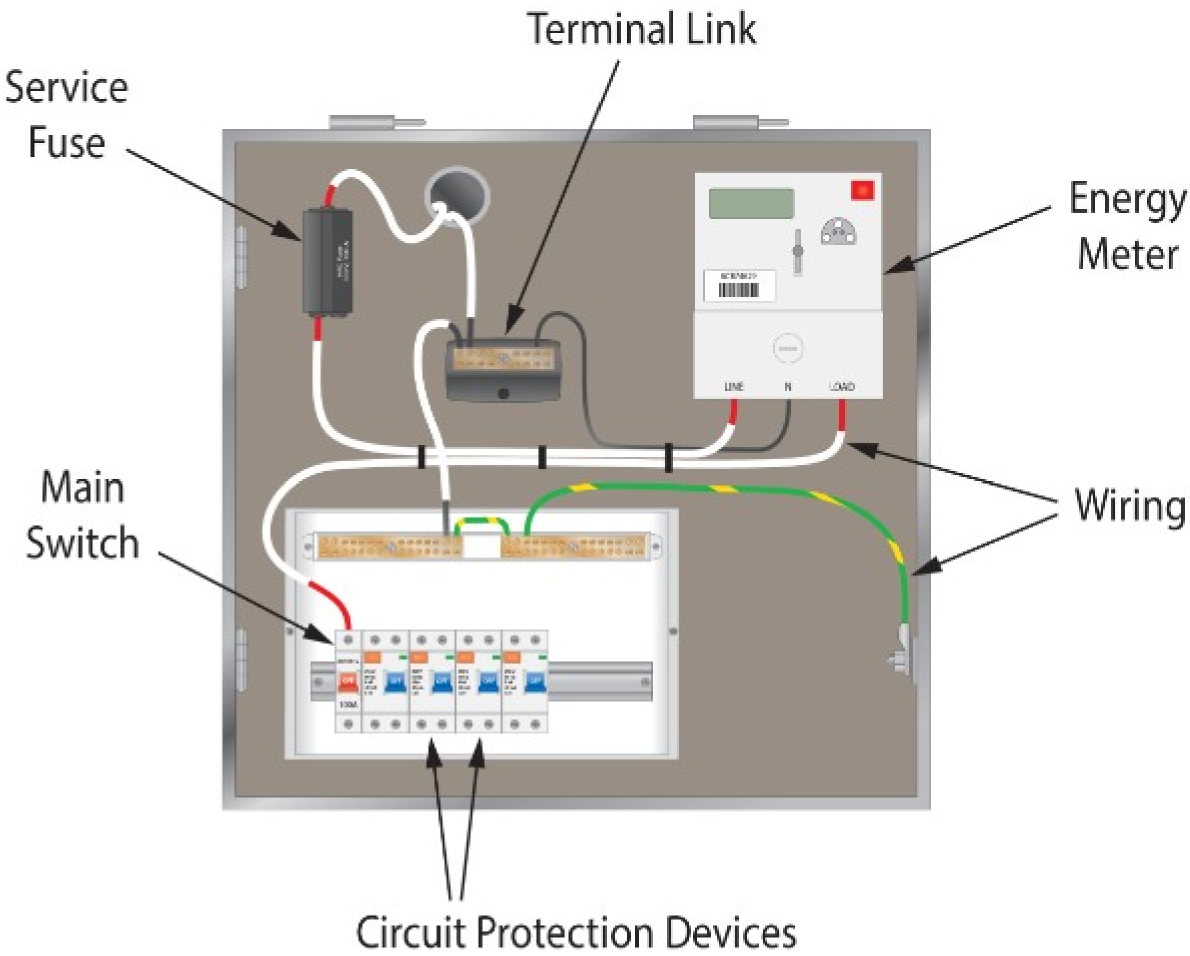
- Provide points at which the installation can be divided into circuits.
- House switchgear and controlgear.
- House metering and monitoring equipment.

There are a number of different types of switchboards found in installations, as described in the following table.

Types of Switchboards	
Type	**Details**
Main Switchboard	• A main switchboard is a switchboard from which an entire installation can be controlled. • Each supply provided to an installation enters the installation via the main switchboard. • Used to house equipment such as: ○ Metering and monitoring equipment. ○ Main switches. ○ Control and protection devices. ○ Links, terminals and bars.
Distribution Boards	• The purpose of a distribution board is to provide a point of connection, protection and control for the wiring and equipment of a sub-section of a larger electrical installation. • AS/NZS 3000:2018 defines a distribution board as “any switchboard other than a main switchboard”.
Safety Services Switchboards	• Used to supply ‘safety services’ such as lifts, emergency evacuation systems, and fire detection and alarm systems. • Safety services are required to be controlled separately to other parts of an electrical installation.
Control Panels	• Control panels are used in installations with extensive control requirements. • Used to house equipment such as: ○ Relays. ○ Contactors. ○ Electronic dimmers. ○ Motor starters.

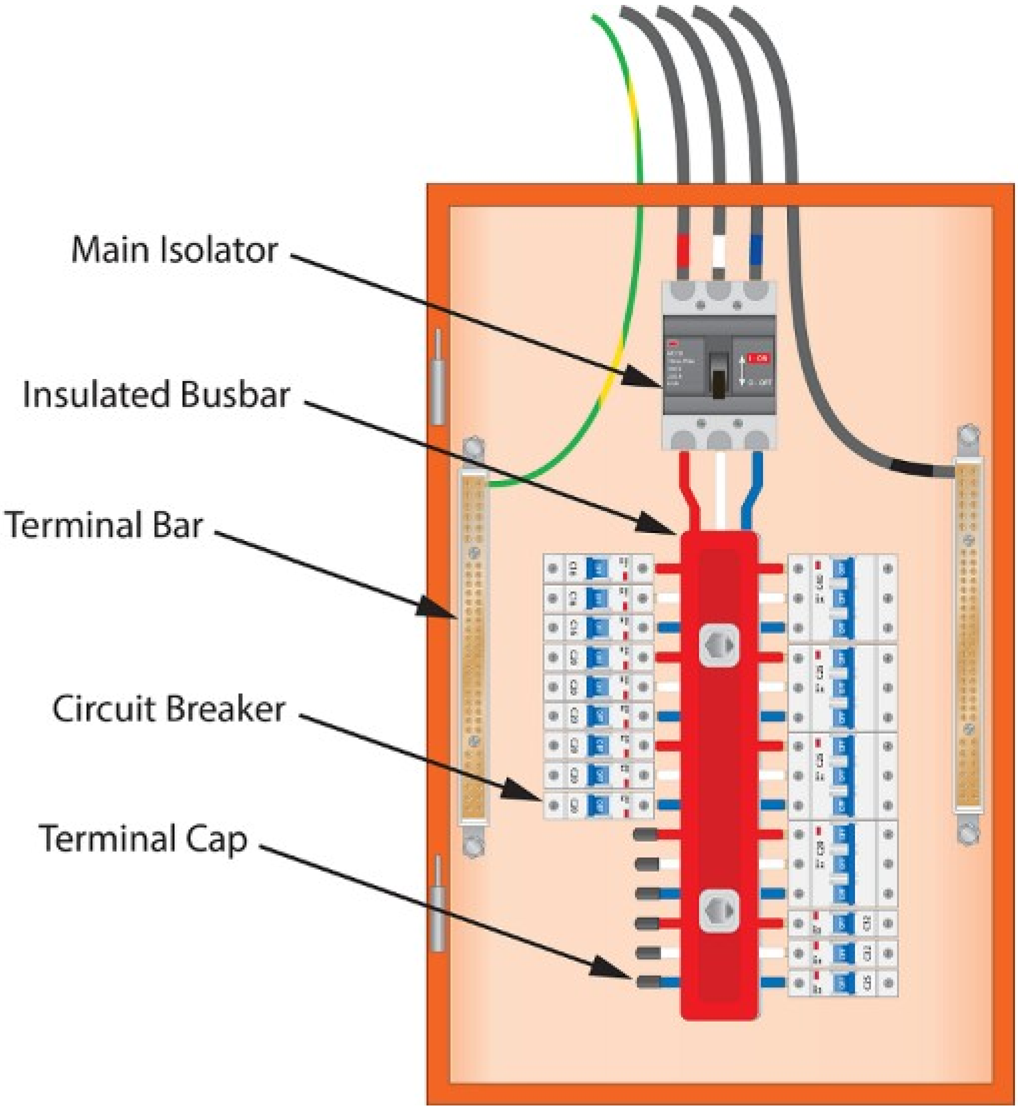
	○ Process monitoring equipment.
Power Factor Correction (PFC) Switchboards	• Power factor correction switchboards are used to monitor and maintain the power factor of an installation within certain predetermined limits. • Contain equipment to monitor the power factor of an installation, along with several contactors and capacitor banks. • Capacitor banks are automatically switched in and out of the circuit (in parallel) to compensate for variations in inductive loading. • Care must be taken when working with PFC switchboards as the large capacitor banks can pose a serious shock hazard.
Temporary Switchboards	• Temporary switchboards are used to provide lighting and power during the construction of a site. • They are systematically removed as each section of the permanent electrical installation is completed and energized. • Temporary switchboards must comply with all the usual requirements for switchboards, as well as some additional requirements as detailed in AS/NZS 3012 Electrical installations: Construction and demolition sites.

The following diagram shows an example of a main switchboard for a single domestic installation.



*Note: Type and arrangement of equipment may vary by jurisdiction – refer to your local Service and Installation Rules (SIRs) for the specific requirements in your State/Territory.

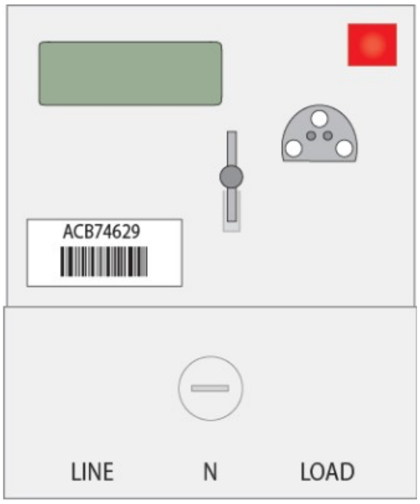
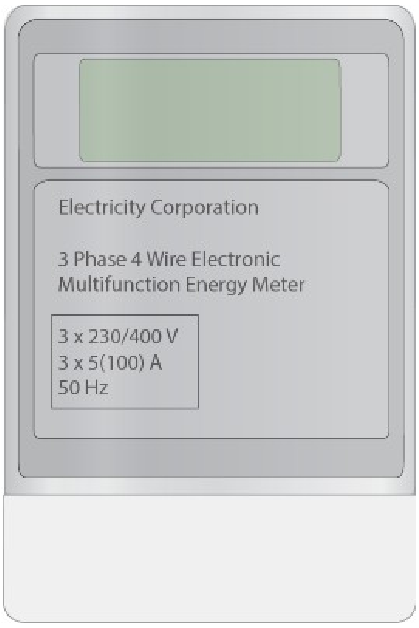
The following diagram shows an example of a distribution board in a commercial installation.

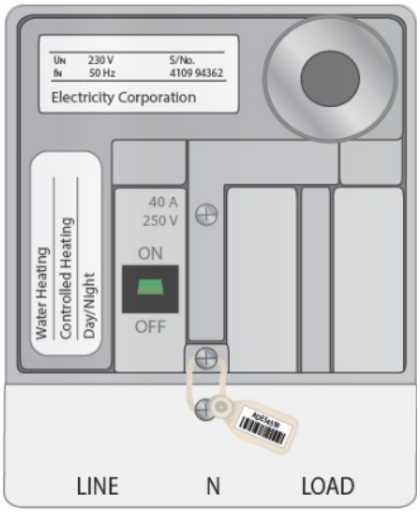


9.2 Metering

Metering Equipment

There are a range of different meters and metering equipment used in different installation scenarios. The supply authority attaches a type of seal in order to detect any tampering of the service providers equipment. Some common types are shown in the following table.

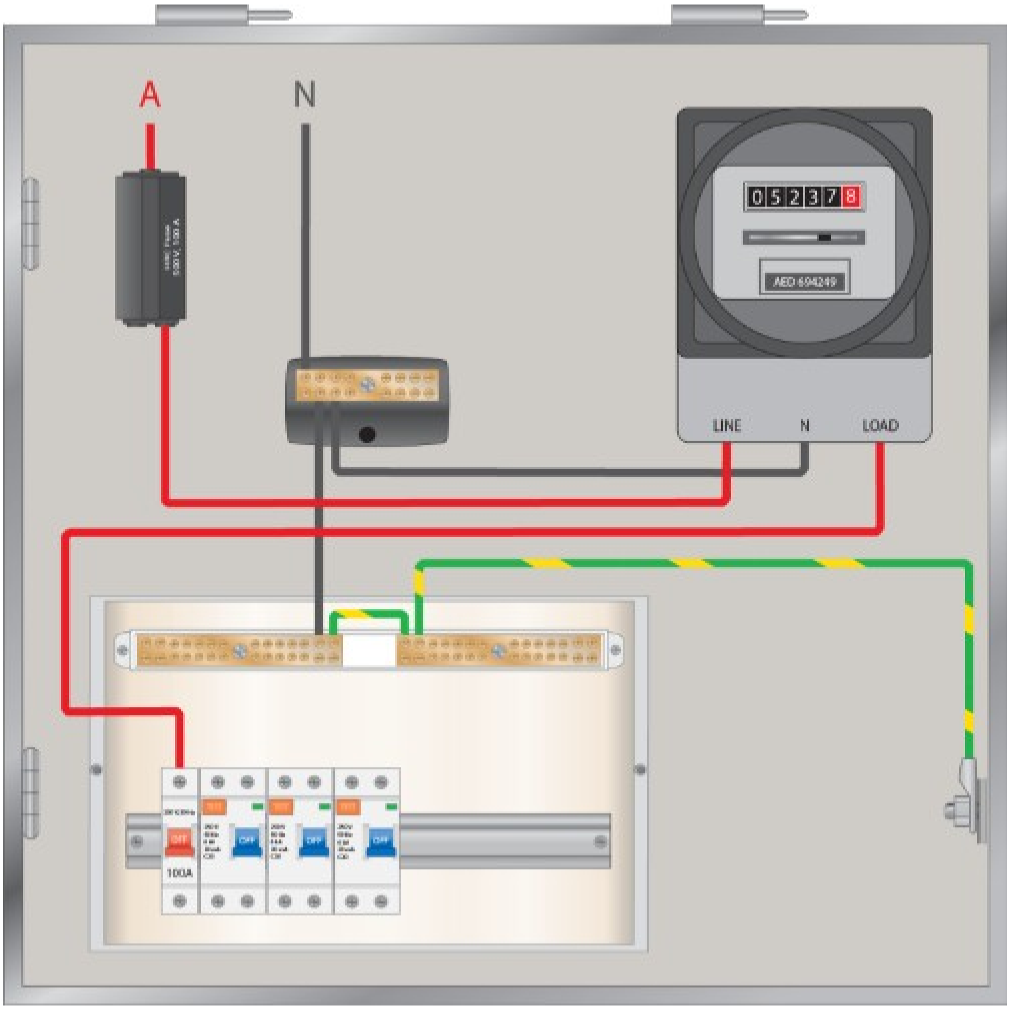
<table>
<tr><th colspan="3">Metering Equipment</th></tr>
<tr><td>Type</td><td>Example</td><td>Description</td></tr>
<tr><td>Whole Current Energy Meter</td><td>
</td><td>Consists of a voltage coil and a current coil.
The voltage coil is connected in parallel with the supply.
The current coil is connected in series with the supply.</td></tr>
<tr><td>Electronic Energy Meter</td><td>
</td><td>Suitable for ‘time of use (TOU)’ metering, where several different tariffs apply depending on the time of day or night.</td></tr>
<tr><td>Polyphase Energy Meter</td><td>
</td><td>Capable of metering energy usage in a three phase system.</td></tr>
</table>

Ripple Control Device		• Used to automatically switch controlled-loads such as off-peak water heating systems. • Switching is triggered by the network provider, via a controlled ripple at a specific frequency sent out along the supply network. • Notice the seal attached between the cover screws to help identify any tampering of equipment.
Current Transformer (CT)		• Used to step-down large values of current for metering. • The line conductor passes through the centre of the CT, becoming the primary winding. • The secondary winding is housed in the CT.

Whole Current Metering

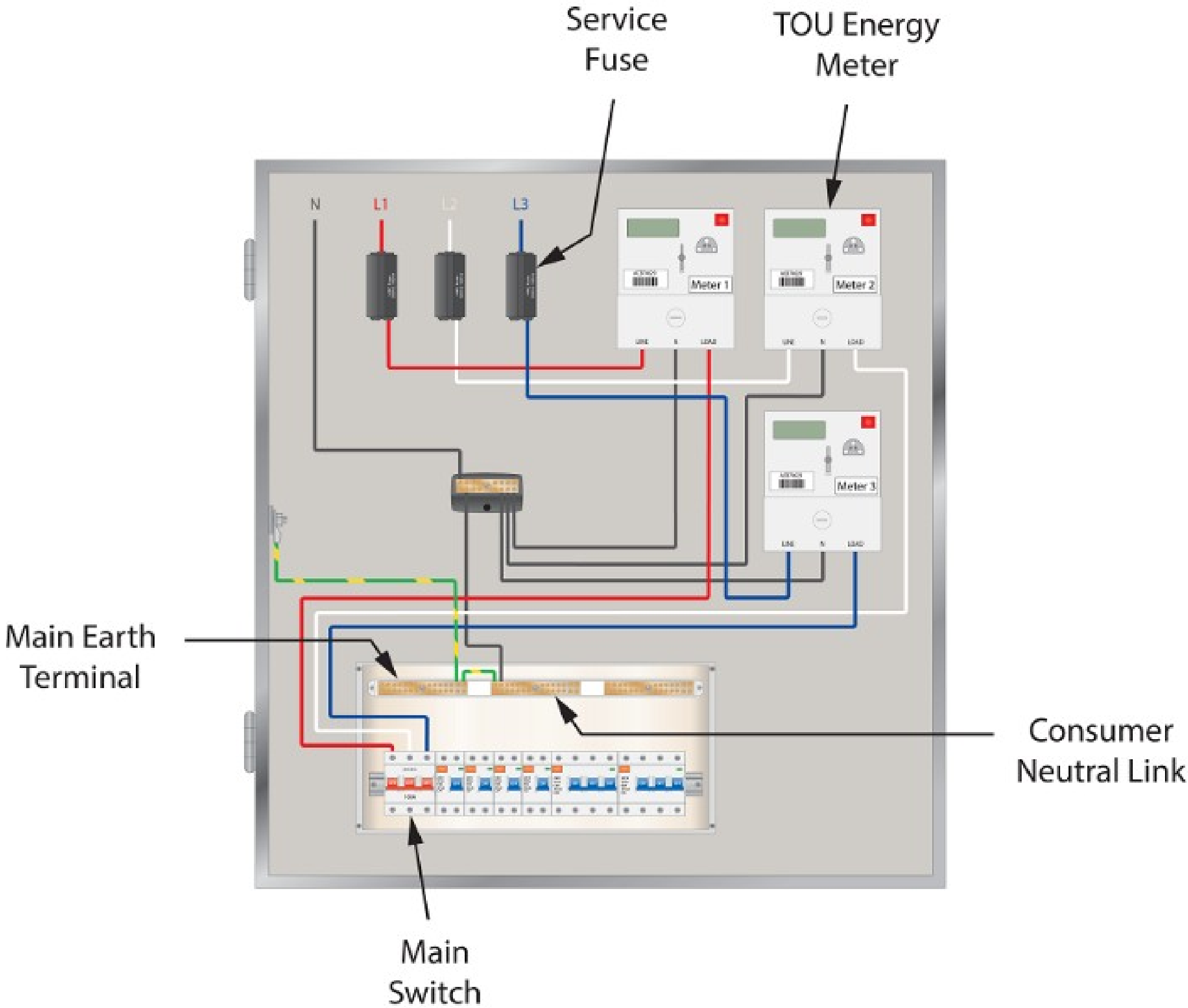
Whole current metering is used for services up to 100 A per phase. The following diagram shows the arrangement of whole current metering in the main switchboard of a single phase domestic installation.

Whole Current Metering Arrangement



Components	Illustration	Description
Whole Current Meter		Whole current meters are connected directly to the supply conductors. The full load current passes through a whole current meter. A neutral connection is necessary for the connection of the meter’s voltage coil.

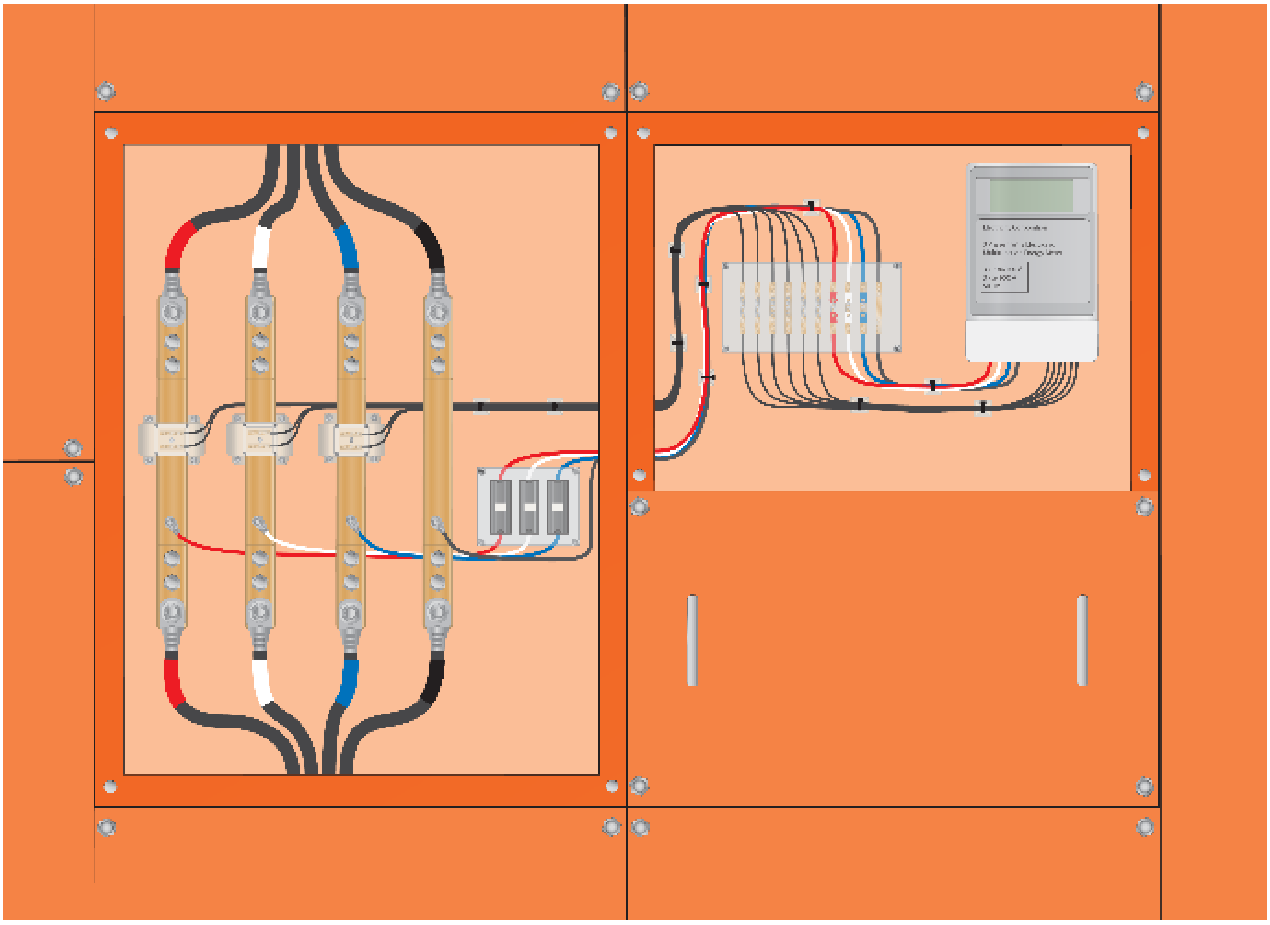
There are a variety of whole current metering arrangements depending on the number and type of supplies and the presence of controlled loads. The following diagram shows a three phase switchboard with electronic TOU metering.

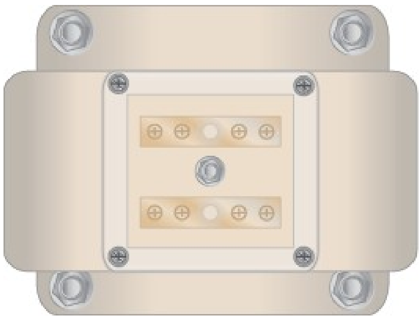


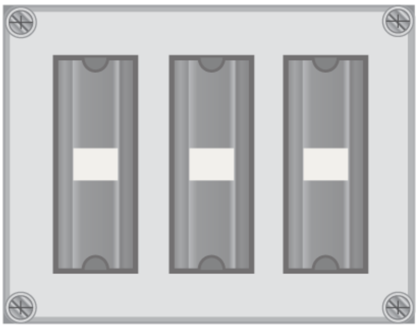
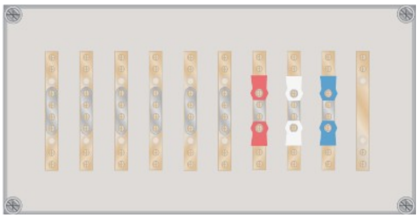
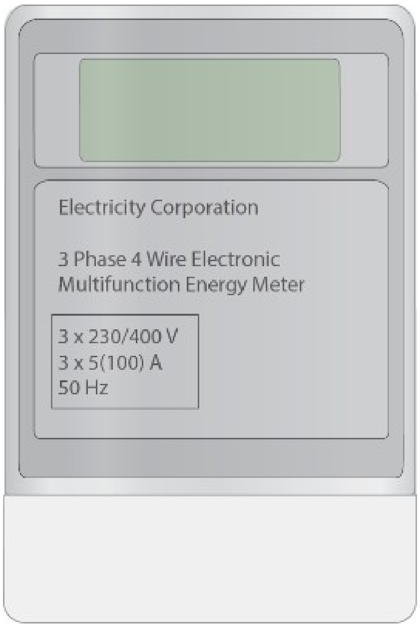
Current Transformer (CT) Metering

For services greater than 100 A per phase, current transformer (CT) metering is used. The following diagram shows the arrangement of CTs and associated equipment inside the main switchboard of a commercial three phase installation.

Current Transformer (CT) Metering Arrangement



Components	Illustration	Description
Current Transformer (CT)		• Measures the load current indirectly by sensing the magnetic field around a conductor. • The magnetic field induces an e.m.f. into the CT coil, which causes a current to flow in the CT circuit that is proportional to the load current flowing in the line conductor.

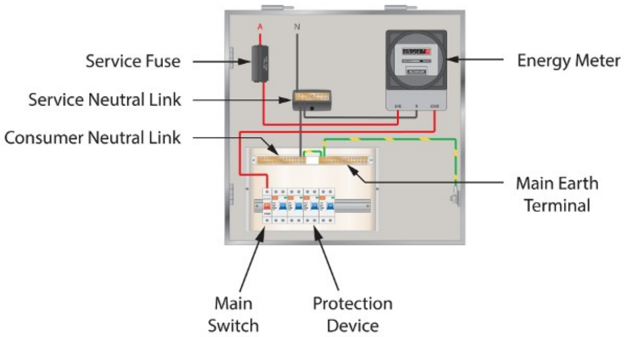
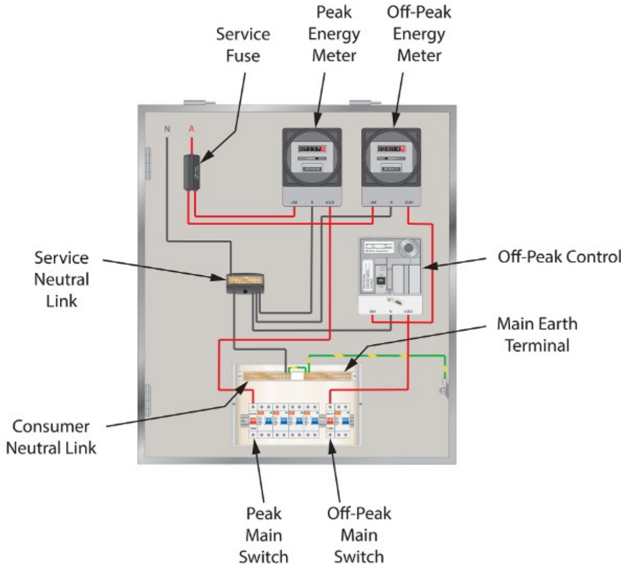
Potential Fuses		• Potential fuses protect the metering equipment.
Metering Test Block		• Allows for testing, shorting and disconnecting the CTs from the circuit. • Note: for safety, the secondary terminals of a CT must be shorted before the meter is disconnected.
Polyphase Energy Meter		• An energy meter is connected to the CT circuit to measure the CT circuit current. • The meter is calibrated to indicate the line current based on the current flowing in the CT circuit.

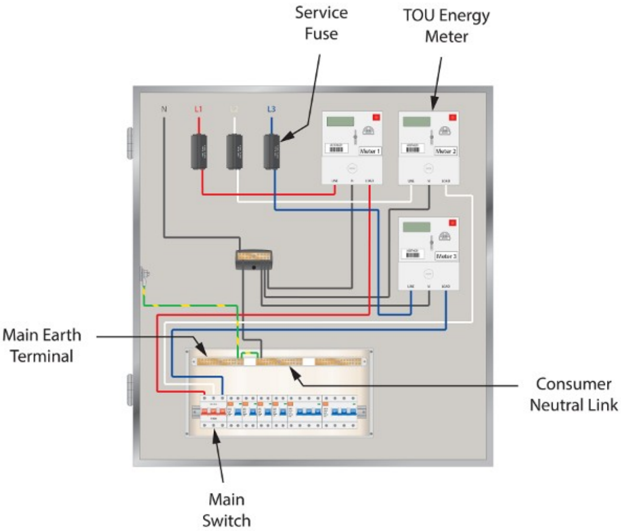
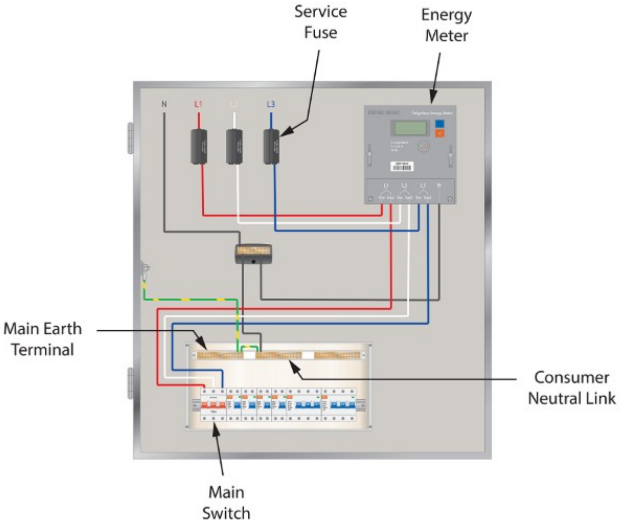
9.3 Switchboards/Distribution Boards Arrangements

Switchboard Arrangements

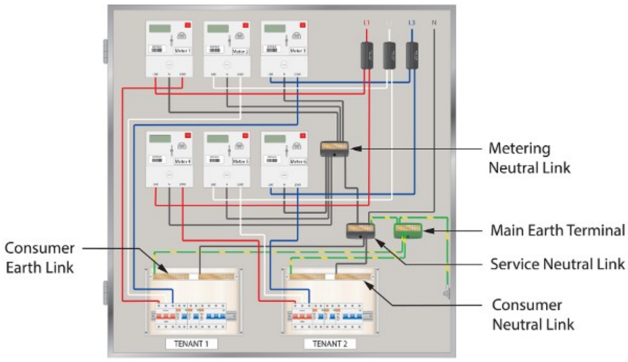
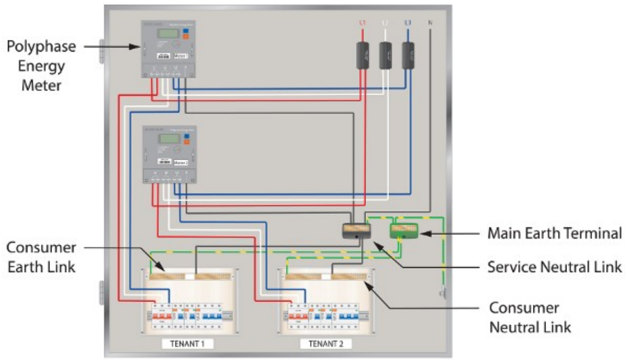
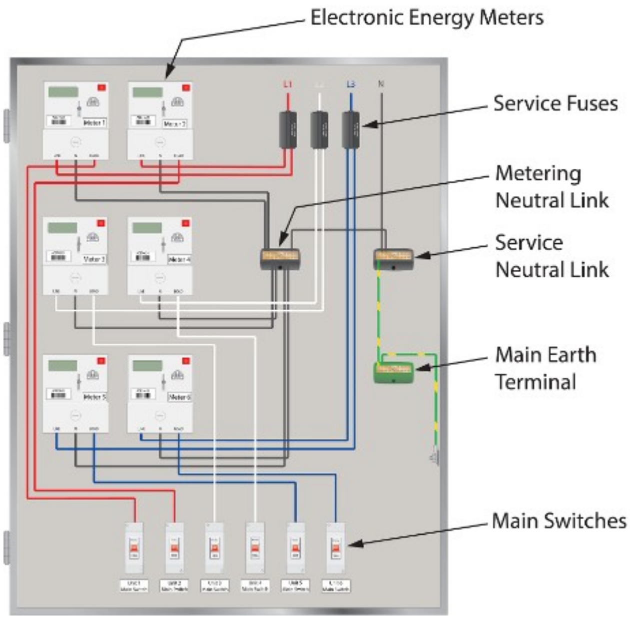
The exact arrangement of wiring and equipment in switchboards varies depending on the purpose of the switchboard, and on the Service and Installation Rules (SIR) of the local network.

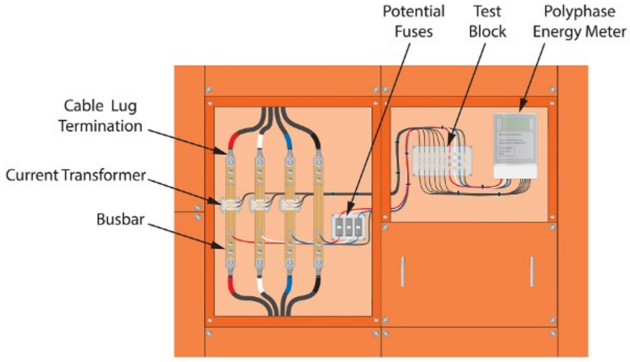
The following table provides some typical examples of wiring and equipment layouts and connections for single phase and three phase main switchboards in domestic installations.

Domestic Switchboard Arrangements	
Type	**Arrangement**
Single Phase, Single Tariff Switchboard	
Single Phase, Dual Tariff Switchboard	

Three Phase Switchboard (single phase meters)	
Three Phase Switchboard (polyphase meter)	

The following table provides some typical examples of wiring and equipment layouts and connections for single phase and three phase main switchboards in commercial and industrial installations.

Commercial/Industrial Switchboard Arrangements	
Type	**Arrangement**
Multiple Tenancy Three Phase Switchboard 1	
Multiple Tenancy Three Phase Switchboard (polyphase meter)	
Multiple Tenancy Three Phase Switchboard 2	

Three Phase Switchboard with CT Metering	

Switchboard Requirements

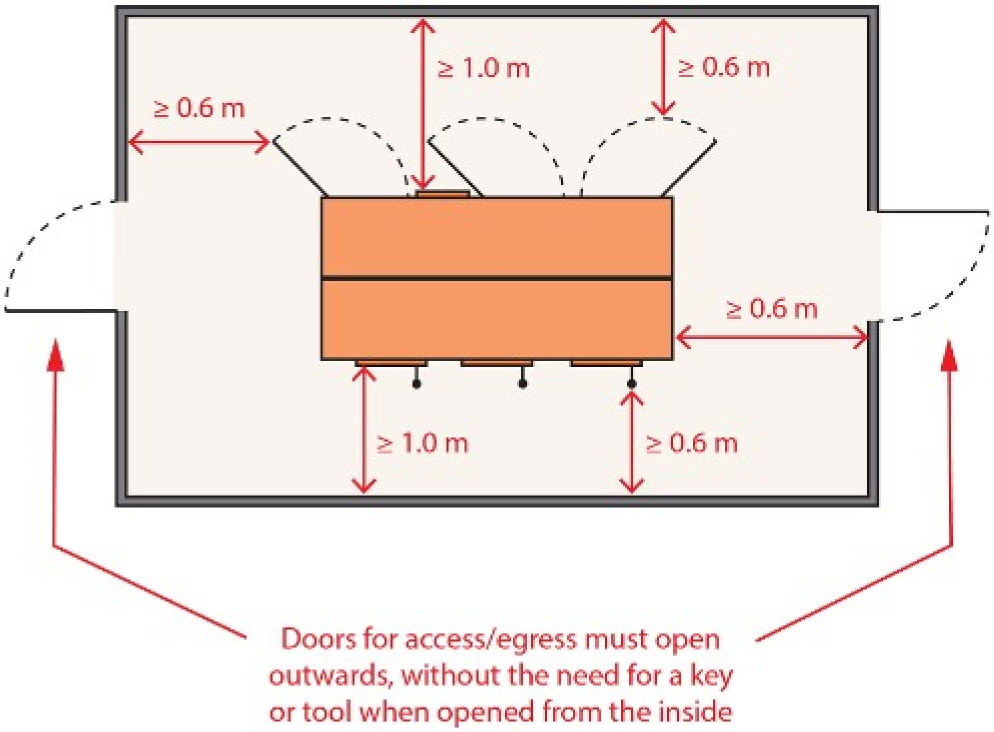
Switchboards and distribution boards are used to house critical protection and control equipment in an installation. For this reason, AS/NZS 3000:2018 Section 2 specifies several requirements regarding the installation and arrangement of switchboards, as summarised in the following table.

Switchboard Requirements	
Issue	**Requirements**
Suitability of Equipment	• Switchboards must: ○ Have an IP rating that is suitable for the installation conditions. ○ Be suitably constructed to withstand the various mechanical, electrical and thermal stresses likely to occur. • Switchboard wiring must be suitable to withstand any thermal and magnetic effects.
Installation of Switchboards	• Must be arranged for ease of access, operation, inspection, testing, maintenance and repair. • Locations for the installation of switchboards must be: ○ Be well ventilated. ○ Allow for a 1 m clearance around accessible faces of the switchboard when the doors are closed (non-domestic only). ○ Allow for a 0.6 m clearance around switchboards when the doors are open. • Main switchboards should be readily accessible and within easy access of the entrance to the building.
Arrangement of Equipment	• Where circuit breakers are mounted in the same row the orientation of the switch mechanisms must be in the same direction.

	• All bare conductors in switchboards must be fixed in place with minimum distances, or suitably insulated, to prevent arcing. • Switchboard wiring attached to hinged panels must have sufficient length to allow movement of the panels and prevent stress on conductors and terminations. • In the interests of minimizing the spread of fire, cable entries to switchboards should provide a tight fit.
Identification of Equipment	• All equipment in a switchboard must be clearly identified on or adjacent to the switchboard, including: ○ Switches and protective devices. ○ Bars and links. ○ Equipment terminals. ○ Common neutrals. • Main switchboards must be clearly labeled 'MAIN SWITCHBOARD' and their location should be indicated at the entrance to the building.

Switchrooms

The following diagram shows the basic clearances, access and egress requirements for switchrooms.



Restricted Locations

There are a number of restricted locations for switchboards. Locations in which switchboards are not permitted to be installed include:

- Within 1.2 m of the ground.
- In a cupboard that is not specifically set aside for that purpose.
- Above open water containers.
- Above a stationary cooking appliance.
- Within any classified Zone of a bath, shower, pool, fountain, water feature, sauna or refrigeration room.
- Within a fire-isolated stairway, passageway or ramp.
- Within a classified hazardous area (HA).

Exceptions apply for some of the restricted locations above. Refer to AS/NZS 3000:2010 Clause 2.9.2.5 for further detail.