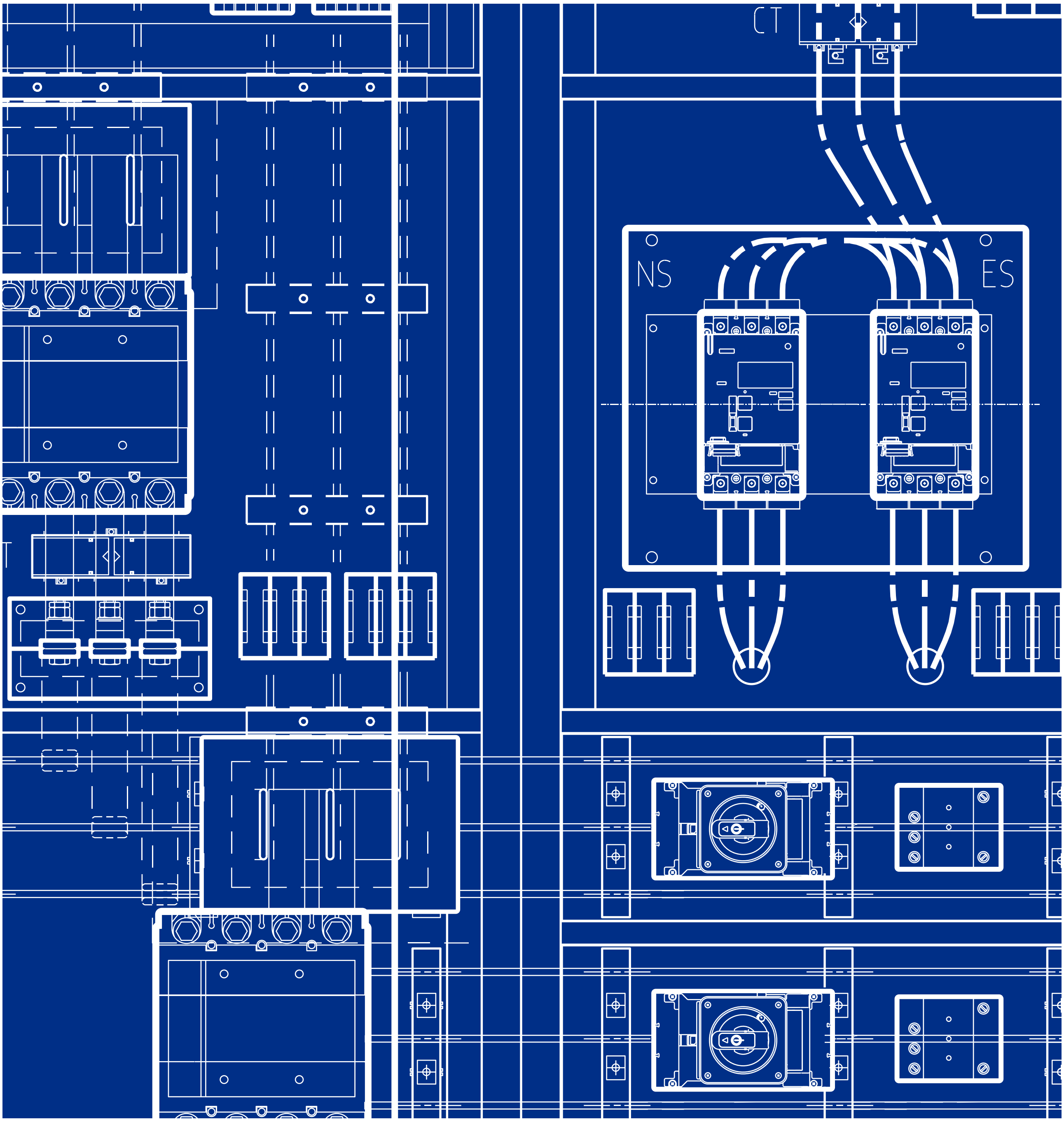
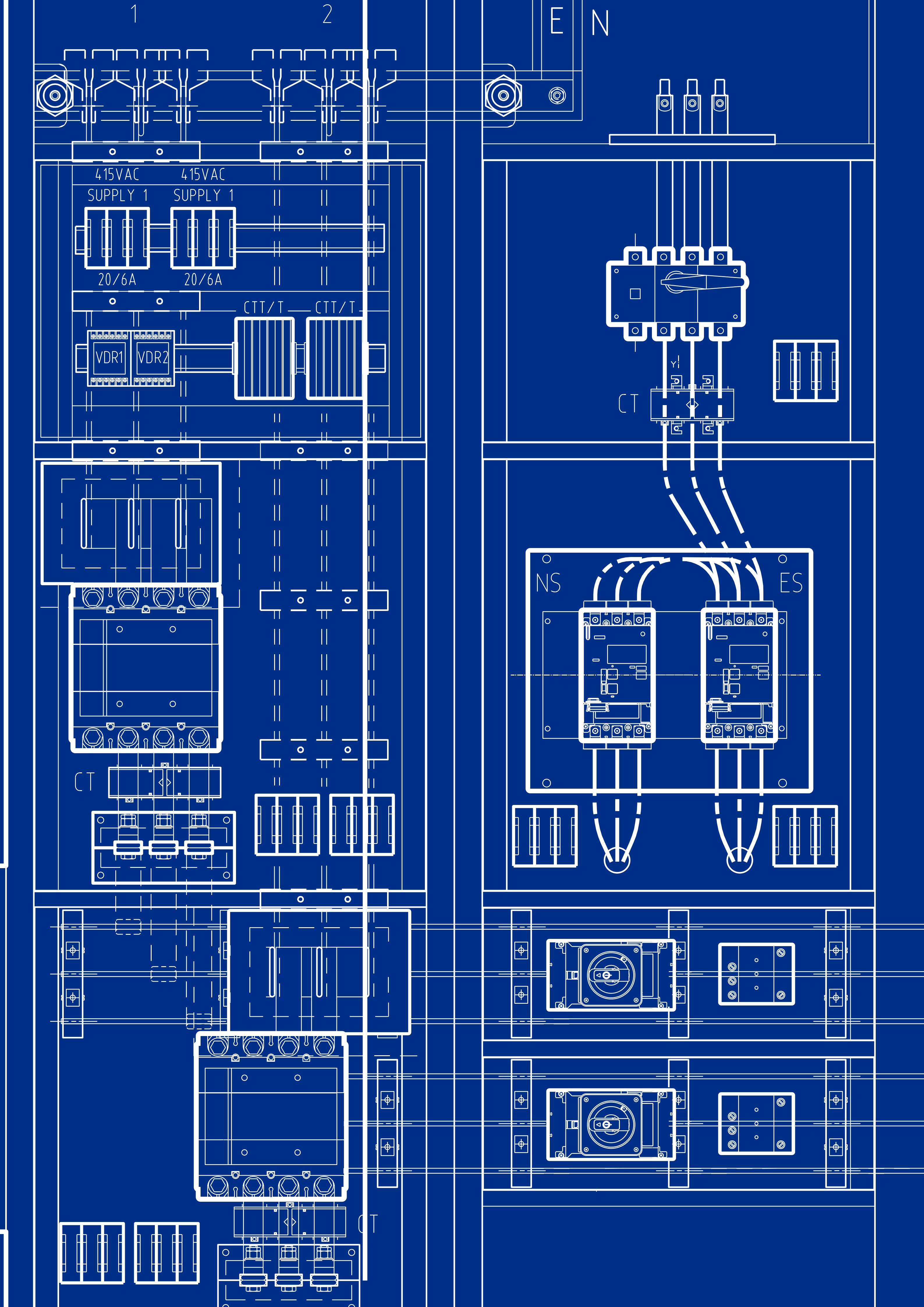
Power Distribution and Protection

Circuit Protection



Handbook

Technical Catalogue 2021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LV Power Distribution Protection Guide Index

1 Introduction to Low Voltage (LV) Circuit Protective Devices

1 Introduction to Low Voltage (LV) Circuit Protective Devices

1.1 Relevant Standards Related to Circuit Breakers and Switchboards

The intent of the information presented in this section is to provide an overview of the most relevant standards that related to switchboards and LV circuit breakers. For the full details of the standards summarised below please contact Standards Australia

Introduction

Within Australia and New Zealand specific standards exist which guide manufacturers of switchboards and switchgear in the design, test and performance requirements of electrical equipment. While there are numerous catalogued standards that are maintained by the Council of Standards Australia and the Council of Standards New Zealand, for the purpose of this section we will only focus on the following standards which are commonly referenced by industry in relation to switchboards and circuit breakers

- AS/NZS 60947-2 Low-voltage switchgear and controlgear Circuit breakers
- AS/NZS 60898 Circuit breakers for overcurrent protection for household and similar installations
- AS/NZS 61008 Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCBs) General rules
- AS/NZS 61009 Residual current operated circuit breakers with integral overcurrent protection for household and similar uses (RCBOs) General rules
- AS/NZS 61439 Low-voltage switchgear and controlgear assemblies General rules

AS/NZS 60947-2 Low-Voltage Switchgear and Controlgear Circuit Breakers

AS/NZS 60947-2 is the low-voltage (LV) circuit breaker product standard. It defines the various definitions, considerations, verification tests and characteristics that must be respected when designing and building an LV circuit breaker.

AS/NZS 60947-2 applies to the circuit breaker and the main contacts that are intended to be connected to circuits. The rated voltage of the circuit breaker must not exceed 1000 V AC or 1500 V DC and the rated current is between 0.5 – 6300 A. Circuit breakers such as miniature circuit breakers (MCBs), Moulded Case Circuit Breakers (MCCBs) and Air Circuit Breakers (ACBs) test verified to AS/NZS 60947-2 are intended for use in industrial applications, but are equally suitable for use in commercial and domestic applications.

AS/NZS 60898-1 Circuit breakers for Overcurrent Protection for Household and Similar Installations

AS/NZS 60898-1 is the low-voltage (LV) circuit breakers product standard relating to ‘household and similar installations’. It defines the various definitions, considerations, verification tests and characteristics that must be respected when designing and building an LV circuit breaker.

AS/NZS 60898-1 applies to AC air-break circuit breakers, typically MCBs for operation at 50 Hz or 60 Hz, having a rated voltage not exceeding 440 V (between phases), a rated current not exceeding 125 A and a rated short-circuit capacity not exceeding 25,000 A.

These circuit breakers are intended for the protection against overcurrents of wiring installations of typical households and similar applications. The intent for these circuit breakers is that they are designed for use by uninstructed people and for not being maintained.

AS/NZS 61008 Residual Current Operated Circuit breakers Without Integral Overcurrent Protection for Household and Similar Uses (RCCBs) General Rules

AS/NZS 61008 is the low-voltage (LV) residual current operation circuit breaker WITHOUT integral overcurrent protection (RCCBs) product standard relating to ‘household and similar uses’. It defines the various definitions, considerations, verification tests and characteristics that must be respected when designing and building an LV RCCB.

AS/NZS 61008 applies to residual current operated circuit breakers functionally independent of, or functionally dependent on, line voltage, for household and similar uses, not incorporating overcurrent protection for rated voltages not exceeding 440 V AC with rated frequencies of 50 Hz, 60 Hz or 50 / 60 Hz and rated currents not exceeding 125 A, intended principally for protection against shock hazard.

These circuit breakers are intended for the protection of persons against indirect contact, the exposed conductive parts of the installation being connected to an appropriate earth electrode.

RCCBs having a rated residual operating current not exceeding 30 mA are also used as a means for additional protection in the case of failure of the protective means against electric shock.

AS/NZS 61009 Residual Current Operated Circuit breakers With Integral Overcurrent Protection for Household and Similar Uses (RCBOs) General Rules

AS/NZS 61009 is the low-voltage (LV) residual current operation circuit breaker WITH integral overcurrent protection (RCBOs) product standard relating to ‘household and similar uses’. It defines the various definitions, considerations, verification tests and characteristics that must be respected when designing and building an LV RCBO.

AS/NZS 61009 applies to residual current operated circuit breakers functionally independent of, or functionally dependent on, line voltage, for household and similar uses, not incorporating overcurrent protection for rated voltages not exceeding 440 V AC with rated frequencies of 50 Hz, 60 Hz or 50 / 60 Hz and rated currents not exceeding 125 A, and rated short-circuit capacities not exceeding 25,000 A for operation at 50 Hz or 60 Hz.

These circuit breakers are intended for the protection of persons against indirect contact, the exposed conductive parts of the installation being connected to an appropriate earth electrode and to protect against overcurrents that may occur typically within a buildings wiring reticulation system.

RCBOs having a rated residual operating current not exceeding 30 mA are also used as a means for additional protection in the case of failure of the protective means against electric shock.

AS/NZS 61439 Low-Voltage Switchgear and Controlgear Assemblies General Rules

Above: Typical switchboard with power distribution and motor control elements

AS/NZS 61439 is the low-voltage (LV) switchgear and control gear assembly (ASSEMBLY) standard and it defines the various considerations, verification tests and characteristics that must be respected when designing and building an LV switchboard.

An ASSEMBLY is a combination of LV switching devices (such as circuit breakers or load break switches), associated equipment (such as metering/measurement, sirens / signaling, controlling devices etc.) installed within an enclosure that includes all the internal mechanical and electrical interconnections and structural parts. All components must also comply with necessary standards (i.e. AS/NZS 60947-2 in the case of LV circuit breakers).

AS/NZS 61439 was published in 2016 and has replaced AS/NZS 3439. The most important attributes of the new AS/NZS 61439 series of standards can be summarised as follows:

1. A new User Template is included to facilitate the creation of a customer specification
2. The final switchboard design must be verified using one of a number of permitted methods
3. The main busbar permissible operating temperature rating has been increased
4. The forms of separation have been expanded to include images for use with circuit breaker chassis
5. The arc fault containment options have been expanded to allow the international variant based on TR61641

Old Standard	New Equivalent
AS/NZS 3439.1:2002 Type – Tested (TTA) and Partially Type – Tested (PTTA) assemblies	**AS/NZS 61439-0** Guide (New to AS/NZ) **AS/NZS 61439-1** General rules **AS/NZS 61439-2** Power switchgear and controlgear assemblies
AS/NZS 3439.3:2002 Distribution boards	**AS/NZS 61439-3** Distribution boards
AS/NZS 3439.4:2002 Particular requirements for assemblies for construction sites (ACS)	**AS/NZS 61439-4** Assemblies for construction sites
AS/NZS 3439.5:2002 Particular requirements for assemblies for power distribution in public networks	**AS/NZS 61439-5** Assemblies for power distribution in public networks
AS/NZS 3439.2:2002 Particular requirements for Busbar trunking systems (Busways)	**AS/NZS 61439-6** Busbar Trunking systems **IEC 61439-7** Marina, Camping, Market and Charging (New to AS/NZ)

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1.2 Application of AS/NZS 60947-2 and AS/NZS 60898-1

Technical Comparison In Reference To Miniature Circuit Breakers (MCBs)

As previously outlined, two relevant standards (IEC/AS/NZS60947-2 and IEC/AS/NZS60898-1) can be applied to LV miniature circuit breakers (MCBs) which will guide the suitability of the device depending on the final application. The MCB should have markings printed onto the casing indicating which standards the device has been tested verified (see figure 1.1).

To differentiate at a very high level, MCBs test verified to AS/ZS60947-2 are typically best suited to industrial applications (i.e. higher mains voltages, higher pollution levels and short circuit rating).

Circuit breakers test verified to AS/NZS 60898-1 are suitable for use in homes, commercial offices, schools etc. To further clarify the difference between the intended application of the standards, AS/NZS 60898-1 sets circuit breaker performance limits to have rated voltage not exceeding 440 V (between phases), a rated current not exceeding 125 A and a rated short-circuit capacity not exceeding 25 kA.

The potential consequences of using circuit breakers designed and tested to AS/NZS 60898-1 and not to AS/NZS 60947-2 can be catastrophic if they are installed into industrial applications.

An MCB designed and tested to AS/NZS 60898-1 is intended for use in clean, low pollution indoor environments. If exposed to harsh, high level pollution industrial environments, it would be expected that the service life and the performance capability of the MCB would be dramatically reduced.

Typically AS/NZS 60898-1 certified MCBs meet the basic performance characteristics to provide proper protection for household installations. MCBs only designed and tested to AS/NZS 60898-1 should not be used in industrial applications.

If cost is not a primary consideration then the ideal solution is to use an MCB that is designed and tested verified to both AS/NZS 60898-1 and AS/NZS 60947-2. This ensures that the performance meets the requirements of use in residential installations and infrastructure industry and applications.

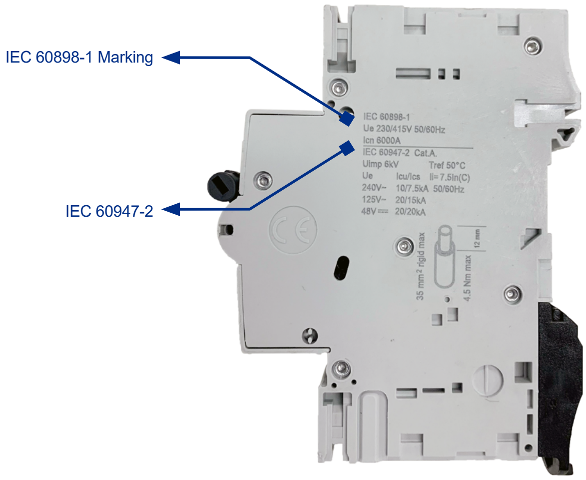

Figure 1.1
How to identify MCBs that are designed and tested to AS/NZS 60898-1 and or AS/NZS 60947-2

	AS/NZS 60898-1	AS/NZS 60947-2
Application	Circuit Breakers are intended for the protection of wiring installations against both overloads and short-circuits in domestic or commercial wiring installations where operation is possible by uninstructed people	Circuit Breakers are intended for the protection of the lines against both overloads and short-circuits in industrial wiring installations where normal operation is done by instructed people
Intended Exposure to People	'Uninstructed people' refers to people who do not hold necessary recognised electrical qualification to inspect and test electrical equipment	'Instructed people' refers to people who do hold necessary recognised electrical qualifications to inspect and test electrical equipment (i.e. an 'A grade' electrician)
Intended Installation Environment	Clean, low pollution	Not clean, high pollution
Intended Installation Location	Load centers	Load centers, panelboards, main switchboards
Rated Current	6 - 125 A	-
Thermal Release Ambient Temp	30 °C	40 °C
Short Circuit Breaker Capacity	< 25 kA	< 50 kA
Impulse Voltage (U_{imp})	4 kV	6 kV or 8 kV
Protection Curves	B, C, D	3 - 5 I_n, 5 -10 I_n, 10 - 20 I_n
Rated Voltage (U_e)	400 / 415 V AC	440 V AC, 500 V AC, 690 V AC
Pollution Degree	2	3

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Short Circuit Breaking Characteristics (I_{cn}, I_{cu}, I_{cs})

O - Represents an opening operation.

C - Represents a closing operation followed by an automatic opening.

T - Represents the time interval between two successive short-circuit operations: 3 minutes.

Rated Short-Circuit Breaking Capacity (I_{cn})	Ultimate Short-Circuit Breaking Capacity (I_{cu})
Is the value of the short-circuit that the circuit breaker is capable of withstanding in the following test of sequence of operations: O - t - CO	Is the value of the short-circuit that the circuit breaker is capable of withstanding in the following test of sequence of operations: O - t - CO
After the test the circuit breaker is capable, without maintenance to withstand a dielectric strength test at a test voltage of 900 V	After the test the circuit breaker is capable, without maintenance to withstand a dielectric strength test at a test voltage of 1000 V
Moreover the circuit breaker shall be capable of tripping when loaded with 2.8 x I_n within the time corresponding to 2.55 x I_n but greater than 0.1 s	Moreover the circuit breaker shall be capable of tripping when loaded with 2.5 I_n within the time corresponding to 2 I_n but greater than 0.1 s

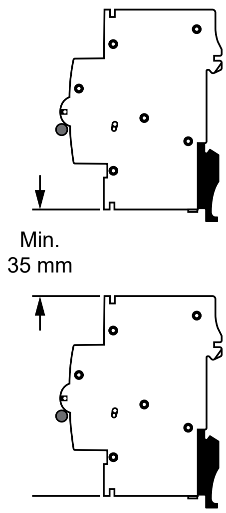
Rated Service Short-Circuit Breaking Capacity (Ics)	
Is the value of the short-circuit that the circuit breaker is capable of withstanding in the following test of sequence of operations: O - t - CO - t - CO	Is the value of the short-circuit that the circuit breaker is capable of withstanding in the following test of sequence of operations: O - t - CO - t - CO
After the test the circuit breaker is capable, without maintenance to withstand a dielectric strength test at a test voltage of 1500 V AC	After the test the circuit breaker is capable, without maintenance to withstand a dielectric strength test at a test voltage of twice its rated insulation voltage with a minimum of 1000 V AC
Moreover, the circuit breaker shall not trip at a current of 0.96 I_n. The circuit breaker shall trip within 1h when current is 1.6 x I_n.	A verification of the overload releases on I_n and moreover the circuit breaker shall trip within 1h when current is 1.45 x I_n (for I_n < 63 A) and 2 h (for I_n > 63 A).

Note: AS/NZS 60898-1 defines / uses 'I_{cn}' and AS/NZS 60947-2 defines / uses 'I_{cu}'.

AS/NZS 60898-1 defines the relation between the rated short-circuit capacity (I_{cn}) and the rated service short-circuit breaking.

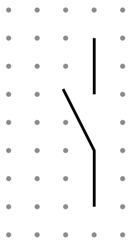
In both sequences all circuit breakers are tested for emission of ionized gases during short-circuit (grid distance), in a safety distance between two MCBs of 35 mm when devices are installed in two different rows in the enclosure.

I_{cn} (A)	I_{cs} (A)
≤ 6000	6000
> 6000 ≤ 10000	0.75 x I_{cn} (min 6000 A)
> 10000	0.75 x I_{cn} (min 7500 A)

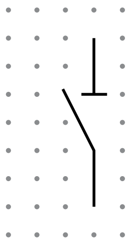


1.3 Relevant Electrical Symbols Related to Circuit Protection Devices

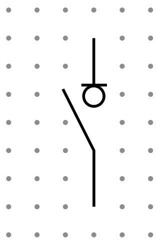
Switching and Circuit Protection Device Typical Symbols



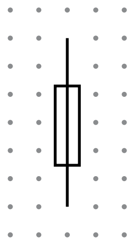
Switch



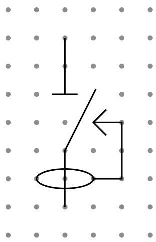
Disconnector



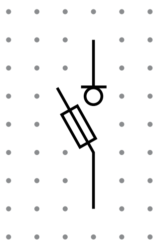
Switch - Disconnector



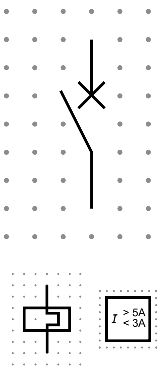
Fuse



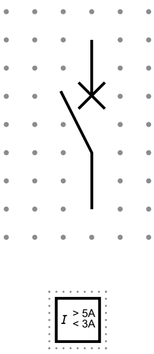
RCCB



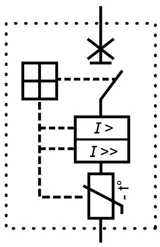
Fuse Switch - Disconnector



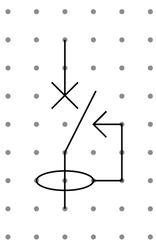
Circuit Breaker With Thermal Magnetic Tripping



Circuit Breaker With Electronic Overcurrent Release Tripping



Circuit Breaker With Electronic Overcurrent Release Tripping With Integrated Overheating Protection



RCBO

1.4 Regulatory Compliance Mark (RCM)

RCM Explained

Regulatory Compliance Mark (RCM) is a symbol that is printed on specific categories of product which signifies that a supplier has taken the necessary steps to have the product comply with the electrical safety and/or electromagnetic compatibility (EMC) legislative requirements.

All Level 1, 2 or 3 electrical equipment offered for sale by registered 'Responsible Suppliers' must be marked with the Regulatory Compliance Mark (RCM), as illustrated in figure 1.2.

The RCM should be placed in accordance with AS/NZS 4417.1 (i.e. generally on the external surface of the electrical equipment as near as possible to the model identification).

All new miniature circuit breakers (MCBs) and residual current devices (RCDs) sold by a responsible supplier within Australia after 2015 must display the RCM labelling on the outer case.

Figure 1.2
RCCB showing the RCM symbol.

Responsible Supplier

A Responsible Supplier is a person, company or business who is an importer or onshore manufacturer of in-scope electrical equipment into the Australian and New Zealand supply chain (first supplier). By law this Responsible Supplier must be an Australian or New Zealand legal entity. Information on Responsible Suppliers is available from ERAC.

Electrical Regulatory Authorities Council (ERAC)

ERAC is the organisation that works towards the coordination of technical and safety electrical regularity functions between the eight Australian states and New Zealand. The council is made up of representatives of the regulatory authorities responsible for electrical safety, supply and energy efficiency in New Zealand and the Australian states, territories and commonwealth.

ERAC National Database

The Electrical Equipment Safety System (EESS) incorporates a National Database that is the gateway for in-scope electrical equipment registration in Australia and New Zealand (MCBs and RCDs are 'in-scope electrical equipment').

The database records the registration details of Responsible Suppliers of electrical equipment in Australia and New Zealand. Responsible Suppliers are required to register their details on the database.

As part of the registration process, Responsible Suppliers also make a declaration that the equipment they sell meets relevant standards and is electrically safe. Responsible Suppliers are required to register all types of Level 2 and Level 3 equipment they sell on the database.

ACMA and RSM

The Australian Communications and Media Authority is an Australian Government statutory authority, which regulates product compliance for Electro-Magnetic Compatibility, Telecommunications, Radio Communications and Electro-Magnetic Radiation.

In New Zealand, these are covered by the Radio Spectrum Management.

The RCM symbol is also used to show compliance for products covered by the ACMA.

2 Fundamentals of Power Distribution

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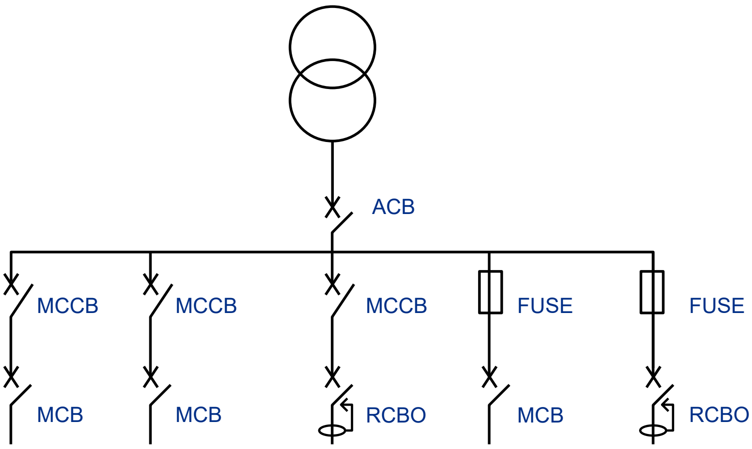
2 Fundamentals of Power Distribution

2.1 Reticulation and Typical Electrical Distribution Systems

Reticulation is also commonly known as Electrical Distribution, and describes the formation of busways, cables, protective devices and all other associated equipment and how they are networked

Figure 2.1
There is no 'typical' reticulation system, however a basic system could be as follows:



ACB: Air Circuit Breaker
MCCB: Moulded Case Circuit Breaker
MCB: Miniature Circuit Breaker
RCBO: Residual current devise with over current protection
FUSE: BS or DIN HRC Fuse

In normal circumstances an electricity supply is taken direct from the supply company's medium or high voltage network, which could be for example around 11 kV (11,000 V). In this type of system we require a “step-down transformer” to convert the supply to a Low Voltage (LV) level of 400 V or 415 V.

Therefore, in an LV system the first (source) device is the step-down transformer. This has implications on the maximum prospective fault level that can be fed to the downstream network and will be discussed later in this handbook.

Several step-down transformers can be connected in parallel, or with back-up generators, but for the purposes of this explanation we shall assume only one transformer is present.

Next in the distribution chain would be the incoming protective device. This could be a circuit breaker or a fuse, for the purposes of this explanation we shall assume an Air Circuit Breaker (ACB) is used.

The ACB is commonly used as an incoming device as it provides overload and short circuit protection, but also has an ability to hold on to (withstand) large fault currents passing through it. A high current withstand allows the opportunity for a downstream protective device to clear a fault should it be closer to the point where the fault has occurred.

Consider what would happen should the ACB incomer be opened or tripped. If the incoming device is in the open position then supply to *all* parts of the system will be lost, therefore the ACB incomer should only trip as a last resort.

Other protective devices such as Moulded Case Circuit Breakers (MCCBs) or fuses can also be used as incoming devices but using an ACB offers several distinct advantages:

- Large fault interrupting (breaking) capacity
- High withstand rating (holds on to large fault currents)
- Removable from its carriage (ideal for isolation indication and maintenance)

The choice would normally be made on the basis of current rating, prospective fault level and/or application requirements (e.g. selectivity). The most common types of devices used in the second (distribution) level are MCCBs and fuses.

Both fuses and MCCBs are highly current limiting devices under fault current conditions, and there are advantages of using either type of protective device.

On the last level we reach the point of final distribution, and the vast majority of protective devices used here are Miniature Circuit Breakers (MCB) or Residual Current Devices (RCD) with overload and short circuit protection (RCBO) . Many of these devices are highly current limiting, and so give ideal protection both in domestic and industrial/commercial applications, although some non-current-limiting types are also very common (legacy devices such as Nema Style MCBs and RCDs).

As a basic requirement the type of device is selected according to the current being drawn at that point of the system and also the maximum prospective fault level where it is to be installed.

NHP

2.2 Fault Currents

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Fault Current Types

When short circuits occur in an electrical distribution system the level of fault current can be so high that it will cause damage to equipment and/or cables due to the thermal (heat) and electromagnetic (mechanical) stresses that are imposed.

The level of heat stresses is a factor of both the level of current flowing to the downstream system and the time taken to eliminate the fault. In protective device terms this is commonly known as the I^2t or Energy Let Through.

Mechanical stresses associated with fault currents are another consideration that must be made. These stresses are attributed to the peak level of current flowing in the system. If the protective device can somehow limit the peak current under fault conditions then the mechanical stresses on the downstream system will be greatly reduced.

A more in-depth discussion of I^2t and Ipeak will be made in section 4 of this handbook.

Fault Currents can occur in different levels and are generally grouped under the labels 'overload' and 'short circuit'. To fully understand the differences it is important to be familiar with the following definitions, as displayed at the right.

In terms of values, for any one device with a pre-determined rated current a short circuit current is greater in magnitude than an overload current.

Prospective Fault Current is the maximum value of current that could occur at any one point in an electrical distribution system under short circuit conditions, i.e. with negligible impedance between conductors.

In normal conditions a short circuit is far less common that an overload.

Fault Current

A current resulting from an insulation failure or from the bridging of insulation

Overcurrent

A current exceeding the rated value (or current carrying capacity)

Overload Current

An 'overcurrent' occurring in a circuit which is electrically sound

Short Circuit Current

A 'fault current' resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions

Arc Fault Current

A luminous discharge of electricity across an insulating medium (Typically a high impedance fault in air)

Earth Fault Current / Ground Fault Current

A current resulting from inadvertent contact between an energised conductor and Earth (Amps / kA)

Earth Leakage Current

A small leakage current resulting from an insulation failure inadvertent contact between an energised conductor and Earth (Milliamps)

Fault Current Limiting Factors

There are numerous limiting factors on the maximum fault level that can be reached in any system, and some of these are:

Capacity of Source

Fortunately a generator or transformer cannot output an infinite amount of current so it is true that the capacity of the source is one of the major limiting factors of fault current.

Due to increasing demand for electricity supply there is a trend for installing higher rated transformers. However, with the increased rating comes another danger. Generally a larger source capacity results in a higher potential fault level, and can put greater stresses on the downstream system.

Also it is normally accepted that a transformer can output more fault current for longer duration than a generator of similar dimensions due its inherent strength.

Source Impedance

The impedance of the source is another limiting factor on the maximum prospective fault level that can be reached. Transformer impedance is expressed as a percentage value, generally around 4 - 6%.

This value represents the percentage value of Primary Voltage required to make full load current (flc) flow in the short-circuited terminals of the transformer Secondary. The transformer impedance has an influence on the maximum short circuit that can be output.

Cable Impedance

One of the most significant limiting factors of fault current is that of the circuit or cable impedance. The basic theory of impedance limiting fault current is based on Ohm's Law, which states the following law:

Voltage = Current x Impedance

$$V = I \times Z$$

or

$$I = \frac{V}{Z}$$

Using Ohm's Law and basic arithmetic we can see that an increase in Impedance results in a reduction in Current, therefore anything that has inherent Impedance will cause the maximum fault level to fall.

For example, cable has associated with it an Impedance (made up of a resistance and reactance), so each additional length of cable is limiting the prospective fault current.

This is the main reason fault levels at the final point of distribution are lower in magnitude than at the point of the source (transformer or generator). The total Impedance is increasing with every conductor that the current passes through, so reducing the maximum prospective fault current.

The total impedance will never reach a zero level, but it can approach a negligible amount. This is what occurs when a short-circuit is present, i.e. that there is negligible impedance between two or more conductors.

Other Limiting Factors

There are numerous limiting factors towards the maximum prospective fault currents, one which should be considered is:

High Voltage Network Impedance

In normal calculations the impedance of the HV network is normally defined as negligible. In practice this is not the case. A comprehensive short-circuit analysis should take consideration of the HV impedance. This is a common situation in rural areas, where long runs of cable reduce the potential of high fault currents.

Other limiting factors exist, but for the purposes of this handbook they will not be discussed.

2

Fault Current – Motor Contribution

Clearly the capacity or rating of the source is the major factor in determining the maximum prospective fault current that may flow as a result of a short circuit. Having said this, we have also determined that the impedance of the source is a limiting factor.

There are also factors that will contribute to the maximum fault current, the most significant being that of motors.

In basic terms motors and generators are very similar devices, with the motor 'consuming' power and generator 'supplying'.

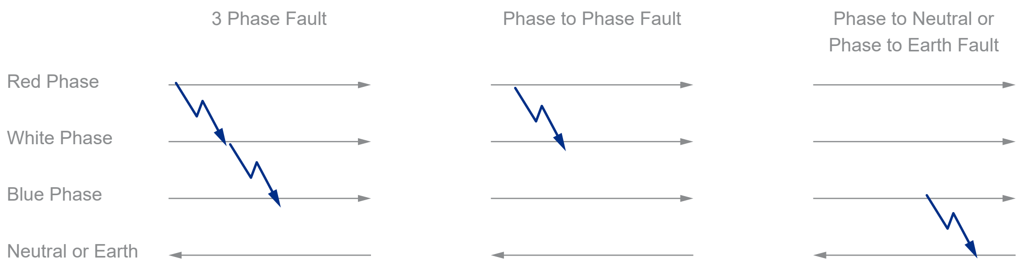
Under short circuit conditions it is common for a motor to continue rotating after isolation of the power supply and eventually contribute towards the fault. In other words, the motor changes from a consumer of current to a supplier of current for a brief time.

Motor contribution is often difficult to gauge. However, from the AS 3851 (Calculation of short circuit currents in three-phase a.c. systems) standard a rule of thumb that can used is that the contribution of motors to the fault current is approximately five times the full load current (flc) of the motor.

Note: Motor Contribution should not be confused with motor in-rush, which requires an alternative type of analysis

Types of Fault

Figure 2.2
Different types of fault can occur, dependent on where the fault occurs. Consider the following:



Fault Type	Approximation Of Fault Current Magnitudes Percentage
Three Phase bolted fault	100%
Two Phase bolted fault	87%
Single Phase bolted fault	50%
Three Phase arcing fault	Up to 87%
Two Phase arcing fault	Up to 65%
Single Phase arcing fault	Up to 20%

Note: The above figures are to be used as a guide, and must not be used in short-circuit analyses.

The type of fault influences the magnitude of the fault current in the system. A three-phase fault is generally accepted to have the largest magnitude, and as such it is classed as the 'worst case' in short circuit analysis. At the same time a bolted three-phase fault is also the most unlikely fault that may occur in a system, and is normally only used in test conditions.

Circuit breakers and other protective devices are designed, tested and manufactured to interrupt full three-phase bolted short circuits, but in practice they are likely to interrupt the more common faults, such as phase-to-phase, phase-to-neutral or phase-to-earth faults.

Short Circuit Calculation

The calculation of short circuit currents is based wholly on Ohm's Law, described above, where the following law applies:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Impedance (Z)}}$$

The Impedance (Z) takes in to account all impedances between the source and the point of the fault. Therefore an increase in Z (Impedance) results in a reduction of I (Current).

We have seen earlier that the source impedance is a major factor in limiting the fault current. The Maximum Fault Current that can be output from a source is calculated using the source impedance, and differs between a transformer to a generator.

Generator Fault Currents

A generator is often said to be the most complex piece of electrical equipment available. Under short circuit conditions the generator will go through a series of stages (sub-transient, transient and steady state), where the inherent reactance varies, and so varying the generator impedance. Each stage lasts for a number of milliseconds and decays before the next stage becomes the most dominant.

The first stage is known as the sub-transient, and can last anything up to 20 msecs.

Due to the speed of modern day protective devices the sub-transient stage becomes the most significant when calculating short circuit currents.

Transformer

Transformer Full Load Current (Iflc)

$$\text{Iflc} = \frac{\text{kVA (Amps)}}{\sqrt{3} \times V}$$

Transformer Short Circuit Current (Isc)

$$I_{sc} = \frac{\text{Iflc} \times 100 \text{ (Amps)}}{Z\ (\%)}$$

kVA = Transformer Rating (VA)

V = Line Voltage

Z (%) = Transformer Impedance (%) (Also commonly known as Voltage Impedance)

The transformer impedance would commonly have a value of between 4 and 6%. This results in a three-phase maximum fault current of around 15 to 25 times the transformer full load current.

Generator

Generator Full Load Current (Iflc)

$$\text{Iflc} = \frac{\text{kVA}}{\sqrt{3} \times V} = \frac{\text{kW (Amps)}}{\sqrt{3} \times V \times PF}$$

Generator Short Circuit Current (Isc)

$$I_{sc} = \frac{\text{Iflc} \times 100 \text{ (Amps)}}{Z\ (\%)}$$

kW = Generator rating

V = Line Voltage

Z (%) = Generator Impedance (as a % rating)

As a simple rule of thumb, the generator impedance would be between 10 to 25%, giving a short circuit level of between 4 and 10 times the generator full load current (Iflc).

Arc Faults

An arc fault is usually initiated by either a breakdown of insulation or a foreign object (such as a hand tool) causing a conduction path through an air gap in a switchboard. When this occurs, an arc is formed between phases or phase to ground. Technically, an arc is defined as a luminous discharge of electricity across an insulating medium, usually accompanied by the partial vaporisation of electrodes.

Right
Results of switchboard arcing faults

Some of the most common causes of an arc fault include:

- Loose or corroded connections exposing live conductors
- Damaged, frayed or pinched wires
- Poorly terminated or loose electrical connections
- Damaged plug in appliance cords and equipment
- Mechanical damage to conductors caused by wayward drill bits, screws driven into live cables
- Back hoes/earth moving equipment cutting through mains
- Rodents, reptiles or insects entering live switchboards
- Ionized gases released from switchgear clearing short circuits
- Accidental contact between live conductors and test probes or other tools

Above
Result of switchboard arcing faults

When an arc is initiated, the live conductors are in close enough proximity to create sparking. The arc itself is caused by uncontrolled conduction of electrical current from phase to phase, or from phase to earth/neutral, and this ionises the surrounding air. When conductive metal is vaporized, a pressure wave develops. A phase to phase, or phase to earth/neutral arc fault can escalate into a three phase arc within a millisecond.

The heat energy and intense light produced at this stage is known as the arc flash. Short circuits and arc faults are extremely dangerous and potentially fatal. The product of arc fault current and voltage generates a massive release of energy that manifests itself in heat and light. The arc temperature can reach four times that of the surface of the sun, causing third degree burns and possible blindness to anyone in close proximity to the arc flash, and potentially igniting other flammable substances. These high temperatures vaporize conductors instantaneously.

Copper vapour expands to 67,000 times the volume of solid copper. This pressure wave can often blow open panels and doors with explosive force, releasing the gases into the atmosphere and potentially exposing the remaining live conductors.

These gases help sustain the arc and the duration of the arc is primarily determined by the time it takes for over current protective devices to open the circuit. The arc can actually extinguish itself in some instances. However, when a protective device identifies the arc as a "normal" load it will not clear the fault. When this occurs, the arc becomes "unlimited" and can continue to vapourise metal and copper until it literally burns holes in metal panels and propagates fire throughout a facility.

Metal is blasted and splattered from the fault location. The shock wave is strong enough to damage anything or anyone within the immediate vicinity.

The potential danger of arc faults in electrical installations is well documented, with a growing number of case studies and anecdotal evidence to show that precautions and design considerations with arc faults in mind must be completed for any electrical installation.

The consequences of an arc fault include significant damage to switchgear, conductors, switchboards and the installation. However, the biggest consequence is the injury or death of operators in the area.

The best form of protection for personnel working in an electrical installation is to reduce the time spent in the area of potential danger. The area of danger is not necessarily an extremely hazardous place for the operator to be but has the potential to cause harm. This is analogous to a worksite that requires hard hats to be worn by workers. The most likely time for an incident to occur in a switchroom is during electrical and mechanical operations, such as switching, isolation and racking of larger circuit breakers.

Time spent in a potentially dangerous area can be minimised by utilising common accessories for switchgear which facilitate remote operating such as motor operators and open/close coils. There are also methods available to complete the racking of circuit breakers remotely. These can be used to remove the operator from the switchroom when switching and racking operations are occurring.

Other forms of protection can also be utilised to reduce injury from such events. The use of technology to detect arc flashes and reduce let through energy are also available. These can be used to limit an arc flash within a switchboard to prevent injury to operators. The costs associated with installing this technology are insignificant compared to compensation, downtime and repairs for any installation where an arc fault event occurs.

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2.3 Methods Of Preventing Damage Caused By Arc Faults

Now that we can appreciate the potential damage that can be caused by arcs, how do we prevent the arc from occurring?

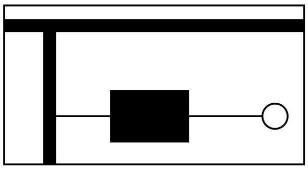
In low voltage installations, most arc damage occurs at the switchboard due to the presence of exposed copper conductors. There is a hierarchy of techniques designed to limit the effect of an arcing fault within a switchboard design:

1. ***Active Arc Fault Suppression:*** achieved by using the appropriate settings on protective devices, OR by using optically triggered arc detect technology

2. ***Passive Arc Prevention:*** achieved by insulating bus bars or by applying appropriate forms of separation in accordance with AS/NZS 61439

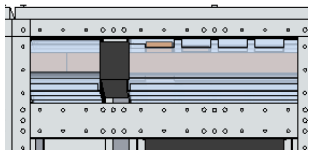
3. ***Containment:*** constructing an enclosure that can sustain extreme mechanical force and can safely vent the arc away from the "personnel" zone. To understand the various techniques that can be applied to achieve the desired results, it is relevant to refer to AS/NZS3000 and AS/NZS 61439

AS/NZS3000 Clause 2.5.5 identifies a number of methods of reducing the risk of arc initiation or reducing the potential damage caused by an arc for boards where the nominal current exceeds 800 A. Of course the optimum result can be achieved by incorporating elements from all three approaches (see figure 2.3).

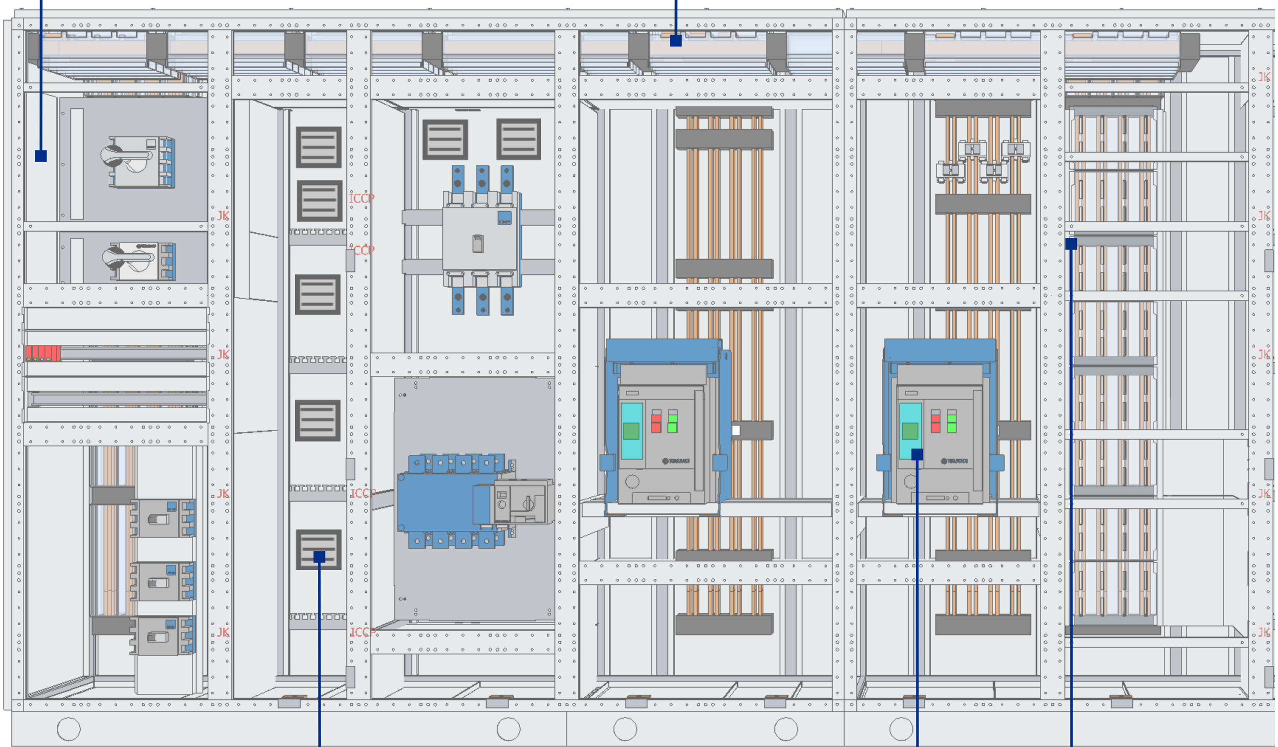


Forms of Separation

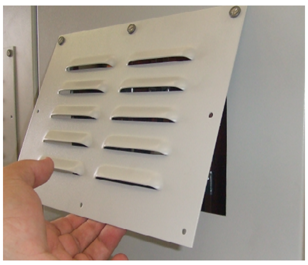
Form 3B shown.



Insulated Busbars

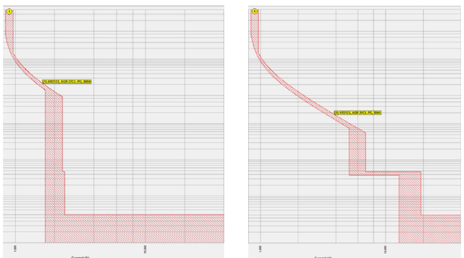


Arc Fault Containment Design



Spring loaded exhaust vent.

Temporary "Maintenance Mode" Protection Settings



Maintenance Mode versus Operational Protection settings.

Arc Flash Relay

Figure 2.3
Typical switchboard designed and constructed incorporating arc fault mitigation practices.

Protective Device Settings

AS/NZS 3000 clause 2.5.5.3 defines the formula for calculating the trip curve settings for breakers to clear an arc fault when it occurs.

The formula is based on what would be considered “worst case scenario” of a low level arcing fault continuing for a long time period and the need for “limitation of the harmful effects of a switchboard internal arcing fault”. To this end, reduction of the upstream breaker clearing time on a given arcing fault current value, based on the prospective fault current at the point reduced to 30% of its value. This is an arbitrary figure to allow for expected fault current under these conditions.

The clearing time will allow for energy release in the arc and “acceptable volume damage” to the switchboard. (This calculation does not take into account any factor for preservation of safety of a tradesperson potentially exposed to this energy.)

The formula as follows:
(Extract from AS/NZS 3000, Clause 2.5.5.3)

$$\text{Clearing time, } t = \frac{K(e) \times I(r)}{I(f)\ \hat{}1.5}$$

Where:

t = maximum clearing time in seconds

k(e) = 250 constant

I(r) = current rating of the switchboard

I(f) = 30% of the prospective fault current

Example:

- Typical 1200 A installation, fed by a supply Authority 1200 A fuse
- NHP Terasaki AR212S (1250 A ACB) is used as the main incomer
- The known fault level at a switchboard is 20.7 kA

Firstly, we need to calculate the clearing time:

$$t = \frac{250 \text{ X } 1200}{(0.3 \text{ X } 20 \text{ kA})\hat{}1.5} \qquad t = \frac{300{,}000}{(6 \text{ kA})\hat{}1.5}$$

$$t = 0.645 \text{ sec}$$

Therefore, the AR212S must be set to clear a fault of 6 kA within 0.645 seconds.

Using NHP’s TemCurve 6 package, we can overlay the supply fuse with the AR212S ACB as illustrated right in figure 2.5:

In this example, the AR212S ACB discriminates with the supply fuse (as is demanded by Clause 2.5.7 Reliability of Supply) and will interrupt the arc fault in accordance with the minimum time defined by the formula in Clause 2.5.5.3. However, it must be noted that the time current curve setting for the breaker to clear the arc fault can occasionally make it more difficult to discriminate with downstream devices.

If this calculation method is applied to switchboards that are subject to higher fault levels, further considerations apply. The board must be designed to withstand the larger forces that will apply when exposed to a short circuit fault for the extended period of time as nominated by the calculation.

Using protective devices settings (such as on circuit breakers) can be practically implemented using a temporary ‘maintenance mode’ protection setting to improve arc flash safety when people are in a switchroom. This typically involves a method of remotely reducing the ‘short circuit pick up setting’ of the circuit breakers trip unit without the need for a person to physically stand in front of the switchboard.

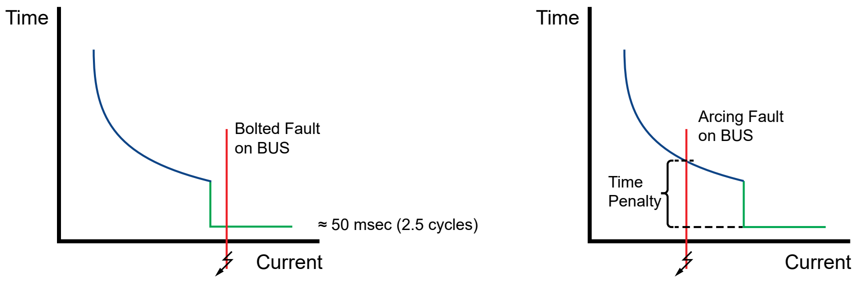


Figure 2.4
Typical circuit breaker protection curves. An electrical Arc is inherently resistive in nature Introduces additional fault impedance, therefore an arc fault current magnitude is low compared to a bolted fault.

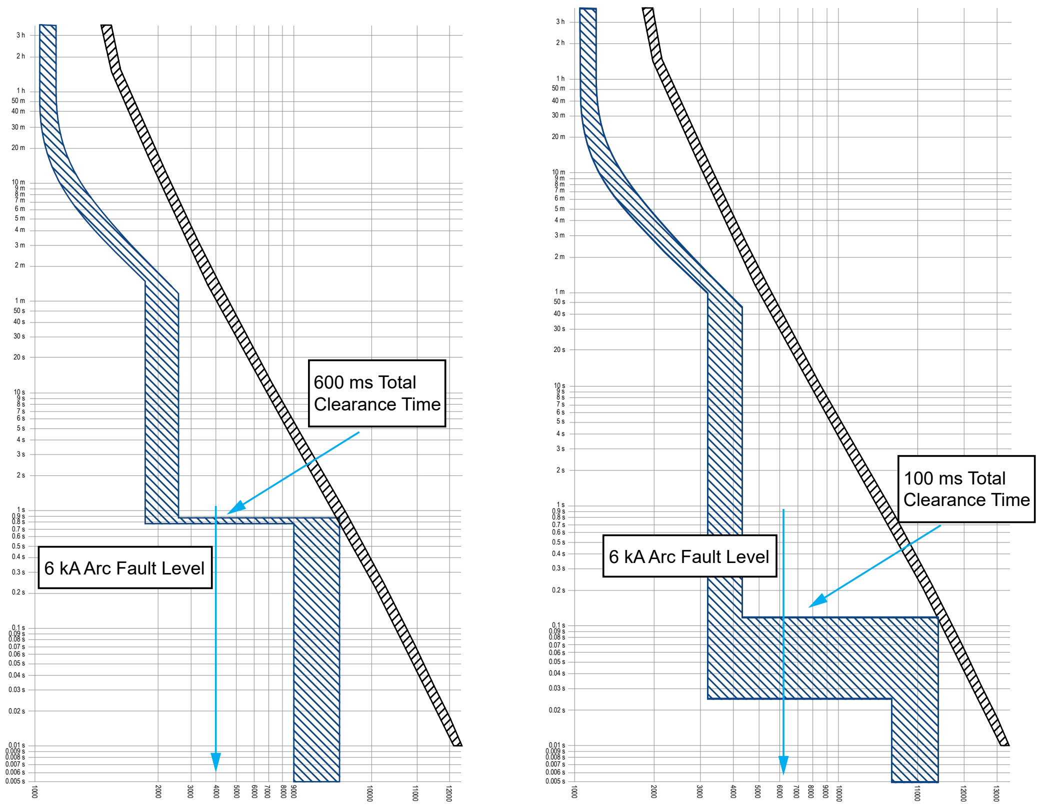


Figure 2.5
Left: Shows an AR212S ACB with 'normal protection settings.

Right: Shows an AR212S ACB with 'maintenance mode' protection settings. Practically a Terasaki AR212S ACBs short circuit protection settings could be configured to clear the 6 kA arcing fault in 30 ms.

2.4 Temperature Rise, Thermal Derating and Switchgear Overheating

An important subject that goes hand in hand with Forms of Switchboard and IP Ratings of enclosures is that of circuit breaker derating.

When passing current, electrically conductive components such as busbars, cables and switchgear will increase in temperature. This is caused by the activity of electron flow and resistance or impedance of the conductor due to the “friction” of electron flow passing around and through stationary atoms, opposing the motion of the electrons. This converts some of the electron’s kinetic energy to heat energy, consequently raising the conductor’s body temperature. The increase in the “latent” temperature of the conductor is referred to as “temperature rise”.

Switchgear is rated with a current carrying capacity based on it’s ability to carry a level of current and effectively dissipate the resultant heat into the surrounding air. All devices are rated as an “open” rating allowing free convection air movement to take place and this air being replaced by air of a nominated “ambient” temperature. This air and heat exchange will reach an equilibrium where the input of current and subsequent increase of temperature stabilises at a particular level of current. This is the nominated full load current of the device at an open ambient air temperature of “XX” degrees, (often 35 degrees Celsius, average over a 24 hour period). If the current is increased above this level, the switchgear may suffer “thermal runaway” where the increase has a snowball effect on the resultant switchgear temperature.

Subsequently when switchgear is mounted within an enclosure, convection air movement is severely hampered and switchgear temperature may increase more quickly. In addition, the surrounding air temperature may be increased by the contribution of the switchgear heat exchange and this may cause the ambient to rise well above the switchgear’s tested ambient, forcing the need for a de-rating or reduction in the current carrying capacity of the devices.

In addition, thermal protective devices such as circuit breakers and thermal overloads are calibrated at an ambient temperature, nominated by the switchgear manufacturer (this figure may vary manufacturer to manufacturer so this should always be checked). If the ambient temperature rises beyond the calibration temperature of the device, premature tripping of the loads may occur.

As an example, consider a 250 amp thermal magnetic circuit breaker calibrated to carry 250 amps continuously in an ambient temperature of 45 deg C. Should the ambient temperature increase to 55 deg C, the breaker may be de-rated to carry only say 235 amps without going into an overload state and “nuisance tripping”.

De rating factors are available from all manufacturers in the form of derating charts or alternatively “ambient compensating curve charts". The derating process is not isolated to thermal magnetic devices and should be observed for all devices switching and carrying electrical current.

Temperature Rise Referencing AS/NZS Standards

The characteristics of conductive materials such as copper are proportional to the actual temperature of the material. In order to maintain the desirable conductive and structural characteristic of a material, it is important that the materials temperature is maintained within specific limits. Through experimentation and testing these limits are well documented and are referred to as the 'thermal limits' of the material.

For example, the resistivity of copper material increases in response to an increasing temperature (i.e. the conductivity decreases). However there are some insulators, where the resistivity of the insulator decreases (increase the conductivity) in response to an increasing temperature (as the stationary atoms get excited by the heat energy which helps the electrons to move creating current).

In regards to protective devices such as circuit breakers, excessive temperatures generally lead to quicker deterioration for the device and the switchboard, often resulting in a switchboard fire.

There are two types of AS/NZS standards that address the subject of temperature rise:

- Components Standards – The temperature rise limit related to the specific product.

- Switchboard Standards – The temperatures rise limit is related to the copper busbars and the connections to Circuit Breakers.

Component Standards

Circuit Breaker Standard (AS/NZS 60947-2)

The terminals maximum temperature rise is limited by 80 K with reference of an ambient temperature of 35 °C which means that the total approved temperature for the terminals of the circuit breaker will be 115 °C.

Switch Disconnector Standard (AS/NZS 60947-3):

The maximum temperature rise limit for the terminals for external connections are equivalent to the Circuit Breaker.

Figure 2.6 – Temperature - Rise Limits for Terminals and Accessible Parts

Description of part *		Temperature-rise limits ** (K)
Terminals for external connections		80
Manual operating means:	metallic	25
	non-metallic	35
Parts intended to be touched but not hand-held:	metallic	40
	non-metallic	50
Parts which need not be touched for normal operation:	metallic	50
	non-metallic	60

* No value is specified for parts other than those listed but no damage should be caused to adjacent parts of insulating materials.

** The temperature-rise limits specified are not intended to apply to a new sample, but are those applicable to the temperature-rise verifications during the appropriate test sequences specified in clause 8.

Figure 2.7 – Temperature - Rise Limits for Terminals and Accessible Parts

Description of part [a]		Temperature-rise limits (K)
Terminals for external connections		80
Manual operating means:	metallic	25
	non-metallic	35
Parts intended to be touched but not hand-held:	metallic	40
	non-metallic	50
Parts which need not be touched for normal operation:	metallic	50
	non-metallic	60

a) No value is specified for parts other than those listed but no damage should be caused to adjacent parts of insulating materials.

Transfer Switching Equipment (TSE) Standards (AS/NZS 60947-6)

The terminals maximum temperature rise is limited by 80 K with reference of an ambient temperature of 35 °C which means that the total approved temperature for the terminals of the circuit breaker will be 115 °C.

Figure 2.8 – Temperature - Rise Limits of Terminals (See 7.2.2.1 and 8.3.3.3.4)

Terminal Material	Temperature-Rise Limits [a, c] (K)
Bare Copper	60
Bare Brass	65
Tin Plated Copper or Brass	65
Silver Plated or Nickel Plated Copper or Brass	70
Other Metals	b

a- The use in service of connected conductors significantly smaller than those listed in Figures 2.6 and 2.7 could result in higher terminals and internal part temperatures and such conductors should not be used without the manufacturer's consent since higher temperatures could lead to equipment failure

b- Temperature-rise limits to be based on service experience or life tests but not to exceed 65 K

c- Different values may be prescribed by product standards for different test conditions and for devices of small dimensions, but not exceeding by more than 10 K the values of this table

8.2.2 Temperature rise

When tested at the highest rated operational current under the conditions described in 9.3.3.3, TSE shall not attain a temperature at any point to constitute a fire hazard or to damage any materials employed in the device and shall not exceed the temperature rise values stated in 7.2.2 of IEC 60947-1.

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3 Types of Circuit Breaker and Earth Leakage Protection Devices

3 Types of Circuit Breaker and Earth Leakage Protection Devices

3.1 Protective Devices

As the name suggests, a protective device is a piece of electrical equipment designed specifically for the purposes of protection.

They can be used to protect other pieces of electrical equipment, or more importantly to protect a human being from an electric shock or electrocution.

There are several types of protective device, each coming in different models, sizes or ratings. Additionally there are many manufacturers spread throughout the world, all producing their own unique protective devices.

This section of the handbook will cover the most basic and common types of protective devices, namely the circuit breaker,and discuss their benefits as well as some basic guides to their use.

Circuit breakers and fuses can be used independently or in conjunction with one another. For example, it is common to connect a fuse in series with a circuit breaker of low interrupting (breaking) capacity so as to enhance the maximum fault level that can be safely cleared. Fuses as protective devices are covered in Section 6

3.2 Circuit Breaker

The AS/NZS 3000 standard gives the most basic and easy to understand definition of a circuit breaker:

“A switch suitable for opening a circuit automatically, as a result of predetermined conditions, such as those of overcurrent or undervoltage, or by some other form of external control.”

In its most basic form the breaker can be thought of as a switch, so the circuit breaker can be used as a simple control device for connecting or disconnecting an electrical supply to a piece of equipment.

However, the most significant difference between a switch and a circuit breaker is that the breaker will open (trip) automatically under fault conditions. Therefore a circuit breaker should be capable of:

1. Carrying a current equal to its nominal rating
2. Detecting and measuring current
3. Automatically opening upon detection of an overcurrent

In terms of its internal construction the circuit breaker consists of two main parts, these are

a. The Switching Unit
b. The Over-current relay (OCR) / Trip Unit

The Switching Unit is the area of the breaker that carries out the opening and closing operations, and must be capable of dealing with high levels of current.

The OCR / Trip Unit is the ‘sensing’ part of the circuit breaker that will detect and measure the level of current flowing through the breaker and determine what operation should be carried out. For example, the trip unit may decide whether the breaker should be tripped immediately or if a time delay should pass before tripping occurs.

The trip unit comes in two different forms, namely the ‘thermal magnetic’ type and ‘electronic’ or ‘microprocessor’ type.

Thermal magnetic protection is the generally the most basic, and is achieved by the combination of a bimetallic (thermal) strip for overload protection and a magnetic element for short-circuit protection. This gives rise to the term ‘thermal magnetic circuit breaker’.

Many circuit breakers have electronic protection relays fitted instead of the traditional thermal-magnetic protection. A series of current-transformers (CTs) are connected to the Electronic trip unit, and measurements are taken to determine what current is flowing through the breaker. The electronic trip unit will then initiate the tripping process should an overcurrent be detected.

The most obvious benefit of using a circuit breaker over a fuse is simply that of convenience. When a fuse detects a fault the fusing element within the device will burn out and create an open circuit. However, the only way to regain a supply to that part of the system is to replace the fuse.

On the other hand once the fault has been determined and repaired the circuit breaker may be re-closed without the need for replacement.

Note: The functions of an in-built trip unit can be replaced by a remote protection relay, but for the arguments of this paper we shall assume that all circuit breakers have their own trip units.

Types of Circuit Breaker

The most basic types of circuit breaker are as follows:

1. Miniature Circuit Breaker (MCB) / Residual Current Circuit Breaker with Overload (RCBO)
2. Moulded Case Circuit Breaker (MCCB)
3. Air Circuit Breaker (ACB)

Figure 3.2.1
ACBs fitted in a Main Switchboard

Relevant Definitions and Acronyms Related to Circuit Breakers

Circuit-Breaker

A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit.

Current-Limiting Circuit-Breaker

A circuit-breaker that, within a specified range of current, prevents the let-through current reaching the prospective peak value and which limits the let-through energy (I^2t) to a value less than the let-through energy of a half-cycle wave of the symmetrical prospective current.

Miniature Circuit Breaker (MCB) (Final Distribution)

A circuit-breaker having a supporting housing of moulded insulating material forming an integral part of the circuit-breaker. MCBs are the most common type of circuit breaker used in domestic applications and are generally preferred by Australian and New Zealand customers over fuses. They are small in construction and as such can carry relatively low currents as well as withstand relatively small fault currents

MCBs are commonly available in current ratings up to 63 A, although several physically larger MCBs can carry currents up to 125 A. MCB contacts open and close in air at atmospheric pressure.

Moulded Case Circuit Breaker (MCCB) (Sub Distribution)

A circuit-breaker having a supporting housing of moulded insulating material forming an integral part of the circuit-breaker. MCCBs vary in terms of rating and size. A typical low end current rating would be 20 A, but in general they are more commonly used from around 160 A upwards and have a typical maximum current rating of 3200 A. When ratings around 63 A and below are present, MCBs tend to be preferred over MCCBs. MCCB contacts open and close in air at atmospheric pressure.

Air Circuit Breaker (ACB) (Incoming Distribution)

A circuit-breaker having a supporting housing of moulded insulating material and usually metal bracing forming an integral part of the circuit-breaker. ACBs carrying large currents (up to 6300 A) and interrupting extremely high fault currents (up to 120 kA). This ability to carry and interrupt large fault currents is mainly due to the construction of the device. An ACB is a strong device which allows it to withstand the destructive forces associated with large fault currents. ACB contacts open and close in air at atmospheric pressure.

Instantaneous Circuit Breaker (ICB) (Typically Used in Essential Services Distribution or Motor Protection)	A circuit-breaker (typically an MCCB or ACB) that does not have ‘overload’ or ‘short time delay short circuit tripping’ protection enabled, only providing instantaneous short circuit tripping.
Circuit Breaker Selectivity Categories	The selectivity category of a circuit-breaker shall be stated with reference to whether or not it is specifically intended for selectivity by means of an intentional time delay with respect to other circuit-breakers in series on the load side, under short-circuit conditions. A circuit breaker with a selectivity category type ‘A’ Circuit-breakers not specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side. An example of this would be an MCB, or thermal magnetic MCCB. A circuit breaker with a selectivity category type ‘B’ Circuit-breakers specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side. An example of this would be an ACB or an MCCB with an adjustable short time protection setting, as part of an electrical trip unit.
Short-Circuit (Making and Breaking) Capacity	Alternating component of the prospective current, expressed by its RMS value, which the circuit breaker is designed to make, to carry for its opening time and to break under specified conditions.
Ultimate or Rated Short-Circuit Breaking Capacity (Icn - AS/NZS 60898)	A breaking capacity for which the prescribed conditions, according to a specified test sequence, do not include the capability of the MCCB/ACB to carry 0.96 times its rated current for the conventional time.
Ultimate Short-Circuit Breaking Capacity (Icu - AS/NZS 60947-2)	A breaking capacity for which the prescribed conditions, according to a specified test sequence, do not include the capability of the MCCB/ACB to carry its rated current for the conventional time.
Service Short-Circuit Breaking Capacity (Ics - AS/NZS 60947-2)	A breaking capacity for which the prescribed conditions, according to a specified test sequence, include the capability of the Circuit Breaker to carry its rated current continiously.
Conventional Non-Tripping Current (Int)	A specified value of current which the circuit breaker is capable of carrying for a specified time without tripping.
Open Position	The position in which the predetermined clearance between open contacts in the main circuit of the MCB is secured.
Closed Position	The position in which the predetermined continuity of the main circuit of the MCB is secured.
Maximum Prospective Peak Current (Ip)	The prospective peak current when the initiation of the current takes place at the instant which leads to the highest possible value.

3.3 Miniature Circuit Breaker (MCB) and Residual Current Devices (RCDs, RCBOs, RCCDs)

Figure 3.3.1
Typical MCBs and RCBO

Standard: AS/NZS 60898, AS/NZS 60947-2 (DIN types), AS/NZS 3111 (NEMA types), AS/NZS 61008, AS/NZS 61009 (RCDs)

The Miniture Circuit Breaker (MCB) and the Residual Current Circuit Breaker with Overload protection (RCBO) are the most common type of circuit breaker used in domestic applications and as such they are easily recognised by the untrained eye. They are small in construction and as such can carry relatively low currents as well as withstand relatively small fault currents.

MCBs and RCBOs are commonly available in current ratings up to 63 A, although several physically larger MCBs can carry currents up to 125 A.

In terms of the Breaking (interrupting) Capacity most can cope easily with 6 kA, 10 kA or 15 kA fault levels dependent on the model and the standard being applied (ie AS/NZS 60898 or AS/NZS 60947-2). Special MCBs can obtain the ability to interrupt fault levels up to 50 kA, but these are rarely called upon.

MCBs and RCBOs are fast acting devices and are ideal for the protection of equipment at the final distribution end of an electrical system. Due to their speed of action they are ideal for protecting cables and/or busbars. The fast clearance of the fault means that significantly less fault current is being passed downstream.

Both MCBs and RCBOs are totally enclosed and the only way to access the internal components of the device is to break through the external casing. This is an important issue as unskilled persons commonly handle them.

Two unique designs exist which are dependent on which standard they are constructed in accordance with. The first type is a DIN type and is more generally a European style of MCB. Examples of these are the NHP-Terasaki Din-T MCBs / RCBOs and the NHP MOD6 MCBs/RCBOs, being the type installed in most homes. The DIN style MCBs are generally fault-current limiting devices and available in a range of breaking capacities to suit most applications.

The other MCBs are the NEMA type, made in accordance with North American standards. NEMA style MCBs, such as the NHP Safe-T are zero point extinguishing devices. The ‘zero point’ is in reference to the point on an AC waveform at where the fault is interrupted. The MCB will ‘hold on to’ the fault current until the AC waveform passes through the zero-point, at which the arc is extinguished.

3

Figure 3.3.2
NHP DIN-T MCBs

Figure 3.3.3
NHP MOD6 MCBs

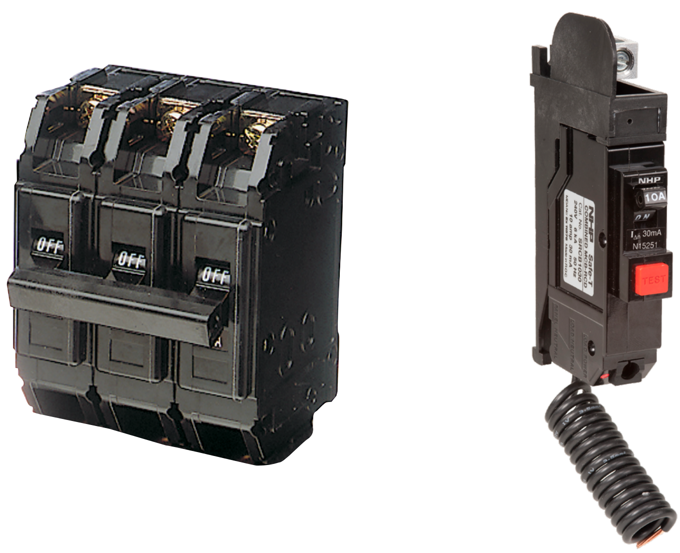


Figure 3.3.4
NHP Safe T MCBs

Common Earth Leakage Protection Devices (RCDs, RCBOs, RCCDs)

Earth leakage protection devices are common place within domestic, commercial and industrial settings where people may come into contact with a live conductor (Earth faults were discussed in section 2.2). A Residual Current Device (RCD) is a protective device which detects and interrupts, where electrical leakage to Earth is present, above its determined threshold. RCDs may also be used to provide protection against fire hazards due to a persistent earth fault current, without operation of the overcurrent protective device.

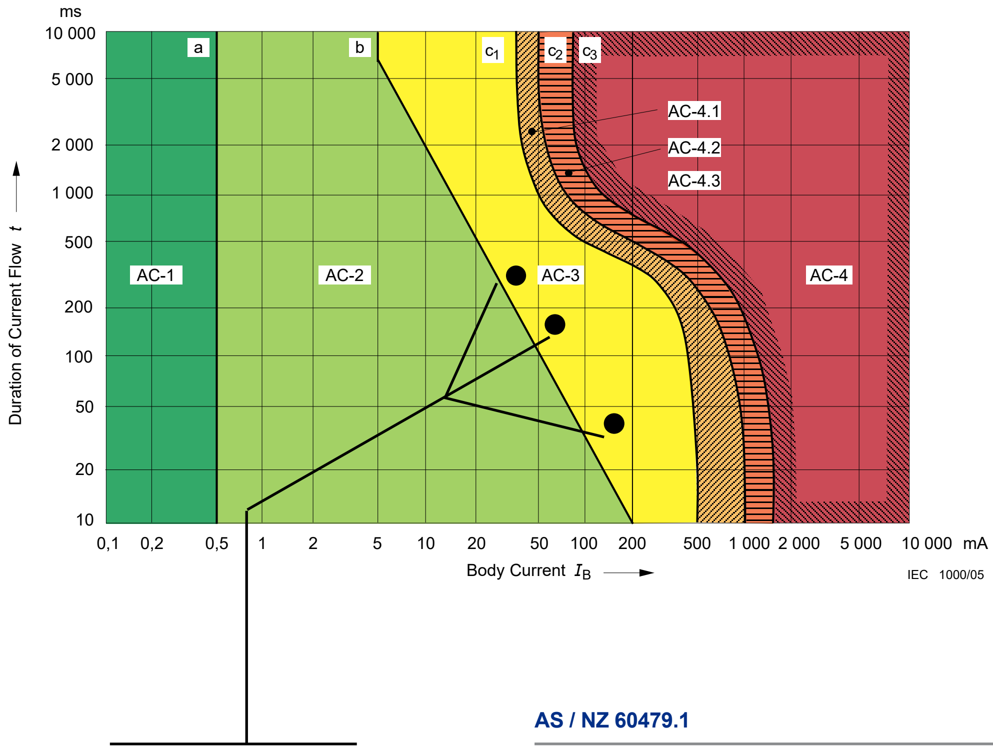
RCDs having a rated residual operating current not exceeding 30 mA are also used for additional protection in case of failure of the physical protective means against electric shock (direct contact).

RCD Trip Times

The effect of electrical current flowing through the human body, depends on the current level and the duration of the current flow. These affects are shown from AS/NZS 60479.1.

The trip time of a 30 mA RCD device, has a time/current tripping curve to reduce the possibility of fibrillation occurring.

Time / Current Zones for AC 15 Hz to 100 Hz for Hand to Feet Pathway



Australian Standard Tripping Points 30 mA Device

- 100% IΔn - 300 ms
- 200% IΔn - 150 ms
- 500% IΔn - 40 ms

AS / NZ 60479.1

AC-1	Awareness level is low.
AC-2	Awareness with involuntary muscle contractions, with usually no harmful effects.
AC-3	Strong muscle contractions with disturbances to breathing and heart function.
AC-4	High possibility of cardiac or breathing arrest, with cell damage and burns. Probability of ventricular fibrillation increases; - AC-4.1 Probability of Fibrillation < 5% - AC-4.2 Probability of Fibrillation < 50% - AC-4.3 Probability of Fibrillation > 50%

Figure 3.3.5
AS/NZS 60479.1 - Time / Current Zones

Residual Current Device (RCD) Options

There are many RCD device options to choose from depending on the application and budget. The below definitions help distinguish between the different types of RCDs that are commonly used through out Australia and New Zealand.

Residual Current Device (RCD)

A Residual Current Device (RCD) is intended to protect people against direct and indirect contact with “live” conductive items. It may also be used to provide protection against fire hazards and equipment failure due to a persistent earth fault current which does not cause operation of the overcurrent protective device.

Residual Current Operated Circuit-Breaker Without Integral Overcurrent Protection (RCCB)

A residual current operated circuit-breaker not designed to perform the functions of protection against overloads and/or short-circuits.

Residual Current Operated Circuit-Breaker with Integral Overcurrent Protection (RCBO)

A residual current operated circuit-breaker designed to perform the additional functions of protection against overloads and/or short-circuits.

RCD Type AC

RCD for which tripping is ensured for residual sinusoidal alternating currents, whether suddenly applied or slowly rising.

RCD Type A

RCD for which tripping is ensured for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising

RCD Type B

RCD for which tripping is ensured for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising and responds to all types of residual currents ie frequencies up to 1 MHz and smooth DC residual currents, in accordance with the tripping characteristic B as defined by IEC Standard 60755

RCD Type F

RCD for which tripping is ensured for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising. In addition to this, they are capable of detecting residual currents from compsite wave forms, which can often occur on the outgoing feeder side of single-phase frequency converters.

RCD Type S

S

RCD for which tripping is ensured for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising, however the tripping has an intentional time delay to provide selectivity with a ‘instantaneous tripping general purpose’ downstream RCD.

Working Principle

The main components of an RCD are the following:

- **The core transformer:** which detects the earth fault current.
- **The relay:** when an earth fault current is detected, the relay reacts by tripping and opening the contacts.
- **The mechanism:** element to open and close the contacts either manually or automatically.
- **The contacts:** to open or close the main circuit.

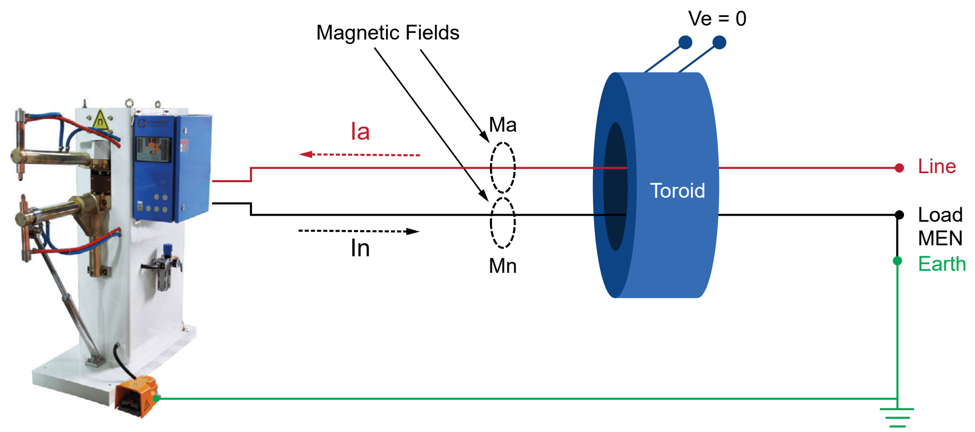
The RCD constantly monitors the vectoral sum of the current passing through all the conductors. In normal conditions the vectorial sum is zero (Ia + Ib = 0) but in case of an earth fault, the vectoral sum differs from zero (Ia + Ib = I Δ), this causes the actuation of the relay and therefore the release of the main contacts.

Figure 3.3.6
RCD operating principle.

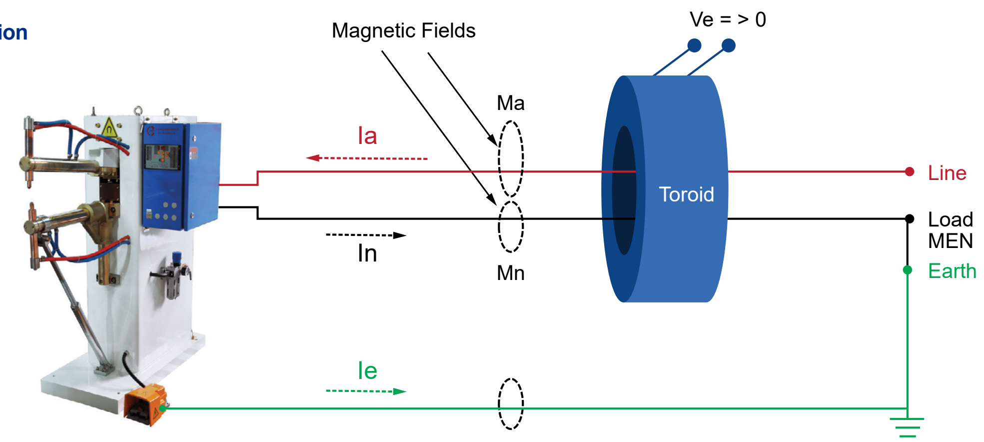
Top: Magnetic fields Ma = Mn so they cancel each other out. No current induced into toroid.

Bottom: Magnetic fields Ma is greater than Mn due to leakage return on earth Ie. Current induced into toroid.

Normal Situation



Earth Leakage Situation



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People Protection

This pictorial shows the operation of an RCD, where a person comes has direct (or indirect) contact with a "live" conductive item.

1. Current traveavels ough body
2. CT picks up current imbalance
3. Sensor detects current imbalance and opens circuit. Fault is cleared and personnel are protected.

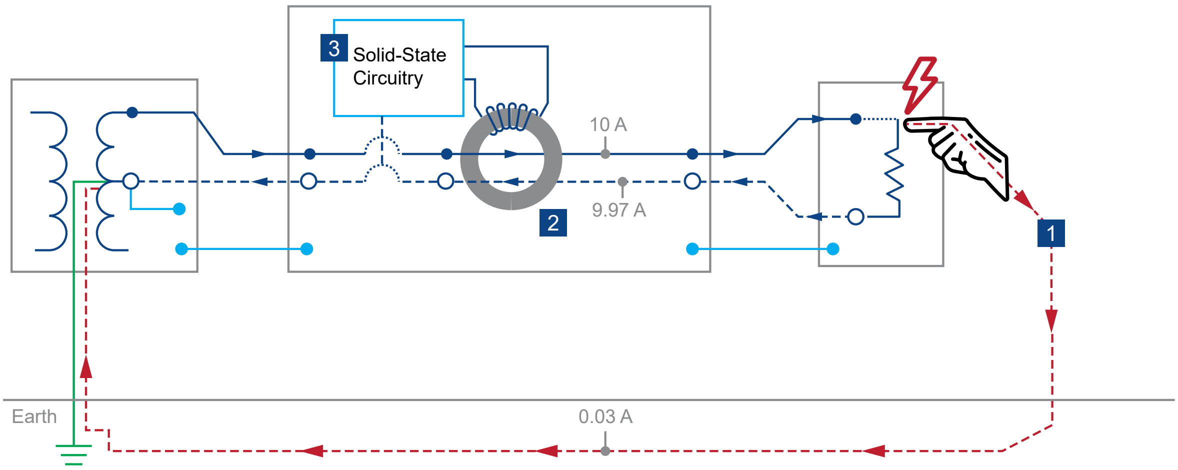


Figure 3.3.7
Personal protection for direct contact

Residual Current Device (RCD) Related Acronyms and Definitions

Earth Fault Current	Current flowing to earth due to an insulation fault.
Earth Leakage Current	Current flowing from the live parts of the installation to earth in the absence of an insulation fault.
Breaking Capacity	A value of the AC component of a prospective current that an RCCB is capable of breaking at a stated voltage under prescribed conditions of use and behaviour.
Residual Making and Breaking Capacity (IΔm)	A value of the AC component of a residual prospective current which an RCCB can make, carry for its opening time and break under specified conditions of use and behaviour.
Conditional Residual Short-Circuit Current (IΔc)	A value of the AC component of a prospective current which an RCCB protected by a suitable SCPD (short-circuit protective device) in series, can withstand, under specific conditions of use and behaviour.
Conditional Short-Circuit Current (Inc)	A value of the AC component of a residual prospective current which an RCCB protected by a suitable SCPD in series, can withstand, under specific conditions of use and behaviour.
Residual Short-Circuit Withstand Current	Maximum value of the residual current for which the operation of the RCCB is ensured under specified conditions, and above which the device can undergo irreversible alterations.
Prospective Fault Current	The current that would flow in the circuit, if each main current path of the RCCB and the overcurrent protective device (if any) were replaced by a conductor of negligible impedance.
Making Capacity	A value of the AC component of a prospective current that an RCCB is capable to make at a stated voltage under prescribed conditions of use and behaviour.

Closed Position	The position in which the predetermined clearance between open contacts in the main circuit of the RCCB is secured.
Tripping Time	The time which elapses between the instant when the residual operating current is suddenly attained and the instant of arc extinction in all poles.
Residual Current (IΔ)	Vector sum of the instantaneous values of the current flowing in the main circuit of the RCCB.
Residual Operating Current (IΔn)	Value of residual current which causes the RCCB to operate under specified conditions.
Rated Short-Circuit Capacity (Icn)	Is the value of the ultimate short-circuit breaking capacity assigned to the circuit breaker. (Only applicable to RCBO).
Conventional Non-Tripping Current (Int)	A specified value of current which the circuit breaker is capable of carrying for a specified time without tripping. (Only applicable to RCBO).
Conventional Tripping Current (It)	A specified value of current which causes the circuit breaker to trip within a specified time. (Only applicable to RCBO).
Pulsating Direct Current	Current of pulsating wave form which assumes, in each period of the rated power frequency, the value 0 or a value not exceeding 0,006 A DC during one single interval of time, expressed in angular measure, of at least 150°.

Arc Fault Detection Device (AFDD)

Commonly used circuit protection technologies such as residual current devices (RCDs), miniature circuit breakers (MCBs) and earth leakage relays (ELRs) focus primarily on electric shock and cable protection.

Since their introduction, the frequency of fires caused by electrical fault has reduced, however are still common enough to warrant further safety measures.

An important characteristic of arc faults is the possibility they can go unnoticed by conventional protection devices. Since they are high impedance faults, hence the low currents may not actuate conventional MCB/RCBO tripping curves.

This means traditional devices may only detect them as if they are overloads (long trip time) or not detect them at all.

Recent technological advancements in waveform monitoring and signal processing have led to a new safety device – the Arc Fault Detection Device (AFDD).

Arc Fault Detection Devices (AFDD) are designed to initiate interruption of sub-circuits during arc fault events, minimizing the potential for fires caused by electrical faults. Modern AFDD design enables the detection of the unique current/voltage waveforms and their relationship during an electrical arc event. The AFDD is an electronic device with no circuit interrupting ability. Instead, it utilises the trip contacts and mechanism of other MCB/RCBO devices in disconnecting supply.

What Is An Arc Fault?

There are two types of arc fault events that can occur – series arc faults or parallel arc faults.

Series Arc Fault

This type of fault may be the result of loose connections, broken conductors, or faulty switching contacts. In such cases the result is an arc that occurs in series with the normal load and as such the arc power is relatively limited in comparison to the parallel arc fault described below. Regardless, this type of arc fault is common and still has a large potential to cause electrical fires and as such the AFDD must be able to properly sense and react to such a fault by interrupting current flow before thermal energy has accumulated enough to cause a fire.

Parallel Arc Fault

Parallel arc faults occur between separate conductors and may typically be the result of physical insulation damage or aged failure. Such a fault may occur between line-line, line-neutral or even line-ground. In such cases the fault current will be limited by the system impedance and the impedance of the arc itself, with a resulting power level far exceeding the series arc event described above. As above, the AFDD must be able to properly sense and react to such a fault by interrupting current flow before the arc thermal energy can accumulate into a fire.

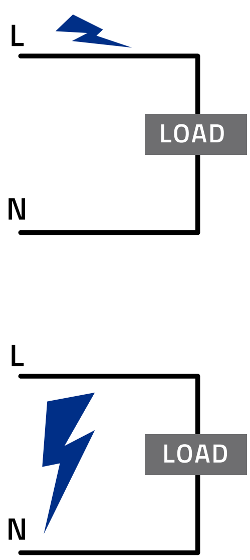


Figure 3.3.8

What Causes Arc Faults?

Common causes for arc faults are pierced cables, damaged insulation, aged cables, vermin damage, loose connections, or trapped cables (see Figure 3.3.9 below).

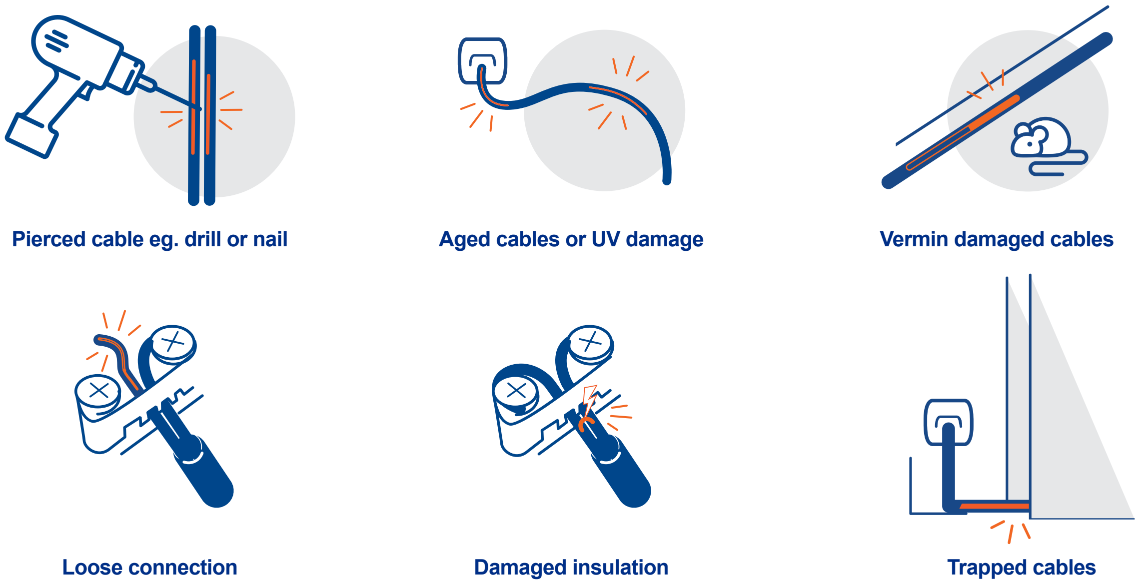


Figure 3.3.9
Common causes of arcing

What Is An AFDD and How Does It Detect Arc Faults?

The Arc Fault Detection Device (AFDD) monitors the relationship between the current and voltage waveforms and, via high speed digital signal processing, detects arc fault anomalies which have certain characteristics. These characteristics form part of the algorithm that the AFDD uses, which is precise enough to differentiate between arc faults and equipment that creates arcs during normal operation - for example, common household switches or electric tools with brushed motors. This ensures that nuisance tripping is minimized.

The performance of Arc Fault Detection Devices (AFDDs) is specified in IEC 62606.

What Do Standards Say About AFDDs?

Australian and New Zealand wiring installation rules AS/NZS 3000:2018;

Clause 2.9.1 states AFDD may be used to protect against arc fault for final sub circuits including fire hazards for the following:

- **a.** Sleeping accommodation (hostels).
- **b.** Storage of combustible materials (textile processing plants)
- **c.** Building with combustible materials (flammable cladding, wooden structures)
- **d.** Fire propagating structures (high rise buildings).

Specially for New Zealand, Clause 2.9.7 for mandates for final sub circuits 20 A or less;

- **a.** Storage of combustible materials (wood working workshops)
- **b.** Storage of irreplaceable items (museums/ art galleries)
- **c.** Historic building made from flammable materials.
- **d.** School dormitories (sleeping accommodation) socket outlets.

3.4 Moulded Case Circuit Breakers (MCCBs)

Figure 3.4.1
Typical MCCB

Standard AS/NZS 60947.2

As the name suggests the outer construction of an MCCB is formed from a moulded material that creates a rigid base in which to house the internal components of the device.

MCCBs vary in terms of current rating and size and this can affect their physical dimension for any given rating parameter. They are available in current ratings as low as 0.7 A but in general are more commonly used from around 100 A and upwards. When ratings around 63 A and below are required, MCBs tend to be preferred over MCCBs (fault current permitting).

At the upper end of the scale, MCCBs rated at 3200 A are also available but they are normally used in applications up to 1600 A. When current ratings at the high end of the scale are required the associated high fault currents and the need to apply selectivity at this level tend to encourage the use of ACBs to feed the next distribution level.

Modern day MCCBs tend to be highly fault current limiting and clear any potentially dangerous and damaging fault currents in a matter of milliseconds. The fast tripping means that a minimal amount of stress is placed on the downstream system but also to the internal components of the MCCB.

Though the MCCB ratings range and breaking capacities can match or even better that of the ACB, one significant difference in the terms of performance is the short circuit current withstand characteristics of the ACB.

MCCBs don't have the same inherent strength as a similarly rated ACB. The ACB is designed to hold onto a fault current and let a faster downstream device clear the fault. One of those faster devices could be an MCCB.

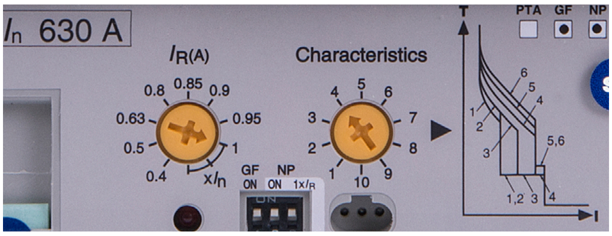


Figure 3.4.2
Example of a two dial electronic OCR.

Moulded Case Circuit Breakers for general power distribution use in modern systems are available with two specific operational configurations. Thermal Magnetic circuit breakers that rely on mechanical devices such as thermal overload elements and short circuit magnetic coils to detect and interrupt faults. Electronic circuit breakers that use miniature current transformers to send a quantifiable signal to an electronic over current relay to trip the circuit breaker under fault conditions.

Within these two basic types there are many functional styles and variations in fault current interruption capabilities and current ranges as well as suitability for special applications such as standing voltage levels etc. The most common voltages in Australia and New Zealand for MCCBs are 400 / 415 V, 690 V and 1000 V. Special purpose MCCBs are also suitable for DC applications.

Some Thermal Magnetic MCCBs are fixed thermal and magnetic settings. Others may have variations such as adjustable thermal/fixed magnetic or adjustable thermal and magnetic. Electronic OCRs come in a number of different styles that allow various configurations and settings to be made within the range.

Some electronic versions are adjustable by flexible current rating variation or “quick set” short time instantaneous adjustments.

Other models allow individual setting functions for Long time overload, short time delayed instantaneous and instantaneous settings (LSI characteristics).

These models allow highly adjustable parameters in both current and time settings as well as adjustable instantaneous short circuit trip level setting. More advanced devices incorporate higher order functionality OCRs.

Some of these units come with LCD panels that indicate readings and functions for programming the device’s behavioural parameters. Course current setting are entered via the dials. Fine adjustment is done within the programmable parameters of the OCR. This has also enabled many advanced features to be incorporated into very compact frame sizes and for full real time access, diagnostic detail and historical data to be accessed via communications and high-speed links to each breaker. These functions now make energy metering, power quality diagnostics and predictive maintenance easier to access and analyse. The breakers are also able to be controlled from external interfaces according to the system administrator’s requirements.

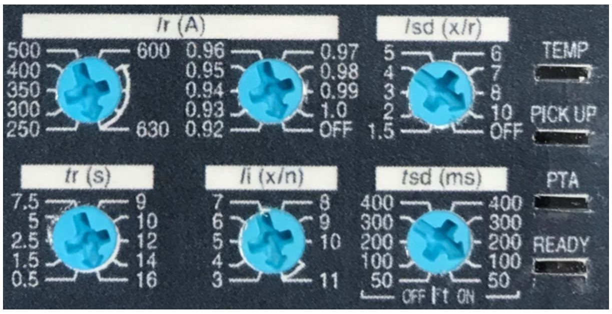


Figure 3.4.3
Example of MCCB LSI adjustment.

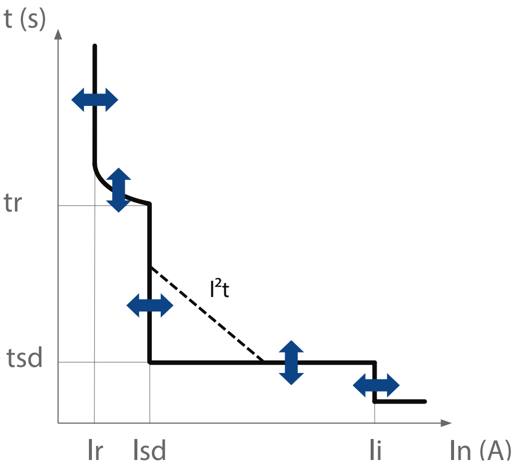


Figure 3.4.4

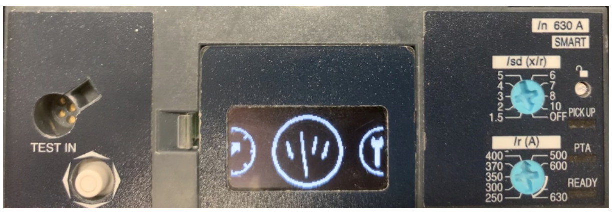


Figure 3.4.5
Typical on-board front face panel showing function icons and course adjustment dials.

Operating principle of Thermal Magnetic MCCB

The thermal magnetic MCCB tripping functions normally stem from the "unlatching" of a common section of the trip, lever mechanism. In the case of the thermal function, in similar fashion to a motor thermal overload, bi-metal strips (bonded slices of metal materials that have a difference in their "temperature co-efficient of expansion") are used to indicate higher than specified current draw by the load. The metal strips are heated as a result of the volume of current and this causes them to bend in a pre-determined fashion until they contact their portion of the trip lever. This causes pressure on the contact latching mechanism to dislodge and allow the breaker's contacts to open under normal spring tension thus tripping the circuit.

The short circuit function is carried out by the "short circuit coils" and a "shot pin" located in the centre of the coils. As the very high current caused by a downstream short circuit begins to rise and flow through the coils a high magnetic field is produced within the core of the coil. The "shot pin" is ejected by this magnetic field and impacts another section of the trip lever which very rapidly dislodges the contact latching mechanism and along with magnetic contact repulsion causes a rapid extinction of the current flow in the circuit. In the case of very high short circuit currents, ionized gasses produced by the arc are forced through the breaker's splitter plates, divided, and cooled and expelled through the arc chutes. The diagram below shows many of the internal mechanisms typical of a thermal magnetic MCCB.

Operating Principle of Electronic MCCB

The electronic MCCB operates via electronic over current relay detection and analysis of the current through the MCCB. This is via a signal sent by miniature current transformers within the breaker to the input of the OCR. The OCR samples the current signal according to its processor sample rate (somewhere between 2000 and 4000 samples per second) and integrates the current level on a rolling time period (in milliseconds). If the level of current exceeds the programmed current level limits the OCR sends a signal to the "Magnetic Hold Trigger" (MHT). This trigger is the mechanism that unlatches the breaker's contacts in the same way as the unlatching mechanism does in the case of thermal magnetic breakers.

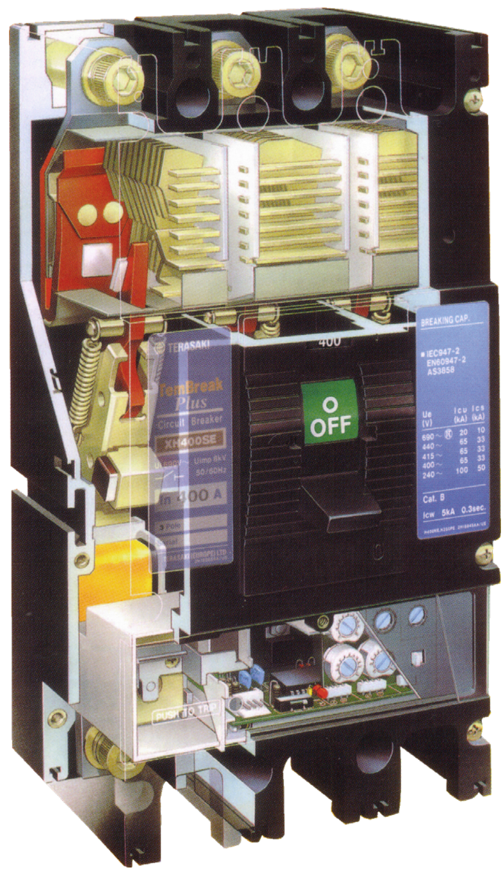


Figure 3.4.6
Top- Thermal Breaker.

Figure 3.4.7
Bottom - Cut away view of typical electronic MCCB

Moulded Case Instantaneous Trip Breakers (ICBs)

An instantaneous trip circuit breaker (an ICB-typically is an MCCB or ACB) that does not have any overload functions or a time delayed low-level short circuit tripping characteristic protection enabled, only providing instantaneous short circuit tripping capability. These are also commonly called Magnetic Only MCCBs.

This type of circuit breaker is ideal for use in motor starting applications where the overload / over current function is being provided by another device in the system and essential services applications.

The below extracts from AS/NZS 3000-2018 outlines the conditions in which ICBs are typically suitable.

Alternatively, other MCCB types are available which include the Long time, short time delay and instantaneous trip settings, but have the ability to deactivate the long time and short time trip characteristic, leaving the MCCB as an instantaneous-only "ICB".

These MCCBs are explained in more detail on the following page.

From AS/NZS 3000-2018

Clause 2.5.3.4
Omission of Overload Protective Device

The following applies:

a. Where unexpected opening of the circuit breaker could cause danger greater than overload, devices for protection against overload current shall be omitted in accordance with Clause 2.5.1.4.

Clause 2.5.3.4
Omission of Protective Device For Safety Reasons

b. Devices for protection against overcurrent shall not be provided for circuits where unexpected opening of the circuit could cause danger greater than over current.

Notes
Example of such circuits are certain safety systems supplies, lifting magnets, exciter circuits of machines and the secondary circuits of current transformers. In such cases the provision of an overload alarm is strongly recommended.

3

Examples of Moulded Case Circuit Breakers that can be configured to provide “Instantaneous only” protection are:

TEMBreak Pro 160 A to 630 A Multi Dial Basic Electronic

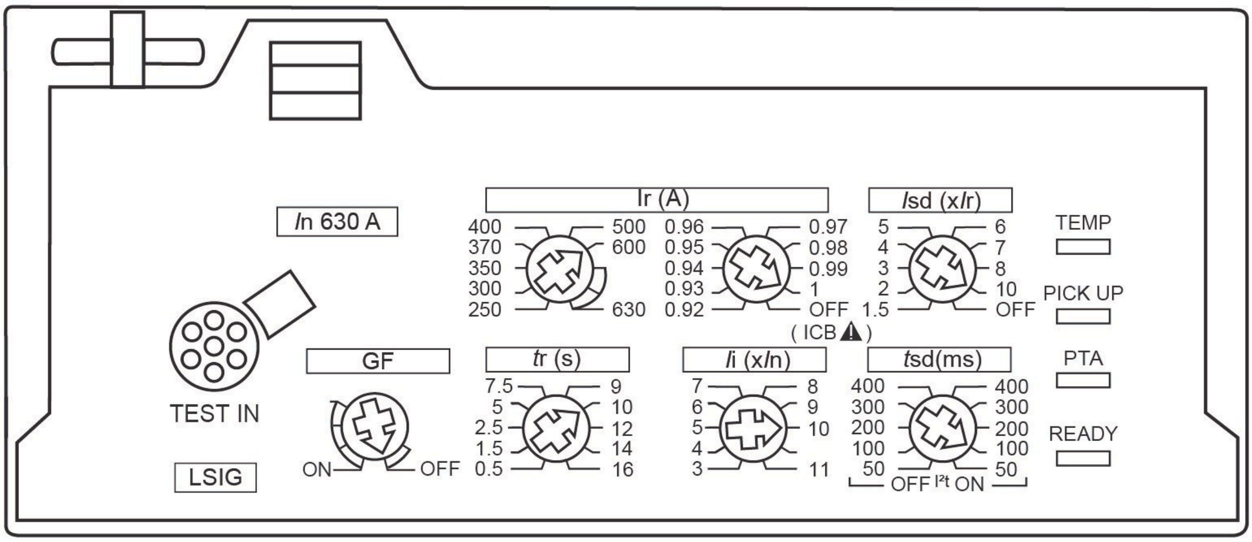


Figure 3.4.8
TEMBreak Pro 160 A to 630 A multi dial basic electronic.

2 Dial OCR

For this series of breakers, the instantaneous only feature can be selected as one of the “standard curve configurations” on the characteristics dial.

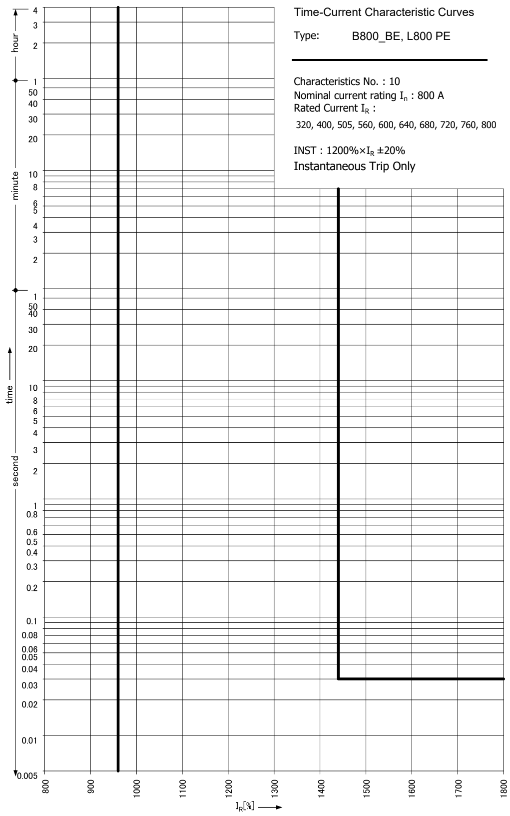


Figure 3.4.9
Top: Dial setting 10 disables the thermal and short time instantaneous portion of the curve

Figure 3.4.10
Right: Typical time current curve of ICB. Curve is as Magnetic Only breaker also.

Earth Leakage Moulded Case Circuit Breakers (CBRs)

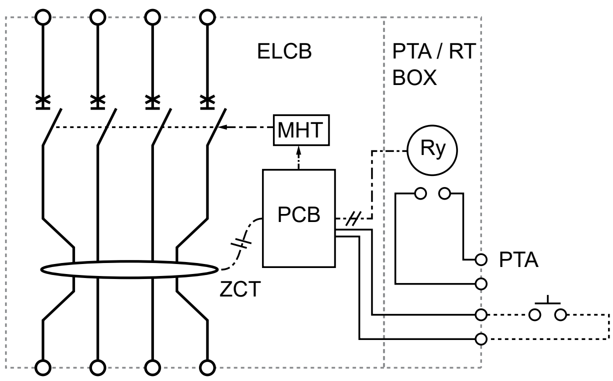
Earth Leakage Moulded Case Circuit Breakers (CBRs) have the protective functions of a thermal magnetic moulded case circuit breaker against overload and short circuit in electrical circuits as well as the detection and tripping functions for very small earth leakage currents.

CBRs feature three major characteristics:

1. The physical dimensions are the same as a standard MCCB
2. The rated voltages 100 / 110, 230 / 240 and 400 / 415 V AC are supported.
3. The rated sensitivity of the earth leakage current and the operating time can be selected from multiple values.

Figure 3.4.11
CBRs are available from 125 AF to 800 AF, 30 mA to 3 A detection

Figure 3.4.12
Terasaki ZS CBRs internal ZCT circuit



ZCT (Zero Phase Current Transformer)

ZCTs are commonly used for earth leakage and earth fault protection. The single cores of a 3-phase system pass through the inner diameter of the ZCT. While the system is fault free, and the outgoing and return current vectors are balanced, no current will flow in the secondary output of the ZCT. When an earth leakage occurs, the residual current (zero phase sequence current) of the system flows through the secondary of the ZCT and is detected by the earth leakage detection circuit. If the value exceeds the selected leakage value this trips the relay within the breaker and causes the main poles to open.

3

Circuit Breakers for 690 V / 1000 V Applications

Figure 3.4.13
Typical 690 V rated MCCB.

The need for systems that reticulate with an increase in voltage levels is necessary where long runs of cable are required to service electrical devices without being subjected to appreciable voltage drop and to assist in reduction in conductor cross sectional area due to lower current draw per kW of power.

Most of the applications are remote operations that include extensive tunnel installations for motor vehicles and trains as well as underground mining operations. These are applications where it is impractical or dangerous to locate generators or higher voltage networks with transformer placements close to the location where the power is needed.

The use of 690 V motors on fans and pumps in transit tunnel projects is common due to the long-distance cable runs and the relatively easy availability of 690 V delta wound motors. For other devices in tunnels such as lighting and security / fire services minimal transformation is required for 690 V to 400 V supply to reticulate a local 400 / 230 V network.

The need for higher voltages introduces many challenges and also requires the use of specialist switching and protection devices to safely cope with the elevated risk and increase in interruption duties. At the 690 V range some 400 V devices are capable and rated to operate at this voltage, albeit at a much reduced fault current level. They may also need additional insulation barriers and rear clearance / insulation to protect against flash over during fault interruption. Depending on the breaker design, line and load connection may be specific so the ability to mount onto a proprietary chassis system may be limited or not possible.

3

1000 V AC Applications

The 1000 V AC reticulation system is normally used in underground mining applications. This is necessary for a number of reasons. The increase in voltage levels lowers the current requirement per kW of power used in the operation. This in turn reduces the cross -sectional area of the conductors needed and offers cost savings as well as ergonomic advantages especially when dragging trailing cables around the tunnels.

MCCBs specifically designed for these applications feature rapid operation and arc extinction as well as larger creepage and arc clearances. Specifically designed insulation barriers and terminal covers must be used as these ensure ionized gasses and ejected materials during high fault interruption do not flash over and ignite within the distribution enclosure.

Most circuit breakers in the 1000 V range are designed to operate on 1100 V as well however with a reduction in fault current interruption capabilities in most cases. In some breaker models this can be a reduction of 50% interruption capacity or more.

Figure 3.4.14
Typical 1000 V rated MCCB.

Figure 3.4.15
Typical underground mine for 1000 Volt distribution.

Circuit Breaker Accessories

There are many different types of accessory for a circuit breaker, dependant on whether we are dealing with an ACB, MCCB or MCB.

For example, an ACB has options on the method of connection into and out of the breaker. On the other hand, an MCB is more restricted in terms of connection options due to the smaller physical size of the device.

Therefore, each type of protective device must be considered independently when considering what accessories should or shouldn't be included.

The following is a list of the more commonly used accessories. The list has been sub-divided in to two groups, 'internal accessories' and 'external accessories'.

Internal Accessories

Auxiliary Switch

Used to remotely indicate the status of the circuit breaker and show whether it is in the Open (OFF) or Closed (ON) position. An Auxiliary Switch will not indicate whether the circuit has tripped to the open position or whether it was done manually or via the Shunt Trip.

Shunt Trip

Allows the circuit breaker to be remotely opened (Tripped). Commonly used in conjunction with a 'Normally Open' pushbutton or switch connected in series. Operation of the switch or pushbutton will energise a coil within the Shunt and opens the breaker.

Alarm Switch

Indicates whether the circuit breaker has tripped or not. Separate from an Auxiliary Switch as it gives only a 'Tripped' or 'Not Tripped' indication.

Undervoltage Trip

Voltage sensing device that automatically trips the circuit breaker should the voltage level fall below a pre-determined level. Can also be used to remotely open the circuit breaker similar to the Shunt Trip. In this case the UVT should be connected in series with a 'Normally Closed' pushbutton or switch. In this case any operation of the pushbutton or switch will remove power from the UVT and so trip the breaker.

External Accessories

Motor Operator

A device fitted onto or within a circuit breaker in order to give remote control of the breaker status. Can operate to open and/or close a circuit breaker.

Connections

Numerous different types of connections are available for circuit breakers. These can be Front Connect, Rear Connect, Plug-In and may be supplied with Horizontal or Vertical connections. These should be specified at the time of order as many are factory-fitted.

Handle Mechanisms

Used on MCBs and MCCBs. Fitted to the circuit breaker fascia and operates the toggle on the front of the device to open or close the breaker. Available as direct mount type, or with a variable depth rod to adjust to the required distance from the breaker.

Terminal Covers

Fitted to the top and/or bottom of the circuit breaker after the cables or busbars have been connected to the breaker terminals. Prevents any direct contact with live conductors within the switchboard.

Motor Starting Protection Moulded Case Circuit Breakers

Specific MCCBs have been developed to work optimally as a Short Circuit Protection Device (SCPD) for motor starters equipped with either direct connected of CT connected over current relays. Generally, there are two motor starting MCCB options available depending on the motor starting characteristics:

1. Fixed overload / fixed hydraulic – magnetic
2. Instantaneous tripping MCCB (ICB)

Hydraulic – Magnetic Trip Unit

A Hydraulic-magnetic MCCB trip unit structure, consists of an electromagnet with an oil dash pot used as a time delay tripping element. When the current is lower than the rated value, the core is pressed against the pipe bottom by the controlling spring and the magnetic resistance is high, so that the movable iron piece is not attracted. However, if overcurrent flows continuously, the magnetomotive force of the electromagnet will increase, the core will overcome the controlling spring force and move toward the lid from the pipe bottom to reduce the magnetic resistance and disengage the latch, and an overcurrent trip will occur. At this time, the viscous resistance of the damping oil in the pipe causes a trip. This time delay operation shows inverse time characteristics that increase the electromagnetic attraction and reduce the operating time as the current increases. If a large short circuit current flows, the movable iron piece will be immediately attracted by sudden increase in leakage flux to break the circuit before the core moves. Both overcurrent and short circuit current are interrupted using the same electromagnet. Hydraulic magnetic type devices for low current rating can be made by changing the number of coil turns, and those for special purposes can be made by adjusting the viscosity of damping oil or the gap between core and pipe.

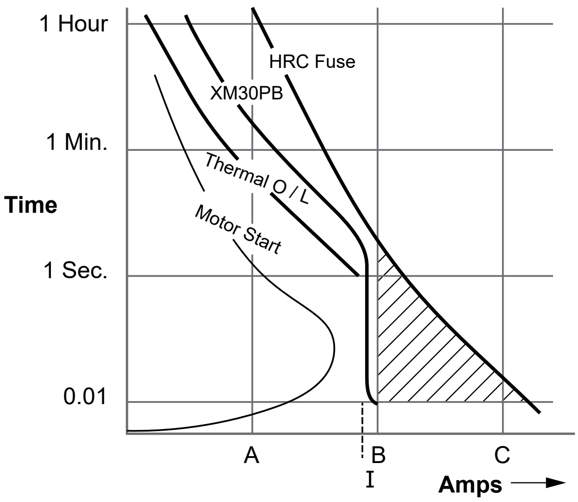
NHP/Terasaki TemBreak Motor Protection Circuit Breaker XM30PB

The XM30PB circuit breaker is a fixed overload / fixed hydraulic – magnetic design that will protect contactor starters with direct connected overcurrent relays at ratings of 1 amp the 12 amps in systems with up to 50 kA RMS prospective short circuit.

The protection is due to the special current limiting effect of the XM30PB.

XM30PB and ICBs Compared to HRC Fuse

The circuit breaker tripping characteristic is more suitable for protection of starters than the HRC fuse. Unlike the HRC fuse, the breaker can be selected to trip instantaneously at a predetermined current level just lower than the maximum breaking current of the starter contactor, thus always protecting the contactor against opening fault currents higher than its capability. This can be seen from the typical breaker and fuse tripping characteristics compared to the contactor breaking capacity in figure 3.4.17. No protection is provided by the fuse when the overcurrent is of value B to C amps, should the contactor open by earth fault relay. If the breaker is used as a SCPD then protection is provided for all currents in excess of the instantaneous trip current of the breaker. Also, the circuit breaker can be tripped by earth fault relay and so prevent the risk of contactor damage due to the long delay of the HRC fuse interruption if the fault current is of a value between B and C.



A- Normal Rating of Contactor
B- Maximum Breaking Current of Contactor
C- Cut-off Current of Fuse
I- Instantaneous Tripping Current of Breaker

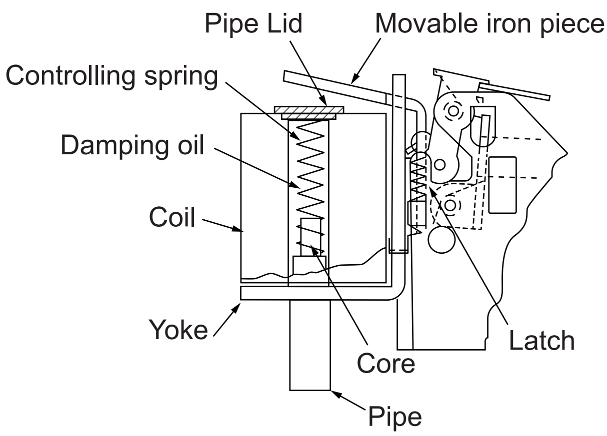


Figure 3.4.16 (top)
The XM30PB circuit breaker

Figure 3.4.17 (middle)

Figure 3.4.18 (bottom)
Typical electromagnet trip mechanism

Non-Automatic Switch Disconnector Circuit Breakers

Most circuit breakers are supplied with the over current relay (OCR) already installed to provide overload and short circuit protection. Some circuit breakers are available without any protection, or in other words, thermal and magnetic trip elements not fitted, or OCR not fitted or disabled. These devices are commonly referred to as “Non-Auto” or “Non automatic circuit breakers” and can be used in several ways.

One common application is to use a stand-alone protection relay that is remote from the circuit breaker. This protection relay can then operate the non-auto breaker and trip it under fault conditions by using a shunt trip device fitted to the breaker. A shunt trip is a device fitted internally that, when energised will hammer the trip bar of the circuit breaker and make it open.

Another use for non-auto devices is as a basic switch. In this case the circuit breaker can be opened and closed as a standard load break switch or isolator. For instance, a non-auto ACB is commonly used as a “Bus-Tie” to join or isolate two areas of a distribution system.

In applications requiring a large number of switching operations it is recommended that a contactor be used in place of the circuit breaker (if the load type and expected duty is within the contactor’s operational range). A contactor is a piece of equipment designed to operate many thousands, even millions of times. Although most circuit breakers can operate 2,000 to 20,000 times, they will be outlasted by the switching performance of a contactor.

Figure 3.4.19
Typical Non-Auto MCCB. No trip adjustment dials fitted as no internal components to perform the function are installed.

3.5 Motor Starting

Introduction to Motor Starting and Circuit Protection

Generally, an item of switchgear is selected on the basis of one or more performance criteria, be it current/power carrying or interrupting capabilities. Additional consideration is often necessary when several different pieces of switchgear are connected in series, none more so than in motor starting applications. As motors play a significant part in most modern-day electrical systems, it is important to ensure that the components of switchgear controlling and protecting the motor will interact with each other, in other words, they are "co-ordinated". In order to protect and operate a motor, several components may be used, each with a different function.

Meeting Standards

The requirements of several standards can be applied to these combination units. The Wiring Rules, AS/NZS 3000:2018, are concerned mainly with setting standards for the fixed wiring. In this regard the concern is the wiring between the protective device and the motor. As motors can experience short term overloading the current rating of a fuse can be up to 4 times, or a circuit breaker 2.5 times the full load rating of the motor. The Wiring Rules allow the overload protection and the short-circuit protection to be provided by different devices.

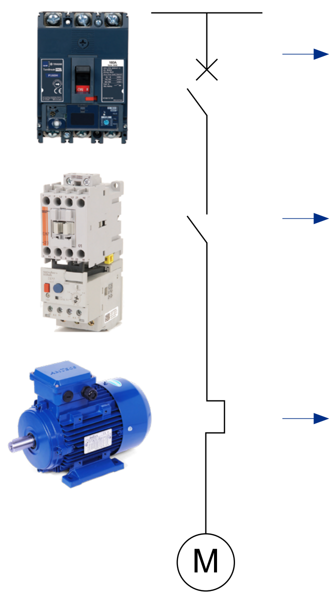
This allows magnetic only circuit breakers, or back-up type fuses to be used, in conjunction with a contactor/thermal overload relay configuration.

Isolating switches must also be provided in the motor or control circuit. These are to be in clear view of any person working on the motor, or provided with a locking device.

AS/NZS 60947.4.1:2015 – specifies testing requirements for the combination of components required to perform motor control and protection functions.

It is accepted in these standards that some damage may be sustained by the components of the starter when subjected to short-circuit conditions, and some maintenance practices employed for the switchgear may be necessary.

A typical set-up is as follows:



Short Circuit Protective Device (SCPD)	The main purpose of the Short Circuit Protective Device (SCPD) is to give protection against short circuits. Commonly used devices are circuit breakers or fuses. Each offer particular benefits and both configurations are commonly used.
Contactor	The function of the contactor is for circuit control, i.e. for the on-off operations of the motor. As contactors are capable of thousands or even millions of operations, they are the most commonly used control devices.
Thermal Overload Relay	An overload relay will provide ideal protection against overloads on the motor, as well as phase loss protection. Although the SCPD may give overload protection, the overload relay curves are more aligned to the characteristics of the motor to prevent overheating. If an over-current fault is detected the overload relay will signal the opening of the contactor or control device, thereby isolating supply to the motor.

Problems that Can Occur

At the instant the motor is supplied with power, it draws an “in-rush current” to its terminals before gradually decaying as the motor accelerates, to a normal operating current. Should the in-rush current be high, it could be detected by the SCPD and classed as a fault current. If a high in-rush current should occur or even after repeated stop-start (inching) operations of the motor, the SCPD may trip, albeit without a fault in the system. This is commonly known as “nuisance tripping” of the SCPD.

Special care must be taken when selecting a SCPD for motor starting applications to prevent nuisance tripping and, at the same time, ensuring adequate protection to the motor and associated cabling. Another function of the SCPD is to protect the control device (e.g. contactor) from high-current, high-energy faults. Therefore, attention must also be paid when selecting a SCPD Starter (contactor + thermal overload relay) combination.

When clearing a fault, every SCPD has a finite opening time, which will result in an amount of fault current and energy being “let-through” to the downstream system and other devices. At the same time a control device, such as a contactor, can only withstand a finite level of fault current and energy, otherwise internal damage and welding of contacts could occur.

Even at relatively low fault levels the electromagnetic forces created by the fault current can cause the contacts of a contactor to lift. This can cause heating or even mild arcing which in turn can damage or weld the contacts of the contactor. Furthermore with thermal overload relays, excessive let-through current from an SCPD can distort or fuse the bi-metal strip in a thermal overload relay. This can prevent the functioning of the bi-metal strip, or alter the relay’s protection characteristics, thus resulting in under or over protection of the motor.

Available Solutions

Good component design, in association with correct component co-ordination, is the only way to ensure safe and reliable protection, and operation under abnormal conditions. Terasaki circuit breakers and Rockwell Automation starter combinations are tested to provide full and safe co-ordination for motor starting applications.

Selecting Protective Devices for Motor Starting Applications

Protective Devices Selection

In most cases very little difference will be noticed in the service performance of a system using fuses as against circuit breakers. The circuit breaker is easier when it comes to restoring power but as tripping should only be the result of a system fault, it is unwise to reclose the circuit breaker without finding the cause. In this regard it is normal for only a “skilled person” to attend to fuse replacement and they are more likely to check for other problems.

As the circuit breaker or fuse is operating in conjunction with separate motor overload protection, it is the contactor which responds to overload problems. This is different to a protective device on a distribution circuit. For this application the advantages of the circuit breaker’s easy return to service has caused a general trend towards using circuit breakers.

Consideration should be given to preventing unskilled people from reclosing a tripped circuit breaker in a motor control application, as a tripping instance is most likely due to a short circuit incident. This can be done by making the switchboard only accessible to the correct people, with maintenance inspection of the MCC cell undertaken to ensure the vented gasses and material have not caused insulation degradation elsewhere.

It must be assumed with both Type ‘1’ and Type ‘2’ co-ordination that if the short circuit protective device has operated there is a fault in the motor, or wiring to it, and that the starter itself needs attention. It is the let-through energy of the protective device which determines the damage to the starter. As this varies greatly between different models, it is essential that only proven combinations are used.

Terasaki Circuit Breakers for Short Circuit Protection

Terasaki circuit breakers have been tested in combination with Rockwell Automation and overloads and can be used for Type ‘1’ and Type ‘2’ co-ordination requirements.

From the testing conducted by NHP, Terasaki and Rockwell Automation, these combinations are formatted into Co-Ordination tables.

Figure 3.5.1
Components for coordinated motor starting.

Type 1 and 2 Coordination

Overview of Coordination

The motor starter consists of a combination of contactor, overload relay and short-circuit protective device (SCPD) being either fuses or circuit breakers. During motor starting and at normal loading, the overload relay protects both the motor and cables by signalling the opening of the contactor, in a time inversely proportional to the current.

However, under short-circuit conditions, the overload relay response time would be too long, and the fuses or circuit breaker must take over to interrupt the fault current, therefore limiting energy passed through the starter components. When this is successfully achieved, the combination is said to be co-ordinated.

The primary function of co-ordination is to ensure that the selected components result in safe interruption of fault currents while minimising damage to the starter components themselves.

As defined in AS/NZS 60947.4.1:2015, with both Type “1” and Type ‘2’ co-ordination,

- The contactor or the starter must not endanger persons or systems in the event of a short-circuit.

For Type ‘1’ co-ordination,

- it allows that the contactor or the starter components, may not be suitable for further service, and may be repaired or have components replaced, prior to returning to service.

For Type ‘2’ co-ordination,

- the contactor and the starter must be suitable for further use,
- with no damage to the overload relay or other parts occurring, with the exception of welding of the contactor or starter contacts, provided that these can be easily separated (e.g. with a screwdriver) without significant deformation.

Why is Co-ordination Important?

Contactors are designed to switch loads frequently. They can carry the high starting currents of motors, but at short-circuit levels, the extremely high current can force the contacts open due to electro-dynamic effects (it is this effect that is needed at normal operating currents to extinguish the arc quickly). Large short-circuit currents can therefore lift the contacts possibly resulting in contact welding or further damage to the starter components.

The importance of selecting the correct SCPD is to minimise the effects of short-circuits, provide safe interruption and a level of performance to meet the criteria for either Type ‘1’ or Type ‘2’ co-ordination.

Where a starter combination has been in service for a period of time, where there have been some MCCB trips and the contactor has been subject to some DOL starts, the performance can differ. Where a starter needs to be returned immediately to service, it is wise to schedule a detailed inspection during a plant maintenance shutdown.

With maintenance procedures and Type 2 selected components, these will provide the end user minimal downtime and minimal lost production, in the event of a fault.

NHP

4 Understanding Performance Characteristics of MCCBs

NHP

4

4 Understanding Performance Characteristics of MCCBs

The Moulded-Case Circuit-Breaker – is a mechanical switching device, that is capable of making, carrying and breaking currents under normal circuit conditions, carrying overloads, but is also required to break currents under abnormal circuit conditions, such as short-circuits of varying magnitudes.

When designing an electrical installation, an MCCB selection is made with regard to; current carrying capacity required, the operational voltage and the Prospective Fault level.

The performance capabilities of a circuit breaker can be determined from the type tests completed to meet the standards, in this case to AS/NZS IEC60947-2

The MCCBs are designated with a fault rating for the service voltage of the installation, which is in line with the capacity of the MCCB to open the circuit under short circuit fault conditions, i.e. their Breaking capacity.

4

4.1 MCCB Related Acronyms and Definitions

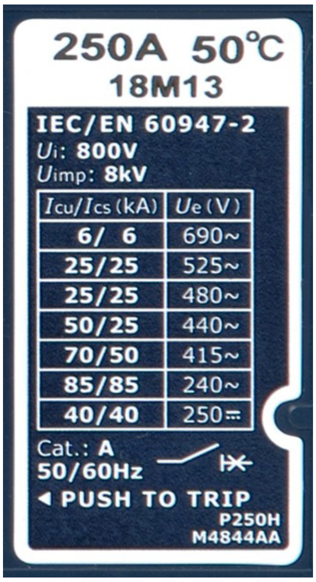


Figure 4.1.1
MCCB rating label number 1.

I_n – Rated Current

This is the maximum value of current that the MCCB can carry indefinitely at a nominated ambient temperature, without exceeding the temperature limits specified for the current carrying parts. I_n is equal to the conventional free-air thermal current - I_{th}. The maximum temperature rise that is permitted on the MCCB terminals when carrying full load current is 70 °C according to AS/NZS 60947-2.

I_r – Overload Current Setting

For circuit breakers with an adjustable overload release, this is the current setting of the long time trip. This will be a % of I_n.

U_e – Rated Operational Voltage

This is a value of voltage which, combined with a rated operational current, determines the application of the MCCB, for operation in normal conditions. Ue is the voltage between phases.

The assigned breaking (I_{cu} / I_{cs}) and making capacities (I_{cm}) are always set at a specified operational voltage (U_e). There will be different values, at different U_e values.

U_i – Rated Insulation Voltage

This is the voltage referred to, when conducting dielectric tests and checking creepage distances.

U_{imp} – Rated Impulse Voltage

This is the maximum voltage the MCCB can withstand without failure.

4

4.2 Types of Over-Current Relays (OCRs) / Trip Units

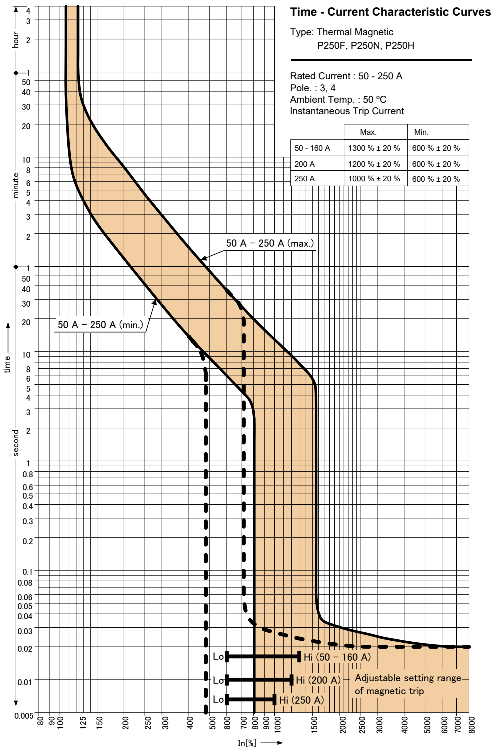


Figure 4.2.1
Typical MCCB Time-Current tripping curves

Overview

The trip unit of an MCCB, sometimes referred to as the Over-current Relay or OCR, determines the response of the breaker when an overcurrent occurs. The type of trip unit is characterised by the type of internal electrical components used to detect, evaluate, and initiate the trip operation mechanism of an MCCB.

There are two types of trip units; Thermal Magnetic that relies on thermal and electromagnetic properties of the current going through its internal components to control and operate the tripping function; and Electronic types which includes current transformers and microprocessor to monitor current and determine when the circuit breaker needs to trip, based on pre-defined parameters.

Thermal Magnetic MCCBs can detect both AC and DC currents. Electronic MCCBs are for AC currents.

The circuit breaker's tripping characteristics for overload and short circuits are defined with a Time Current curve.

The Time Current curve is normally an inverse time delay, where low level overloads take a long time to trip, whilst high level overloads have a much quicker trip time.

This relationship is shown in figure 4.2.1

The Thermal Trip Setting of an MCCB (Ir), is commonly matched to the rated current of the circuit, thereby under normal rated current conditions, the trip unit will carry this current level indefinitely without tripping. Depending on the standards to which the circuit breaker complies, the must trip thresholds of time and current may vary, model to model.

Generally, at calibrated temperature the thermal response will cause a trip in the breaker at between 115 % and 135 % nominal current within 2 hours.

The Magnetic Trip or Instantaneous section of an MCCB (Ii), is designed to react quickly to a short circuit event. The tripping point can vary depending on the MCCB Fig. 4.2.1 Typical Time Current curve design, frame size and nominal rating.

The time current characteristic is shown on a logarithmic scale to allow compact plotting of the large values of current and time. The maximum and minimum limits of the curve are the tolerance bands for calibration processes, with the characteristic curve of most MCCBs following the 'average' curve within the tolerance band.

Both types of Trip Units have their advantages and disadvantages and should be selected with the performance and tripping characteristic to suit the application.

4

Thermal Magnetic Releases

These trip units have two elements in their construction which combine to form the tripping curve.

The Thermal portion of the curve "T", - refer to fig 4.2.2, which protects against low level over-currents for an extended period of time, utilises bi-metal elements which are heated proportional to RMS current's magnitude, and by way of deflection the bimetallic strip actuates the trip mechanism release of the MCCB.

Where an MCCB has a fixed thermal trip, the Ir will be I_n, whilst where the trip setting is adjustable, I_r will be a % of I_n

The magnetic portion of the curve "M", relies on the properties of magnetic solenoid operation in instantaneous and short time response, to high over-currents at multiples of the nominal current I_n.

The magnetic operation of the breaker is engaged when exposed to short circuit current.

During short circuit fault conditions the electromagnetic force of the high current produces a magnetic force in the short circuit coil that causes a solenoid shot pin to thrust against a calibrated spring and if sufficient force is produced, impact the trip mechanism and unlatches the breaker contacts. The speed of this response assists the current limiting properties of the circuit breaker.

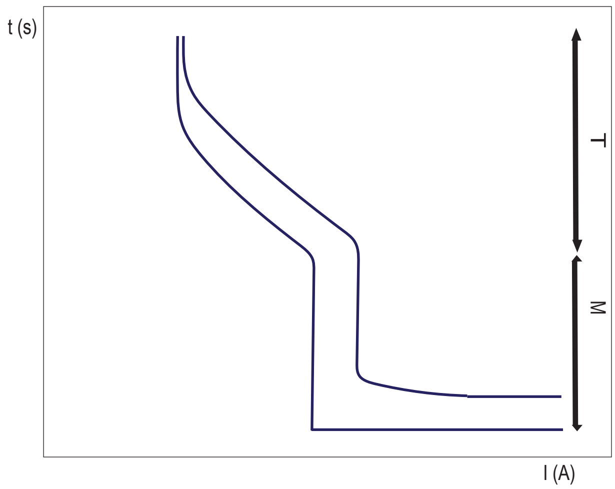
The Magnetic Current I_m setting of the breaker determines the magnitude of current that the Trip unit will respond as fast as mechanically possible in response to high short circuit fault current.

The Magnetic release of an MCCB may be of a fixed multiple of I_r / I_n, or have an adjustable magnetic setting range, as multiples of I_r / I_n.

Hence, there can be four variations of Thermal Magnetic type release MCCBs;

- Fixed Thermal and Magnetic (FF)
- Adjustable Thermal, Fixed Magnetic (TF)
- Adjustable Thermal and Magnetic (TM)
- Magnetic only (MA)

Figure 4.2.2
Thermal and Magnetic response regions.



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Electronic Releases

With the advent of electronics, the traditional tripping curve of Thermal Magnetic types has been able to be replicated, plus extended adjustment capabilities to allow for additional flexibility in protection settings.

The Electronic Trip Unit utilises a microprocessor to monitor phase currents and initiates a trip response in accordance with preset conditions. Integral current transformers for each pole of the breaker constantly supply the proportional representation of the actual current to the ASIC (Application Specific Integrated Circuit). When the measured values exceed the set current parameters for a specific time, the microprocessor signals the trip mechanism to open the MCCB.

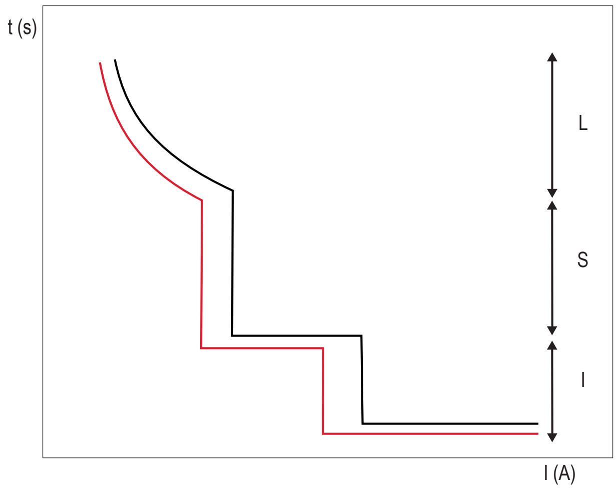
The trip characteristic determined by an Electronic trip unit can be broken up into different segments, with Long time “L” being inverse time delay, like the Thermal section, and Short time and Instantaneous with definite time delay and associated current magnitude, as shown in the general electronic characteristic curve in figure 4.2.3.

The Electronic trip units allows for additional functionality to be included, with Ground fault and I^2t protections included in the microprocessor calculations.

There can be many variations of Electronic over-current relays, L-I, L-S-I, L-S-I-G, I (ICB), and specific pre-defined curves configured to suit different applications.

With high performance Electronic trip units, the addition of inbuilt metering, remote screens and network communications allow operators to see real time information on current and power, as well as historical information from trip events.

Figure 4.2.3
Long time, Short time and Instantaneous response regions.

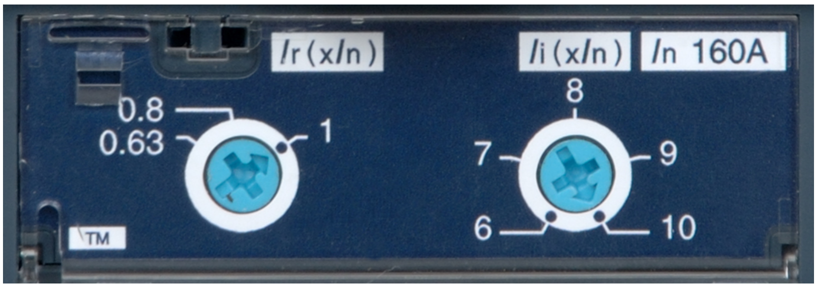


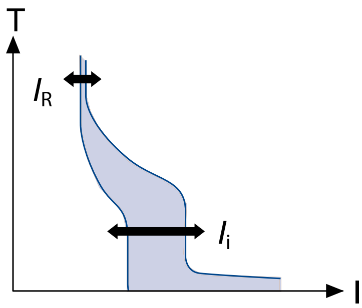
4.3 Setting of OCRs and Trip Units

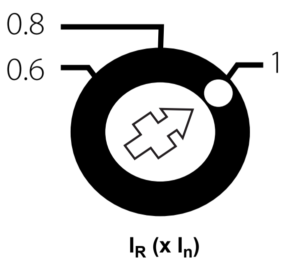
Thermal Magnetic MCCB Settings

Many Thermal Magnetic trip MCCBs in the market have adjustability of the Thermal and Magnetic tripping points. These trip characteristic settings are adjusted using dials on the face of the Trip Unit.

Figure 4.3.1
Adjustments for Thermal and Magnetic tripping values.

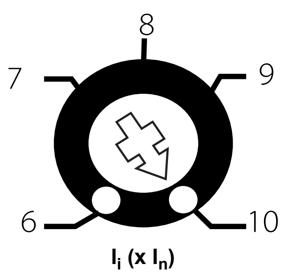






For the MCCB current setting (I_r), being the thermal element, the scale on the adjustment dial may be a percentage or fraction of rated nominal current (I_n) for the MCCB, or as an actual current value. The normal setting range available is down to 60 %, 70 % or 80 % of the MCCBs nominal rating, with the setting dependent on the current carrying capacity of the cable to be protected, or connected equipment.

The scale used should be clearly marked adjacent to the Ir, dial, with the setting point continuously adjustable between Min and Max, but are calibrated at the marked factors.



For Instantaneous Current settings (I_i), being the magnetic trip adjustment, the scale on the adjustment dial is shown as multipliers of the rated nominal current (I_n) of the MCCB.

These may be defined set points, or continuously adjustable depending on the magnetic elements construction. The setting point of the magnetics should be based on selectivity requirements and allowance for temporary inrush of over-currents of a connected load.

For those Thermal Magnetic MCCBs with a fixed value, the thermal trip current setting (I_r) and / or the magnetic instantaneous current setting (I_i) are defined for each MCCB selection.

4

Ambient Temperature Consideration

Where an MCCB is installed in an ambient higher than it's nominated calibration temperature, a number of factors need to be considered.

As In is the maximum permissible current at the nominated ambient temperature, to ensure internal current carrying components thermal threshold and connection terminals do not exceed the limits prescribed, a reduction in the permissible current has to be factored.

With the effects of excess of operation and connection temperatures varying with frame size rating, construction breaks and connection method, the deratings factors for each trip unit will having different factors, which can be represented as either a curve or in table format.

The tripping elements of Thermal circuit breakers react to the effects of heating, so the tripping characteristics will differ with changes in ambient temperature, with premature tripping of a circuit breaker occurring at elevated ambient temperatures.

Derating a circuit breaker can be achieved by adjusting the Ir setting of its trip unit, in line with the derating factors.

For example, where a circuit breaker is required for 100 Amp in 70 °C ambient, a 125 A trip unit (with calibration temperature of 55 °C) with maximum permissible current of 113 A in 70 °C, a reduction of 10 % or factor of 0.9 would be utilised.

The I_r setting point is 1 / 0.9 (1 / factor), for the set point to ensure premature tripping does not occur, for 100 Amps it would be 110 Amps at in 70 °C.

Likewise, where the Thermal Magnetic MCCB is installed in a lower ambient than calibration temperature, the tripping time will be increased, so it should be verified that protection of cabling and equipment is still maintained.

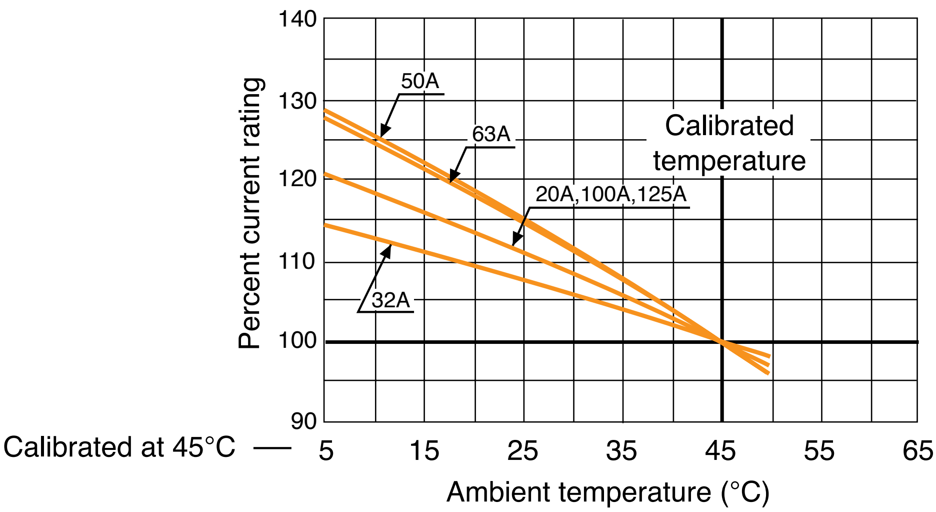


Figure 4.3.2
Typical ambient re-rating curves.

Electronic MCCB Settings

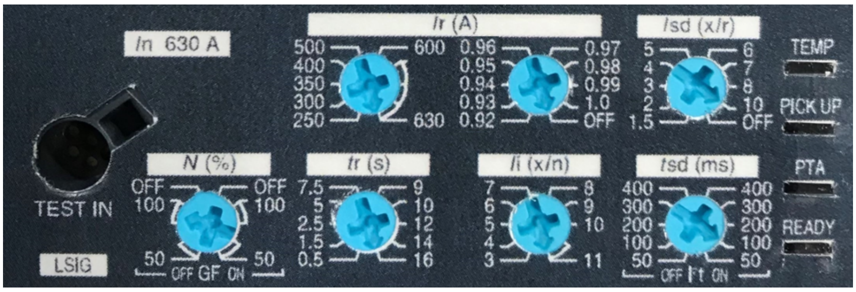
The wide diversity of trip characteristics that may be adjusted and the manner in which they are adjusted, can vary greatly depending on the Electronic Trip Units fitted in the MCCB selected. The trip unit protection adjustments available are:

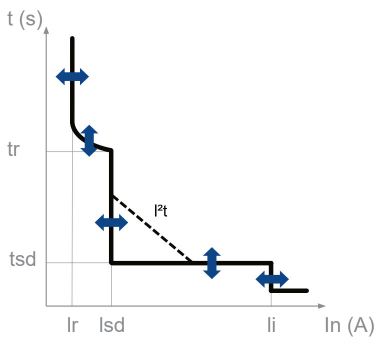
L	I_r	Long time protection adjustment
	t_r	Long Time Delay
S	I_{sd}	Short time protection adjustment
	t_{sd}	Short Time Delay
	I^2t	I^2t curve on Short time protection ON or OFF
I	I_i	Instantaneous protection adjustment
G	I_g	Earth Protection Threshold
	t_g	Delay protection Earth

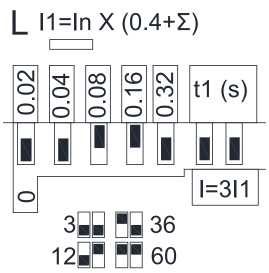
An electronic trip unit may have some or all of these depending on its specification and performance level.

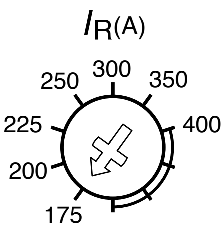
Some or all the settings for fault current magnitude and relative time delay may be adjustable by dial or dip switches for incremental % steps on the front of the OCR, with some products offering secondary dials for fine scale adjustments, or screen setting of 1 Amp increments to provide greater accuracy in settings, depending if it is a simple, basic or performance version OCR.

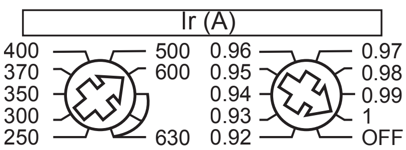
Figure 4.3.3
Adjustments for Long time, Short time and Instantaneous tripping values.









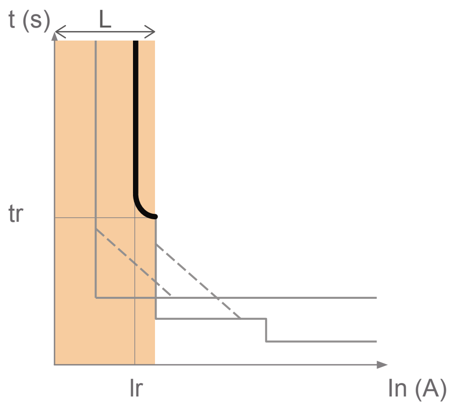


I_r -Trip Current Setting - Long Time

The normal setting range available is down to 40% of the MCCBs nominal rating, with setting flexibility for a circuits current rating, cable size or connected equipment.

t_r -Trip Delay Adjustment - Long Time

Typical adjustment range is from 0.5 to 16 seconds, with reference to 6 times I_r.

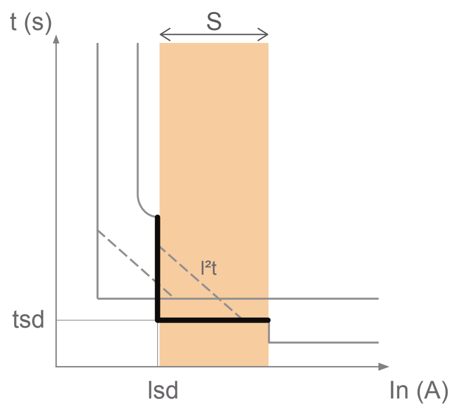


I_{sd} -Trip Current Setting - Short Time

This is used in-conjunction with Ii instantaneous setting, with setting a curve to match a load profile, having low level short circuit protection whilst allowing for short time inrushes, and providing settings to allow Selectivity between breakers.

Typical adjustment range is from 1.5 to 10 times the MCCBs nominal rating.

This function is not offered in simpler electronic trip units.



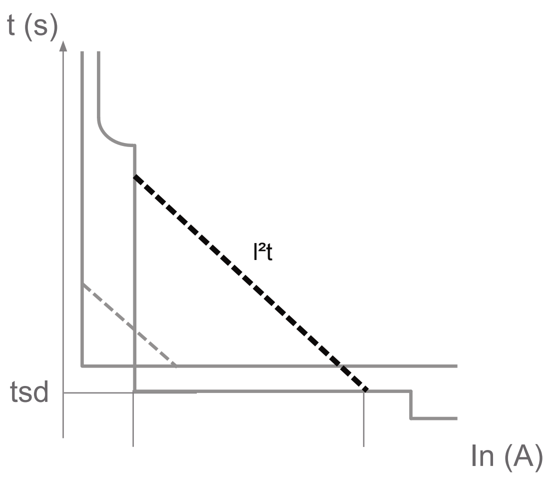
t_{sd} -Trip Delay Adjustment - Short Time

Typical adjustment range is from 50 to 400 milliseconds, with reference to 10 times I_r.

I^2t - Inverse Adjustment - Short Time

With this function "ON", it changes the transition from Short time to more resemble a Long time trip setting which is similar to be an inverse time curve, rather than a square step. Additionally, the sharp right angled section part of the characteristic is removed (shown as a dotted line).

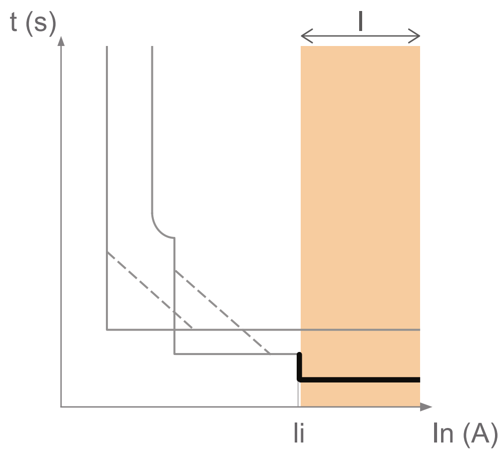
This function is extremely useful when setting of multiple breakers in series for selectivity, and allowing for load fluctuations, like motors starting.



I_i - Trip Current Setting - Instantaneous

The adjustable instantaneous allows short-circuit protection to be matched to the load and supply characteristics, adjusting a circuits earth-loop impedance and providing Selectivity between breakers.

Typical adjustment is from 3 to 15 times the MCCBs nominal rating, with setting range varying dependent on trip units and MCCB frame sizes.



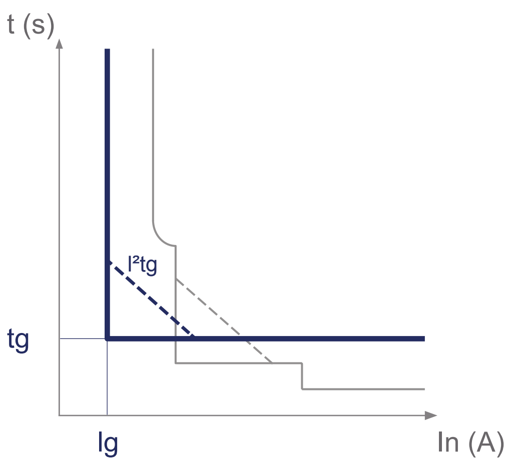
I_g - Trip Current Setting - Ground Fault

This provide early detection of phase to earth faults, initiating tripping before the fault is seen by the I_{sd} and I_i points.

The tripping point can either be a fixed %, or adjustable from 20 % to 100 % of the trip units nominal value I_n.

t_g - Trip Delay Adjustment - Ground Fault

Typical Setting delay is from 50 ms to 500 ms.



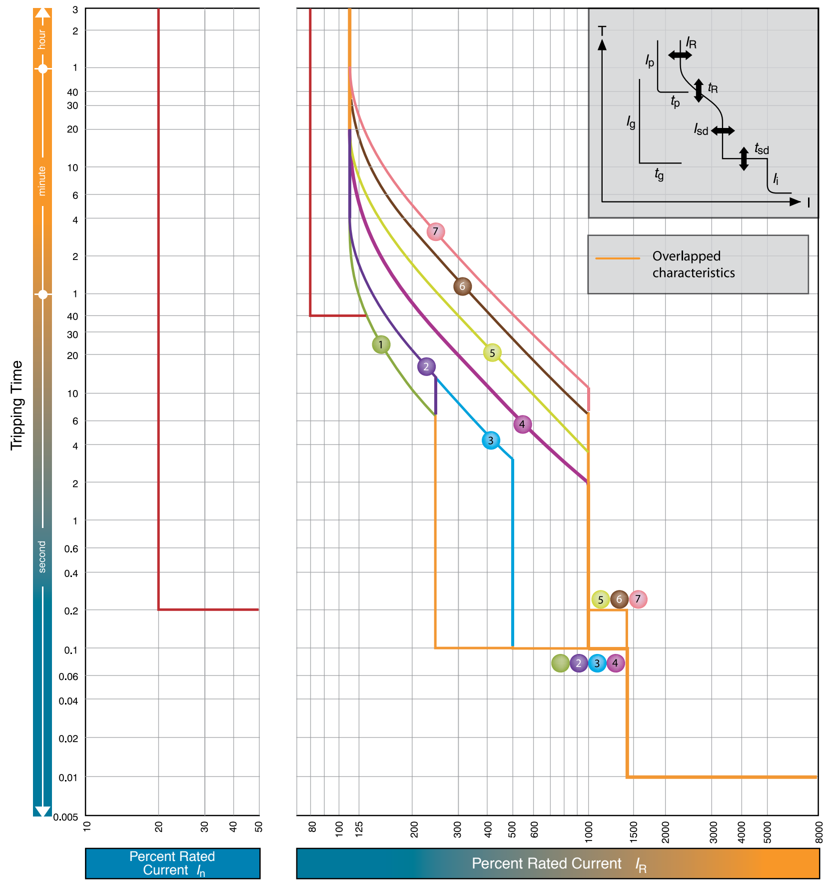
Adjustable Neutral Protection

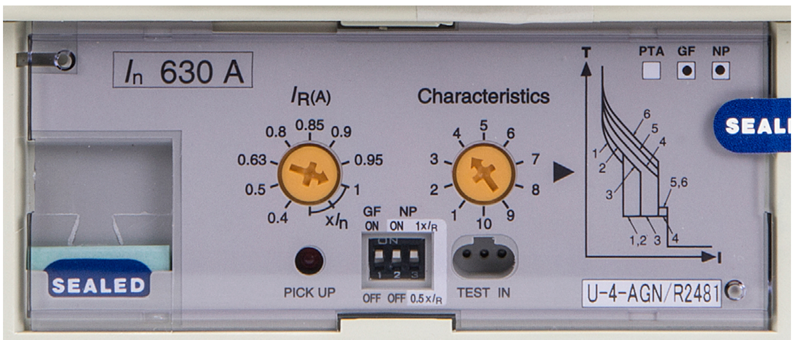
In general four pole MCCBs that provide switched neutral protection, the long time and instantaneous elements in the neutral pole are related to the settings in the phase poles, however in wiring of an installation with balanced three phase loads, it can be appropriate for the neutral conductor to be smaller than the active phases.

In this case the neutral conductor will be under protected, and requires a lower level of protection. The Electronic trip unit with adjustable neutral protection can be utilised with setting for either 50 % or 100 % of I_n.

Figure 4.3.4
Typical pre-defined time current trip curves.

Figure 4.3.5
Typical Electronic trip unit with 2 dial setting.





Preset Characteristic Curves

For ease of setting for some users with standard applications, some Electronic MCCBs offer tripping characteristic selection from a series of preset trip characteristic curves, selectable via one dial, rather than configuring a curve from multiple dials.

These curves are defined in the user manual for the MCCB and are designed to suit different types of general applications.

The Long-time current trip level Ir is set independently at discrete fractions of In to provide appropriate level of overload protection.

Additional curves for special applications are also defined, with very inverse curves similar in shape to a fuse, designed to grade with upstream devices such as local supply authority fuses, where selectivity with the supply authority is required, or for Generators and long cable runs.

An Instantaneous only characteristic, may be available, which has no Ir function thereby allowing the MCCB to function as an ICB (Instantaneous Circuit Breaker) which only responds to short circuits, and are mainly utilised in motor starting or grading applications where downstream devices offer the lower level overload protection.

High Performance OCR MCCB Functions

With the advent of increased processing power in microprocessors, the information which an electronic trip unit MCCB can provide is vast. This allows for the performance and reliability of any electrical system to be improved in critical and continuous production installations.

Measurements in Real - Time of the basic electrical variable measurements utilized are:

- Current for each phase and 4th pole neutral
- Ground fault current
- Phase / phase voltages and phase/neutral for the 4 pole
- Network frequency and phase rotation

With the MCCB reading these in real time, information on the measured values of Power and Energy, Power factor and Harmonic distortion are available.

Within the breakers with electronic trip units, memory is used to retain measured values, with a cause of trip recorded. Last information prior to trip is systematically stored.

Each trip event is saved with the following typical information:

- Trip cause
- Phase pertaining to the fault
- Fault current value of the cause – long time, short time, instantaneous or ground.
- Event times

The OCR may store the cause and current values of up to the last 10 trip events. This information can be accessed via communication devices, but also in the Information menu of the embedded display.

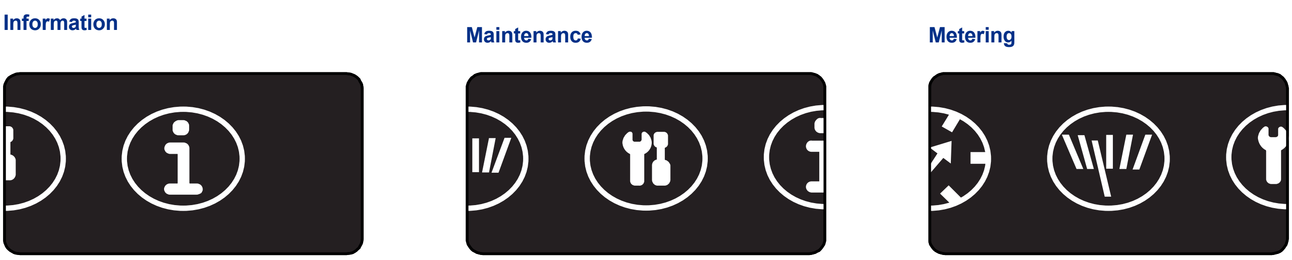
In addition to Trip alarms, warning levels or custom tripping parameters can be defined for process monitoring and controls

Pre-Trip Alarm (PTA)

In operations, the knowledge that a trip may potentially occur allows maintenance or production personal to remedy a potential issue, with a pre-trip alarm warning about the imminent trip risk due to a current being > 90 % of I_r overload level.

Indication of PreTrip from an internal auxiliary circuit signaling an overload pre-alarm output contact, which is connected to external circuitry providing visual or audible indications, or via monitoring of the pre-alarm point via communications.

Figure 4.3.6
Additional functions available with high performance trip units.



Metering and Communication

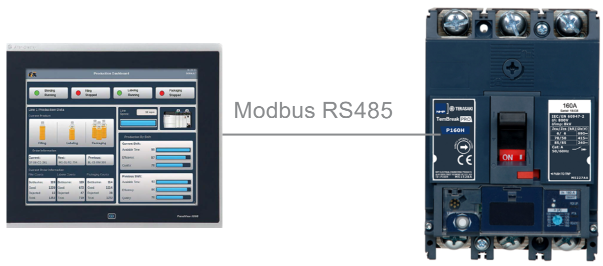
With the MCCBs installed inside switchboards, to make all the information accessible without maintenance personnel opening doors and exposing themselves to potential hazards, the information of basic electrical variable measurements in real-time can be accessed via local screens,

The monitoring and imparting of information via network connection to PLC / SCADA systems, combined with historical incident recording, is very useful in determining possible equipment condition and serviceability after one or more fault events.

The adjustment of circuit breakers can be initiated remotely which allows reduced settings for maintenance mode prior to the switchroom being accessed.

This can prevent serious interruption to process and production, system damage and monetary losses, and in worst cases personnel injury.

For data acquisition, either local viewing or via communications and SCADA, some configuration examples are shown in Figure 4.3.7 to 4.3.9.



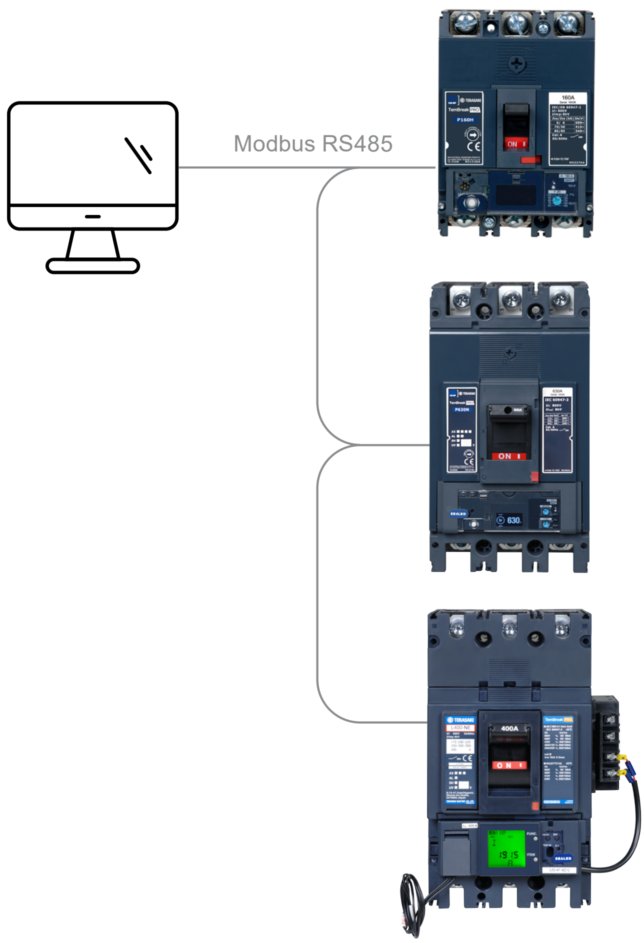


Figure 4.3.7
Top - Individual External display for external doors of Switchboards.

Figure 4.3.8
Middle - Individual PLC screens local or remote from Switchboards for monitoring multiple MCCB.

Figure 4.3.9
Bottom - Individual PLC screens local or remote from Switchboards for monitoring multiple MCCBs.

4.4 Making and Breaking Capacities Definitions

Short-Circuit Breaking (or Making) Capacity

A breaking or making capacity for which the prescribed conditions include a short circuit - The design selection can utilize rating of Ultimate or Service values.

I_{cu} – Ultimate Short-Circuit Breaking Capacity

This is the highest short circuit current the MCCB is capable of breaking without being damaged. The value is always quoted as symmetrical RMS, at specified U_e values.

The specified test sequence of operations is: O – t – CO, which has the circuit breaker interrupting a short circuit two times, after which the circuit-breaker to still functional, but is not required carry its rated current continuously.

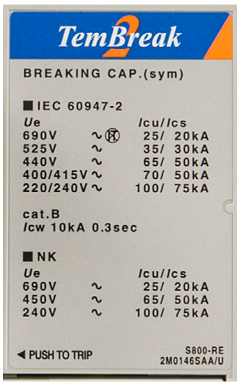
I_{cs} – Service Short-Circuit Breaking Capacity

The rated service short-circuit breaking capacity of a circuit-breaker is the maximum short-circuit current value which the circuit-breaker can break three times.

The specified test sequence for a Service breaking capacity has of operations of: O – t – CO – t – CO, which has the circuit breaker interrupting a short circuit three times, at a defined power factor, after which the circuit-breaker to still functional, and can carry its rated current continuously, with verification of temperature rise.

This provides additional breaking capability for higher risk applications.

Figure 4.4.1
MCCB rating label number 2.



I_{cw} – Short Time Withstand

This is the ability of an MCCB to withstand the thermal and electrodynamic effects of a short circuit, in the closed position for a specified period of time, and is applicable to circuit breakers with of selectivity category B.

This is utilised in ACBs and larger rating MCCBs to withstand a fault and allow selectivity for the downstream circuit breaker to trip.

Circuit breakers with a Selectivity Category A do not have an I_{cw} rating.

I_{cm} – Short-Circuit Making Capacity

The making capacity is the highest short circuit current the MCCB is capable of closing onto without being damaged, or creating a safety issue. The value is always quoted as an asymmetrical peak current, at specified U_e values.

4

4.5 Limitation Curves – Current Peak - Ip (kA)

A circuit-breaker which is of Current limiting type, when subject to a short circuit initiates the opening operation and adds arcing impedance before the prospective short-circuit current has reached its first peak. As the arc is quickly extinguished upon the contacts fully opening, the thermal and dynamic stresses expressed on system components are reduced from those, if exposed to the full prospective short circuit current.

The limited short-circuit current waveform, versus the prospective short-circuit current, is represented by the diagram.

The value to which the peak is reduced, varies with the prospective short circuit current (RMS) available.

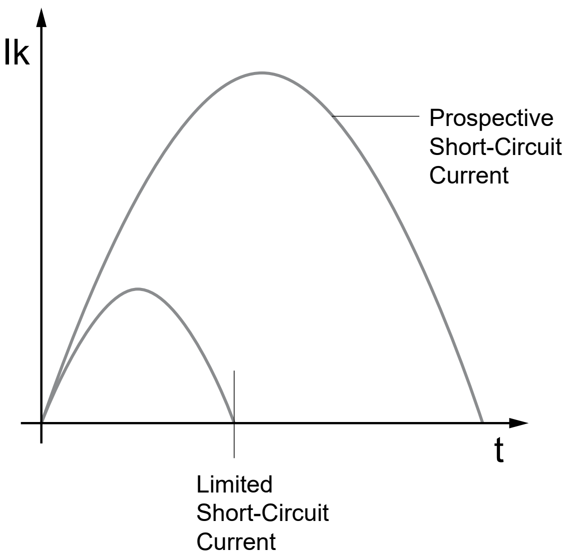


Figure 4.5-1
Current limitation of MCCB.

The following diagram shows the Peak limitation curve for a circuit-breaker.

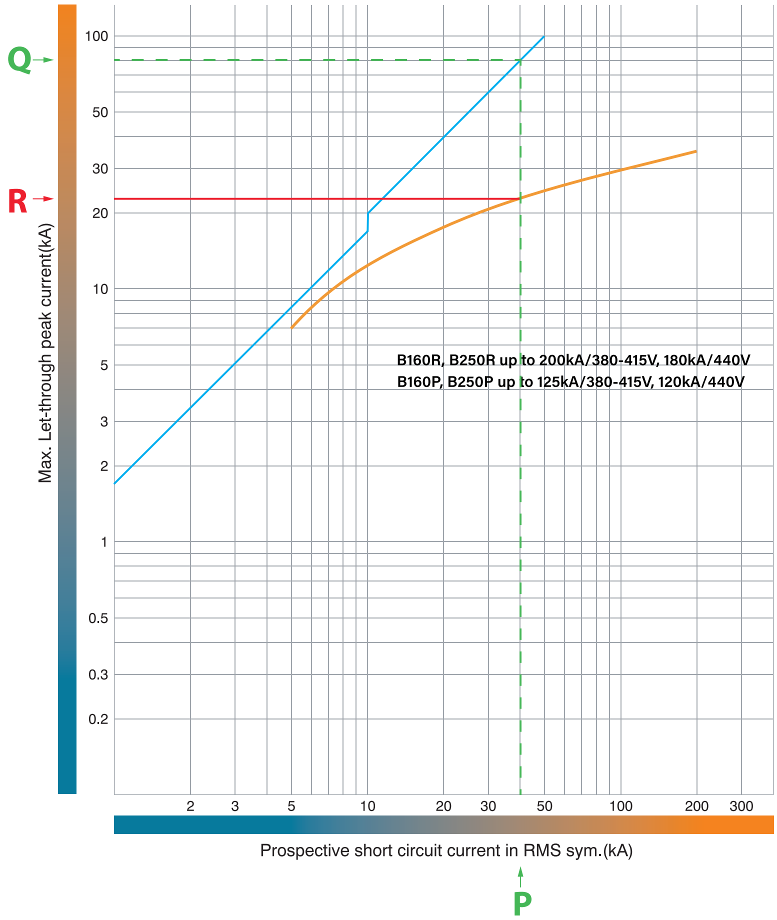


Figure 4.5.2
MCCB IP limitation curve.

The Horizontal axis shows the effective values of the symmetrical prospective short-circuit current, while the Vertical axis shows the relative peak value. The current limiting effect is shown by the limited peak value curve.

For a potential Prospective fault – of RMS value "P", a line is taken up to the point of intersection with the curve, and it is then referred across to the resultant limited Peak value.

To compare against the prospective peak (i.e. as if the breaker had no limitation effect) the line from "P" is continued up to the short-circuit current line, and referred across to the Potential peak value, - point "Q".

Different Circuit Breakers can have different limitation curves, which are based on constructional factors, relating to total opening time, and impedances during opening for specified Ue voltage levels.

For the example shown, we can see that for a 40 kA RMS Prospective fault, it has limited the Fault peak downstream of the MCCB to ~ 20 kA, from the prospective peak of ~ 80 kA.

The current limiting circuit-breakers in reducing the current peak, the electro-dynamic stresses and the consequent mechanical stresses are also are reduced.

This is also utilised to achieve back-up protection between two circuit breakers in series.

4.6 Specific Let-Through Energy Curves I²t

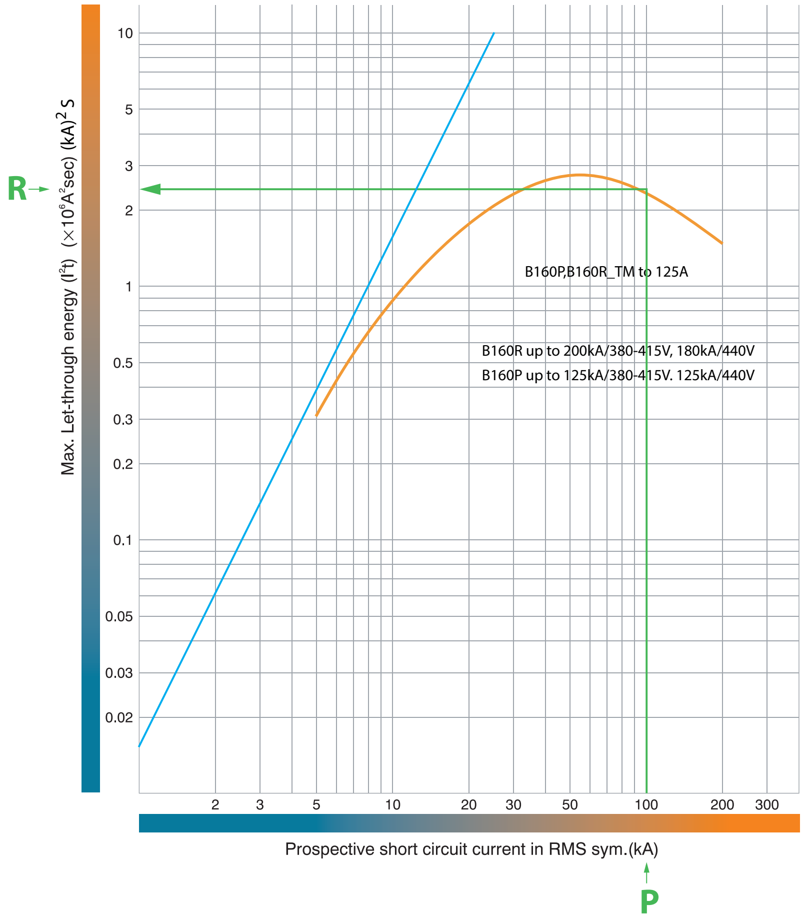


Figure 4.6.1
MCCB I^2t limitation curve.

The specific let through energy, of the fault current limiting circuit breaker during the trip is termed I^2t, measured in Ampere Squared, seconds. This can be denoted as $(kA)^2s$ or $*10^6\ A^2$ sec. The effect of limitation and reduction of trip times influence the value of the specific let-through energy of a circuit breaker.

The specific let-through energy is calculated, by the squaring the effective fault current, and multiplying by the time taken for the circuit breaker to trip.

For specified U_e voltage levels, this information is normally provided from a curve, giving values of I^2t, related to break time as a function of prospective RMS current up to the maximum prospective current, being rated short-circuit breaking capacity of the circuit breaker.

The above diagram shows the energy limitation curve for a circuit-breaker.

The Horizontal axis shows the effective values of the symmetrical prospective short-circuit current, while the Vertical axis shows the specific let-through energy values, in $*10^6\ A^2$ sec.

The limiting effect is *shown* by the limited I^2t value curve.

For a potential Prospective fault – of RMS value "P", a line is taken up to the point of intersection with the curve, and it is then referred across to the resultant limited energy value.

The limitation of I^2t by the circuit breaker, reduces heating of cables, busbars and equipment in the circuit.

Different Circuit breakers can have different limitation curves, which are based on constructional factors, relating to total opening time, and impedances during opening.

For the example shown, we can see that for a 100 kA RMS Prospective fault, it has reduced the Let though energy, downstream of the MCCB to ~ 2.25 $*10^6\ A^2$ sec.

5 Introduction to Cascade (Back-Up) Protection

5 Introduction to Cascade (Back-Up) Protection

5.1 Introduction

Circuit protection is fundamental to electrical safety.

Generally, in power distribution, two types of circuit protection are used.

1. Fuse protection
2. Circuit breaker protection

Both of these types of devices are only in place to protect against damage to electrical conductors. The damage to these conductors may range from over temperature resulting in degradation of the insulation properties of their covering to protection against the effects of high level current flows that can rapidly cause mechanical damage to the conductor itself. There are many other reasons apart from over currents that need to be protected against. So the big question is "What is a "Fault"?

Definition: *Any current flow that is unpredicted, considered dangerous or exceeds the circuit design parameters.*

a. Earth Leakage
b. Earth Fault
c. Over Current (in many forms)
d. Arcing Faults (between phases, phase to earth / neutral)
e. Bolted Short Circuits

a) Earth Leakage

Earth Leakage is generally measured in Milli Amps. The definition of the harmful earth leakage level varies and is generally dependent on the type and size of the circuit according to the standards. For light and power under 32 amps, 10 to 30 milli amps is considered leakage.

For larger feeder circuits into the hundreds of amps, 500 mA to 2 or 3 amps may be considered harmful. In the thousand amp feeder levels, up to around 30 amps may be the break point. For all applications the acceptable level of leakage is circuit and “acceptable risk” associated.

b) Earth Fault

Earth Fault can be considered in a similar way to earth leakage however in a higher value bracket. Earth faults are measured in ranges generally as a percentage of the circuit’s nominal current carrying capacity. For example a circuit nominal current of 1000 amperes may have a level of 20% earth fault level value to interrupt.

The use of earth fault detection ensures a faster detection time for potential damage mitigation to the installation.

The detection of earth faults by pass the normal protection features of the circuit breaker to ensure identification and interruption before the current flow gets to a critical level undetected by the normal protection features of the breaker.

The level of earth fault would normally not be high enough to cause direct damage to conductors however may cause severe damage to the installation and compound to a full blown arcing fault if left undetected.

c) Over Current / Overload

Over Current / Overload is the most common fault requiring protection. There are many causes of this phenomenon, a few of which are not well understood by the general electrical trades. Overload is caused by constant and regular current draw of the circuit, above the continuous current rating of the conductor that would cause a temperature rise in the conductor that may degrade or destroy the insulation or chemical composition of the conductor’s physical elements. This often occurs to sub mains where additional distributed loads are included without regard to existing upstream infrastructure. It may also occur when connected devices are upgraded or in cases where electric motors are subjected to loads beyond their design capacity. This level of fault occurs over a relatively long period of time.

d) Arcing Faults

Arcing Faults vary in orientation and magnitude greatly. They can range from low current “tracking” events to full blown high power arcs drawing many thousands of amperes. The current flow expels “pollutants” into the surrounds and can cause massive destruction to life and equipment if not detected and the current flow interrupted quickly. Some may self extinguish however the behaviour is very unpredictable and depends upon many factors including conductive clearances and available “fuels”. They may ionise between active conductors between phases or between active and earth / neutral potentials. They may start at a relatively low level of current flow however the increase in the flow is determined by the intensity of ionization. Lower levels of ionization have higher levels of impedance and vice versa. Their behaviour is a product of this fact and directional magnetic flux of the arc. Coronial induction may determine the extent of the ionization.

e) Bolted Short Circuits

Bolted Short Circuits are the rarest of the types of fault described in this subject. They are generally caused by incorrect movable cross connection of conductors. This fault is the most demanding on protection devices and they must be able to withstand peak forces to the maximum possible fault flow at the point. This is called “Prospective Short Circuit Current”. This current flow is only generally limited by the circuit impedance until the device begins to interrupt.

Prospective Short Circuit Current

Prospective Short Circuit Current is the maximum available level of short circuit current available to flow from the source to the short circuit limited by the circuit impedance. The maximum level is attainable at the output terminals of the supply source (transformer, generator, solar invertor etc). As we move further down the reticulation system, the fault current reduces due to the embedded impedance of the conductors. The greater the distance, the smaller the conductor, the greater the impedance and therefore the lower the prospective fault current. The material composition of the conductor also has a bearing on the result (aluminium v copper). Protection devices must always have a capacity to withstand / break the full prospective current available at their point of installation.

Before choosing ***any*** device, it is wise to determine what the fault current is at that juncture and choose accordingly.

Determination of Prospective Fault Current

Determination of Prospective Fault Current is paramount to safe electrical engineering practice and conformance to requirements of the AS/NZS wiring rules.

The starting point is at the source. Seen here are "ready reckoners" as a starting point from supply transformers and generators. You will notice that the figures are much lower with generator supplies. The generator cannot produce or sustain short circuit currents to the level of transformer fed systems. The generator has a limiting "sub transient reactance" to overcome under these conditions and goes through a number of characteristic changes when under transient conditions.

Transformer kVA	Full Current (A)	4 % Impedance	4.5 % Impedance	5 % Impedance	6 % Impedance	6.5 % Impedance	7 % Impedance
200	278	7	6.2	5.6	4.6	4.3	4
300	417	10	9.3	8.3	7	6.4	6
400	556	14	12	11	9.3	8.6	7.9
500	696	17	15	14	12	11	9.9
750	1043	26	23	21	17	16	15
1000	1391	35	31	28	23	21	20
1500	2087	52	46	42	35	32	30
2000	2782	70	62	56	46	43	40

Generator kVA	Generator kW 0.8 P.F	Generator FLC	Short Circuit Amps in kA				
			% Sub Transient Reactance				
			12 %	15 %	20 %	22.5 %	25 %
50	40	69.5	0.58	0.46	0.35	0.31	0.28
100	80	139	1.16	0.93	0.7	0.6	0.56
250	200	348	2.9	2.3	1.75	1.55	1.4
500	400	696	5.8	4.6	3.5	3.1	2.8
750	600	1043	8.7	6.9	5.2	4.6	4.2
1000	800	1391	11.6	9.3	7	6.2	5.6
1250	1000	1739	14.5	11.6	8.7	7.7	7
1500	1200	2087	17.4	13.9	10.5	9.3	8.4
2000	1600	2783	23.2	18.6	13.9	12.4	11.2

Example Tabular Estimator Excerpt

With a starting IPros at the head end of 30 kA, a conductor 95 mm of 49 metres in length will have an IPros at the end of 12 kA approximately. This example can be worked for the next step using approximate calculations for the remainder of the circuits downstream.

With careful documentation of the power single line, a fairly accurate representation of the system fault currents may be determined and educated choices may be made as to the suitability of devices for the application.

Line Protection - Copper Conductor

mm2	Length of the Line in Metres													
35	-	-	-	-	-	-	1.5	1.8	2.2	3	3.7	7.2	14	18
50	-	-	-	-	-	1	2.2	2.6	3.1	4.2	5.3	10	21	26
70	-	-	-	-	-	1.4	3	3.6	4.4	5.9	7.4	14	29	36
95	-	-	0.8	0.9	1	2	4.1	4.9	6	8	10	20	39	49

Isc kA	Short-Circuit Current At the End of the Cable													
50	49	48	48	48	47	45	41	40	38	35	33	25	17	14
30	29	29	29	29	29	28	27	26	25	24	23	19	14	**12**
20	20	20	20	20	20	19	18	18	18	17	17	14	11	10

Fault Levels (Possible Outcomes)

Different possible outcomes from different scenarios are listed below depending upon a number of factors.

Three phase bolted fault	= 100 % IPros max
Two phase bolted fault	= 87 % IPros max
Single phase bolted fault	= 50 % IPros max
Three phase arc fault	= 87 % IPros max
Two phase arc fault	= 65 % IPros max
Single phase arc fault	= 50 % IPros max

These figures should be kept in mind when determining the “probability of exposure” to particular levels of fault current and frequency of occurrence.

The importance and correct usage of these estimations will become apparent as we go through the practical examples at the end of this publication.

5.2 Introduction to Selectivity and Cascade

With the increased reliance on electrical supply in both commerce and industry it has been widely recognised that a guaranteed reliability factor must be considered at the design stage of any electrical system.

This is evident if we consider the following points:

- Dramatic increases in requirements Emergency Generators and as such also for Automatic Transfer Switches (ATS) to minimise any downtime as a result of main supply loss
- Co and Tri Generation with varying power output levels and contributing capacities
- Increased attention being paid to Type-1 and Type-2 co-ordination between circuit breakers and contactors for motor starting applications
- Increased specification of Arc Detection and Protection devices, to limit any potential damage to the main switchboard as a result of an arc fault and conform with AS/NZS 3000
- Increased awareness of selectivity between protective devices especially in respect to Safety Service Circuits

Selectivity plays a significant role in the circuit breaker market within Australia, more so than in other major markets such as Europe, USA or Japan.

In many industrial applications any amount of downtime can result in the loss of hundreds of thousands, if not millions of dollars per day. Also, within areas of industry such as health and services it is critical that a continuous supply is guaranteed.

The concepts of selectivity and cascade are commonly confused. They are not opposites; in fact with cascading an element of selectivity is still achieved.

Cascading

Cascading can be utilised when the potential fault that a downstream device has to interrupt is larger than its breaking capacity. It involves the co-ordination of two devices in series being used to interrupt the fault as opposed to the downstream device alone.

The technique of cascading is used in applications where the protective devices are feeding non-essential loads. The reason being, that in order for an upstream device to cascade with or 'back-up' a downstream device it may have to trip.

The technique is a recognised method for fault interruption, being stated in standards such as AS60947-2 (IEC 60947-2) for circuit breakers and AS61439 for switchboard assemblies.

Consider the following example:

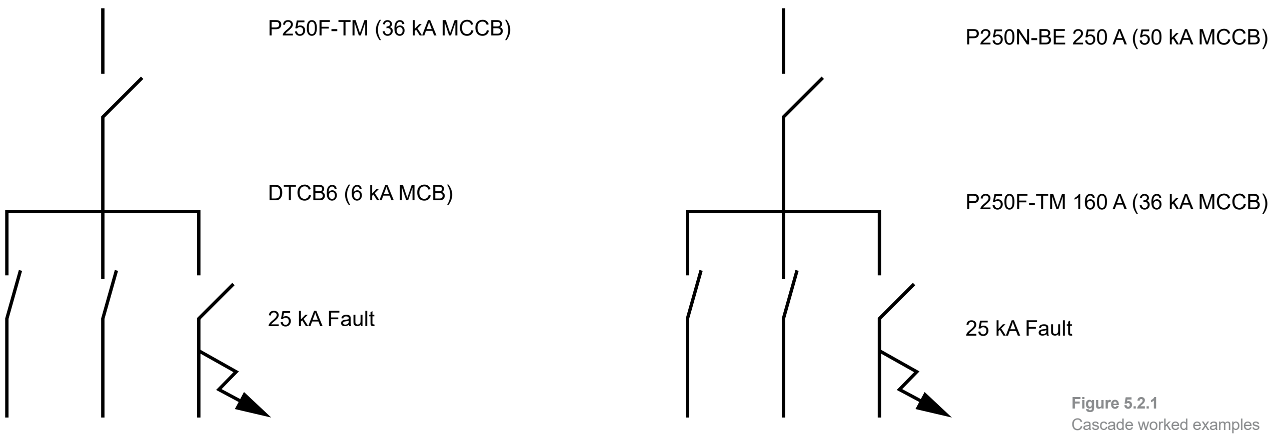


Figure 5.2.1
Cascade worked examples

Under normal operating conditions the Din-T6 MCB can interrupt a fault current of 6 kA, without any damage to the device. This is the limit of fault current that the device can be guaranteed to break twice and still be fully operational. If a fault level should be slightly above this level only once then the device will most probably clear the fault safely, however no guarantee can be made that it will be operational afterwards (if this should occur then the device should be replaced).

If this Din-T6 MCB is connected in series with an MCCB, type P250F-TM then it will be able to clear a potential fault of 36 kA. This is because the MCCB effectively backs-up or helps the MCB to clear the fault.

With situations such as this the P250F-TM MCCB may or may not actually trip. In several circumstances the upstream MCCB will certainly assist the downstream device to clear the fault, however with fast operation of the MCB the resultant fault level may not be enough to trip or open the upstream breaker. This concept is known as "Enhanced Selectivity" and will be discussed later in this paper.

As can be seen, when cascade is achieved it does not necessarily mean that there will be no selectivity. Even with devices such as MCCBs, where the constructions are similar for each frame size and are comparable in terms of their tripping times as well as energy let through and peak let through figures, a certain amount of selectivity is still achieved.

There is no rule of thumb to determine the fault current that two devices in series can interrupt, and is why manufacturers normally provide easy to use, quick reference cascade tables. This eliminates the need for any engineer to try and approximate the fault level he or she thinks that two devices in series will be able to clear safely.

The one basic requirement of cascading is that the breaking capacity of the upstream device be at least equal to the prospective fault current. This element of safety ensures that should the downstream device happen to fail then the upstream device can cope with the fault on its own.

It is always recommended to use a protective device that has a breaking capacity greater than or equal to the maximum prospective fault current at the point of installation.

It is always recommended to use a protective device that has a breaking capacity greater than or equal to the maximum prospective fault current at the point of installation. However, the use of Cascade (back-up) offers another option that can be used in particular projects.

The most obvious benefit is the potential cost savings that can be made in specifying a protective device with a breaking capacity lower than the maximum prospective fault current in the system, however there is one additional benefit that can be gained. Under certain conditions it may be possible to specify an MCB rather than an MCCB. This clearly has a cost advantage, but there can also be a significant saving in unit volume.

Let us take an example of a cascade application using NHP-Terasaki circuit breakers:

Under normal circumstances we would select a 63 A rated circuit breaker with a breaking capacity greater than or equal to the prospective fault current of 20 kA.

The most obvious choice would be an P160F-TM with a 63 A thermal trip as it has a breaking capacity of 36 kA. Using Cascade we can instead use a DTCB6 MCB rated at 63 A, which has a breaking capacity of 6 kA.

By using the upstream P160F-BE MCCB the two devices acting together are capable of interrupting a fault current greater than the maximum prospective fault current downstream of the MCB.

By referring to the Selectivity / Cascade charts at the end of this paper we can see the following:

		Upstream MCCB
Downstream MCB	kA (rms)	P160F-BE
		36 kA
DTCB6 2-20 A	6	36 / 36
25 / 63 A		36 / 36

The combination of an P160F-BE (upstream) MCCB and a DTCB6-63 A (downstream) MCB is capable of interrupting a fault current of 36 kA which is greater than the maximum prospective fault current of 20 kA.

Clearly there is a difference in costs between a 63 A MCB and a 63 A MCCB. The additional benefit is the saving in space or volume.

If several MCBs are to be used then there can be a significant amount of space saving to utilise the benefit of cascade protection. In the above example we can also see that should the P160F-BE be opened or tripped then supply to all downstream breakers is lost. Hence, it is recommended to use Cascade protection in applications involving feeds to non-essential loads.

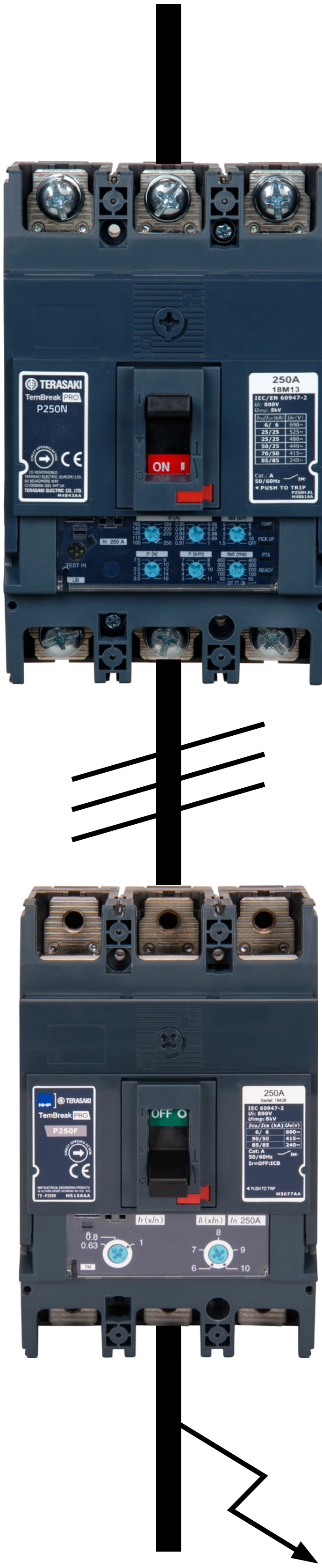


Figure 5.2.2
Physical example of Figure 5.2.1.

5.3 Concept of Selectivity

Selectivity, also known as 'discrimination' is associated with continuity of supply

Consider the following diagram:

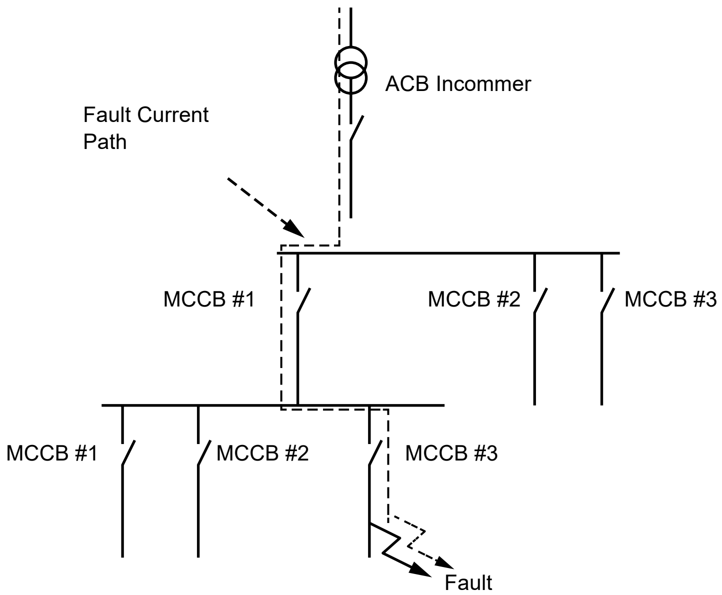


Figure 5.3.1
Fault current through multiple beakers.

As can be seen from the above, should a fault occur downstream of MCB#3 then the fault current will pass through the ACB Incomer and MCCB#1, as well as MCB#3. In other words, the fault current follows the shortest path with the least amount of resistance (impedance).

Each protective device in the path to the short circuit will detect the fault current, the concept of selectivity is to ensure the device immediately upstream of the fault, in this case MCB#3, interrupts the fault. This maintains a continuous supply to parts of the system that are fault free, for example loads downstream of MCCB#1, MCCB#2, MCCB#3, MCB#1 and MCB#2.

If the incoming device ('ACB Incomer' from above) trips and clears the fault then supply to every part of the system will be lost.

As the ACB is generally the device closest to the source, in this case a transformer it will normally be exposed to the highest prospective fault current, and must be capable of interrupting (breaking) large currents.

Secondly, as an ACB can hold on to large currents for a significant duration (up to 3 seconds) it has the capability to let devices further downstream clear the fault before it will react. For this reason, the most commonly used incoming device is an Air Circuit Breaker (ACB) in larger installations.

From a construction viewpoint an Air Circuit Breaker (ACB) is a strong device capable of holding on to (withstanding) and interrupting (breaking) very large fault currents.

Moulded Case Circuit Breakers (MCCB) and Miniature Circuit Breakers (MCB) have a different purpose, and this is to clear a fault as quickly as possible and eliminate any potential damage to equipment and/or danger to personnel. As both MCCBs and MCBs operate in a similar way (i.e. to limit the peak fault current and let through energy) careful attention needs to be paid in terms of selectivity when co-ordinating any combination of these devices.

Types of Selectivity

Full / Total

Full or Total Selectivity is where the device closest to the fault will always interrupt (break) the fault before the upstream device up to the prospective fault current at the point of the downstream device.

Partial

Partial Selectivity differs only in that selectivity is guaranteed up to a defined level of fault current (known as the selectivity level, or Is) after which one or both devices may trip.

In numeric terms, if the prospective fault current is 25 kA then full selectivity will mean that the downstream device will clear the fault and trip before the upstream device up to 25 kA.

Once again, in numeric terms if we have a prospective fault cu-rrent of 25 kA then we may only have a guaranteed selectivity level of 20 kA. This means that for faults up to 20 kA only the downstream device will trip. For faults between 20 kA and 25 kA the downstream device may trip on its own as above, however there is a possibility that both may trip.

Another important consideration at the design stage of an electrical distribution system is to determine whether full or partial selectivity is actually required. A regular occurrence on project specifications is a requirement for 'Total Selectivity up to X kA'. After a quick analysis of the system it is clear that X kA is not achievable, possibly as a result of the capacity of the source device, the transformer impedance or the impedance in the circuit wiring.

If this case is true then there is no major advantage in specifying a high level of selectivity if that level of fault current cannot be achieved. In other words, it is not necessary to specify devices that will give selectivity up to X kA when a more suitable and cost-effective solution is available.

Consideration should also be paid to the probability of faults. The figures stated in selectivity and cascade tables are circuit breaker combinations under full 3-phase bolted short circuits. Full 3-phase short circuits are highly unlikely to occur in practice.

More common types of fault are phase-to-earth or phase-to-phase faults, where the fault level is greatly reduced. In test conditions a 3-phase bolted short circuit is considered to be the 'worst case', resulting in the largest prospective fault current.

5

Selectivity Analysis

There are three main methods of selectivity analysis, these are:

- Time - Current Selectivity
- Current Selectivity
- Energy Selectivity

A brief explanation will be made of each type, and where they are used.

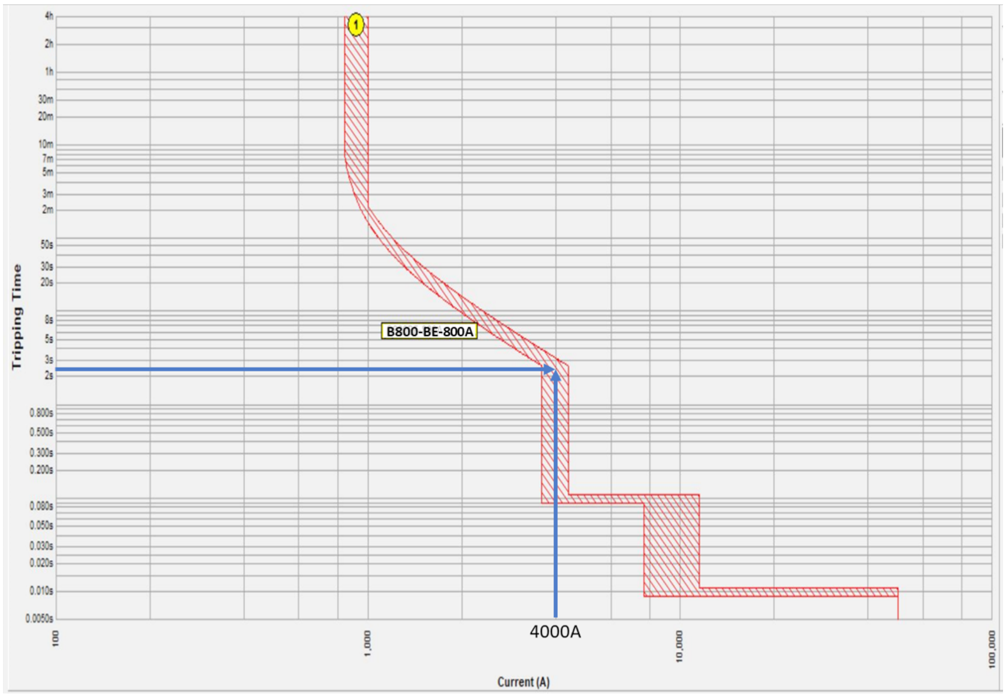


Figure 5.3.2
Typical time - current curve

Time-Current Selectivity

Time-current selectivity analysis involves the study of the (tripping) characteristic curves for all protective devices in an electrical system, and the aim is to ensure that the downstream device trips (opens) before the upstream device for each value of fault current that may occur.

Each protective device be it a circuit breaker, fuse or protection relay has a unique characteristic curve associated with it. The curve is set on a time-current scale where the tripping/opening time can be determined for increasing values of fault current.

For example, using the characteristic curve we can determine that an B800BE (800 A rated Electronic MCCB) will trip in 2.5 seconds should a fault current of 4000 A flow through the breaker (see figure 5.3.2 above).

There are three main areas to the characteristic curve for an electronic type circuit breaker

Long Time Delay (LTD)	area of the characteristic curve that is best suited for overload protection
Short Time Delay (STD)	Is effectively an intermediate setting between a standard overload (LTD) protection and the standard short circuit (INST) protection. It is the STD area of protection that distinguishes a device with thermal-magnetic type of protection from electronic. The STD allows devices to be co-ordinated by using the adjustable time and current settings to ensure that the tripping characteristics of two devices never overlap.
Instantaneous (INST)	area of the characteristic curve that is best suited to short-circuit protection.

Consider the following generic characteristic curve for an Electronic type Terasaki MCCB.

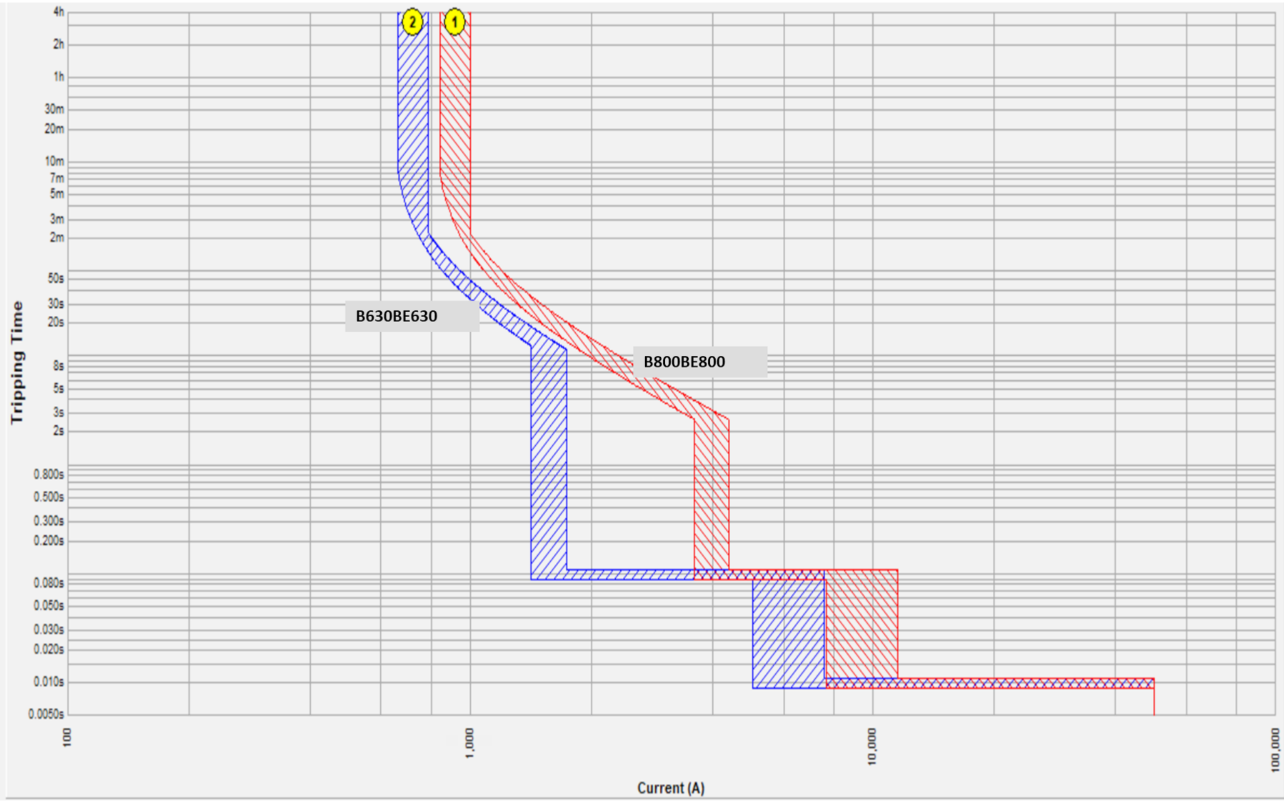


Figure 5.3.3
Typical time - current curve comparison.

Time-Current selectivity analysis is the most commonly used within the electrical industry, mainly because it is a graphical form of analysis and opposed to a calculated form. It is relatively easy to see that if the characteristic tripping curves of two devices do or do not overlap. However this concept is fully justified only over a specific range of the curves.

By doing a time-current selectivity analysis it may appear as though there is total selectivity as the curves do not overlap. However if the protective devices are exposed to very high current values it is always recommended to refer to manufacturers' tables to gauge actual selectivity levels under short circuits for those combinations of breakers.

Time-Current Selectivity analysis is normally the first check that selectivity between two protective devices is achievable, but is only effective in the overload to low level short circuit regions. By ensuring the device characteristic curves do not overlap we can guarantee selectivity will be achieved in the overload area.

In the short circuit region we have to carry out a more in-depth study, and the use of device characteristic curves has only limited use.

Under short circuit conditions it is possible to predict how each protective device will operate as a stand-alone unit, from contact repulsion to the point of final arc extinction. However, further analysis must be carried out to determine how the protective devices act when two or more devices are connected in series.

The additional analyses are known as Current Selectivity and Energy Selectivity analysis, and are explained in the following pages.

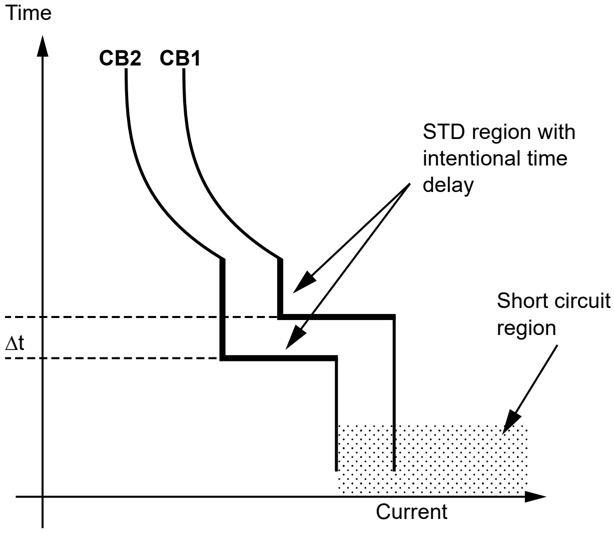


Figure 5.3.4
Two breakers in series.

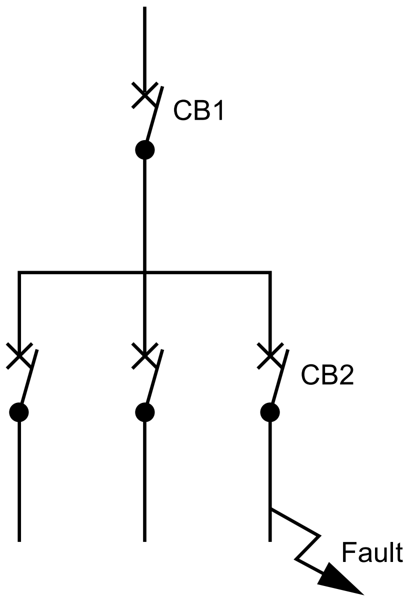
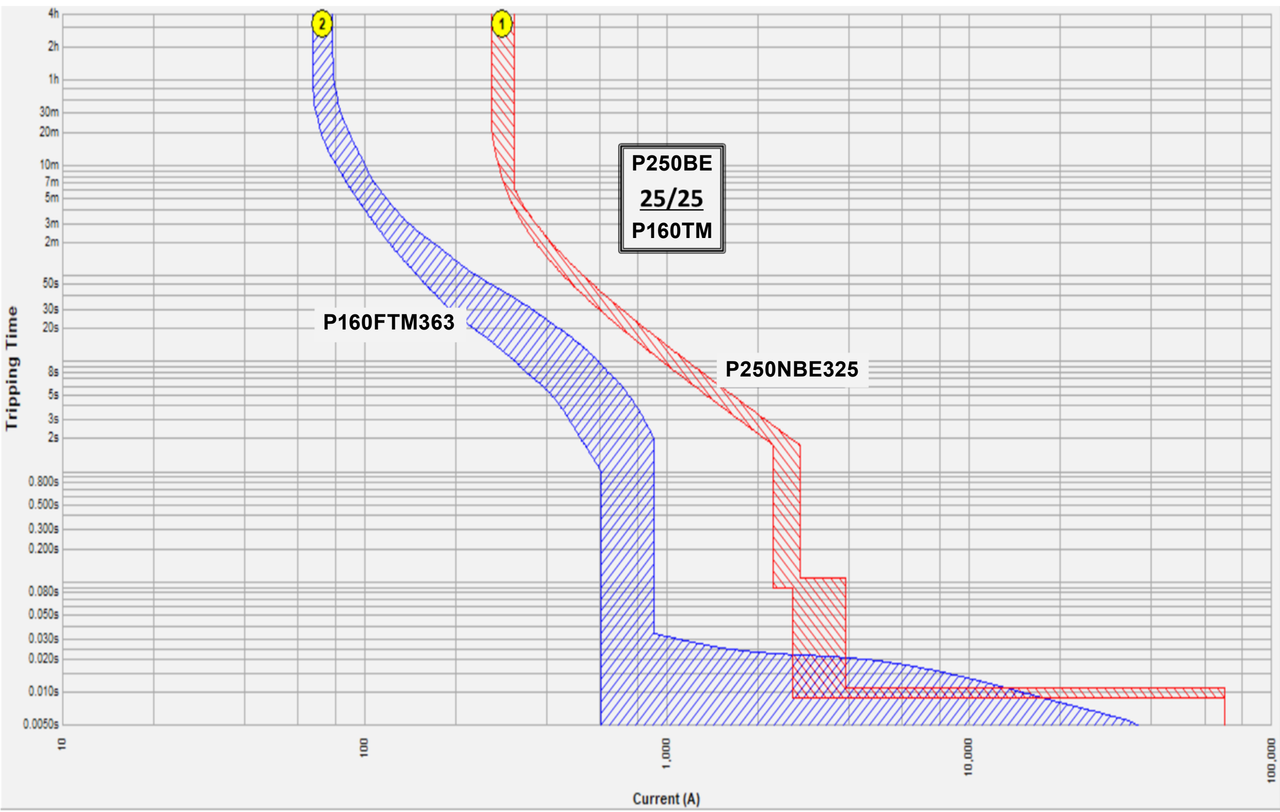


Figure 5.3.5
Two breakers in series.

AS/NZS3000:2018 requires certain levels of selectivity to guarantee reliability of supply under certain conditions. The reliability level depends on the recipient circuits and their purpose. For instance Safety Service Circuits such as those supplying lifts and fire detection / suppression equipment require an added level of security of the supply, so that they may remain operative under fault conditions in other parts of the system. In these instances selectivity shall be provided up to a level between 30% and 60% of prospective fault current. This means that if the prospective fault current at the installation point of the downstream breaker is 20 kA, selectivity shall be guaranteed in the overload and instantaneous regions of the time current curves as well as between 6 kA and 12 kA in the short circuit region. The example shown in Fig 5.3.6 illustrates selectivity between the selected devices up to 25 kA as well as in the time / current zone and the instantaneous regions.

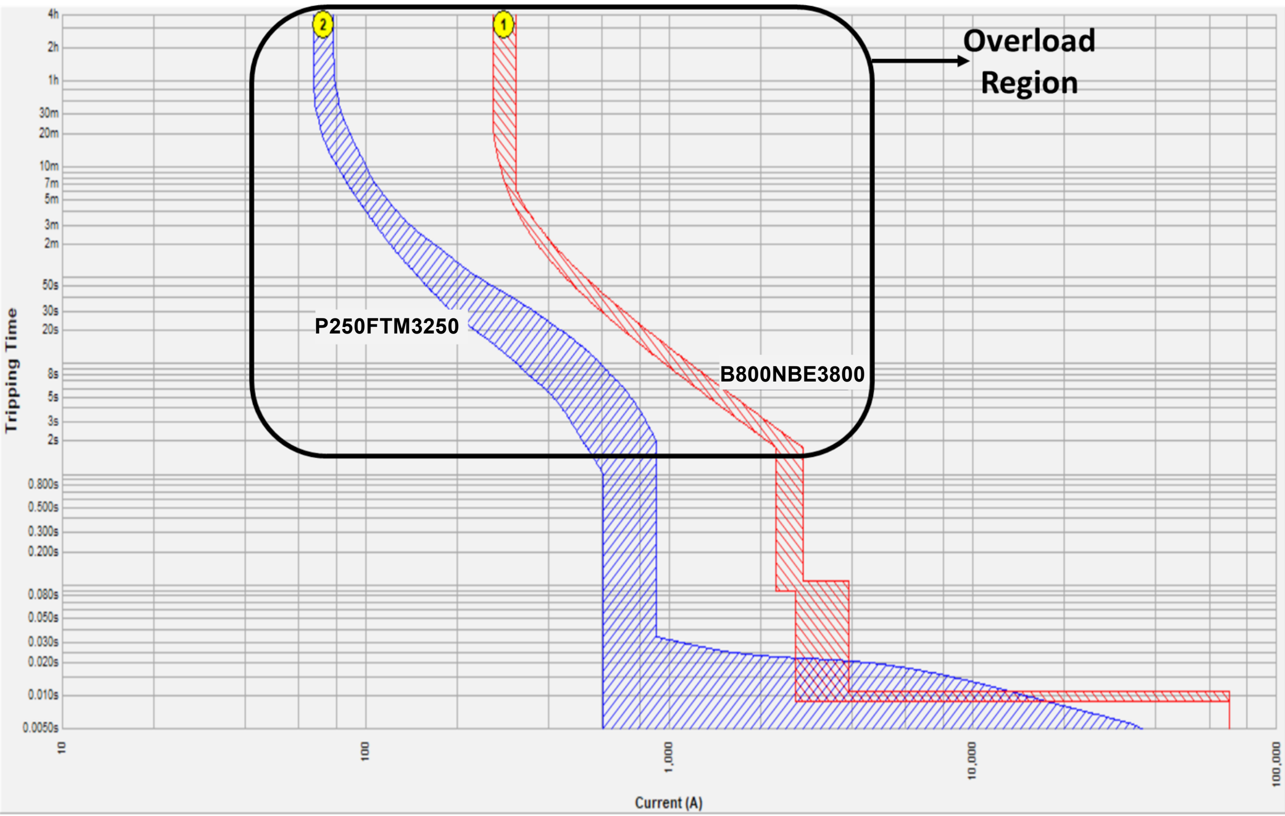
Figure 5.3.6
Typical Electronic V Thermal Magnetic curves.



For general circuits when 2 circuit breakers are connected in series, for applications where the downstream device current rating is less than 250 amps, selectivity is deemed to be achieved if the upstream breaker's rating is 1.5 x or greater than the downstream breaker's rating. For example, 63 A upstream, 40 A downstream.

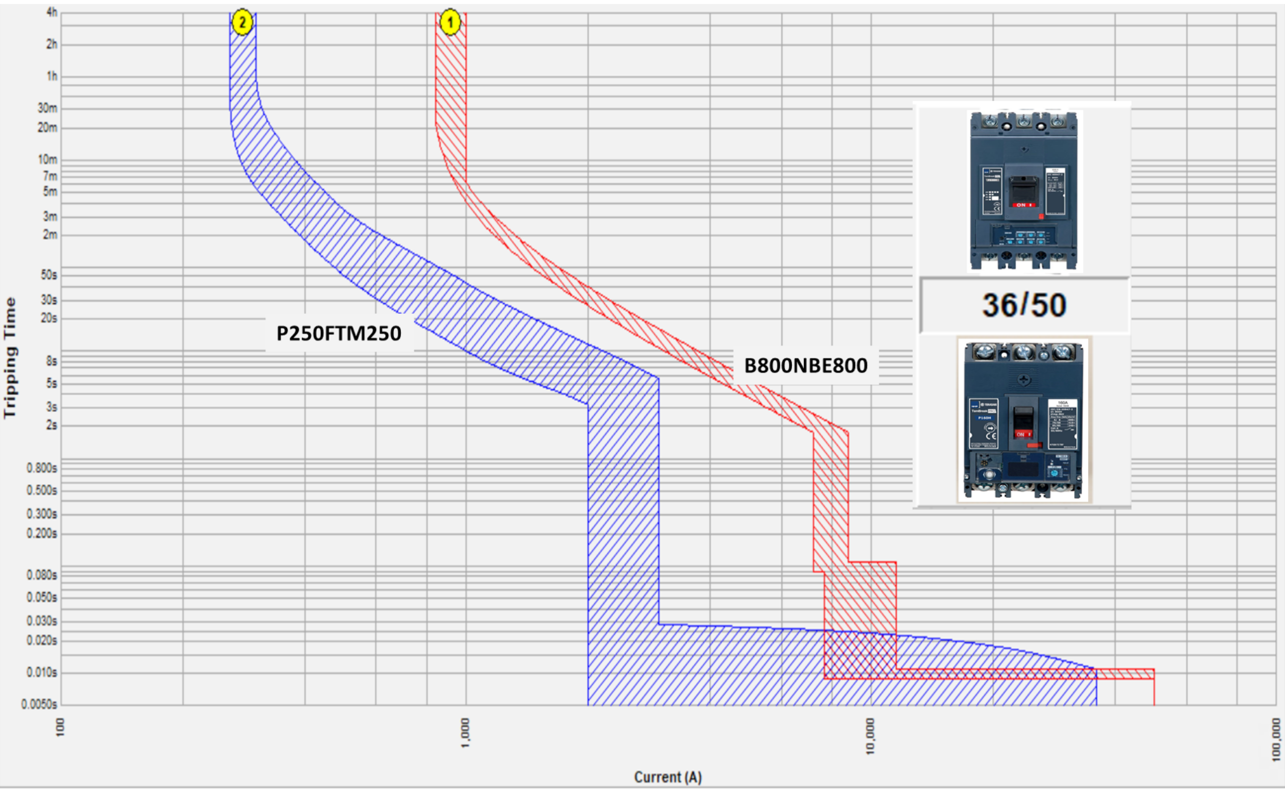
For general circuits where the upstream device is greater than 250 A but less than 800 A selectivity should be provided by comparison of the overload curves. (see figure 5.3.6)

Figure 5.3.7
Overload region shown.



For general circuits where the upstream device is 800 A or greater, selectivity shall be provided by a co-ordination study using manufacturer's data. An example of manufacturer's data according to tested combinations of breakers is shown in the inset of Fig 5.3.8. Further examples can be seen in tabular form published by the manufacturer.

Figure 5.3.8
MCCB / MCCB selectivity cascade example.



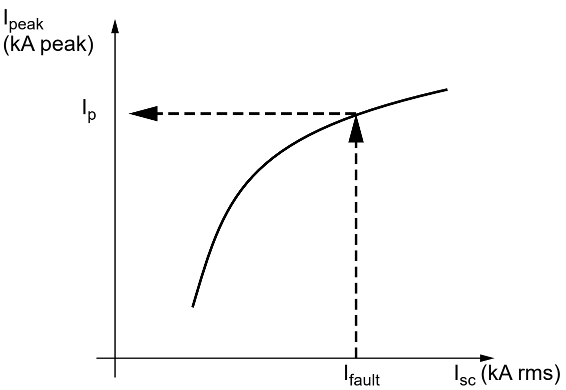
Current Selectivity

To determine the current selectivity level between two breakers under short circuits we firstly have to examine the peak let through current of the downstream device. Most circuit breaker manufacturers have a series of "peak let through curves" that can be used to determine the peak level of current that a device will let through under fault conditions. Most modern day circuit breakers are highly current limiting, and as such will limit the peak current to a high degree under short circuit conditions.

Figure 5.3.9
Top - Peak Let Through current of downstream breaker at XX kA.

Figure 5.3.10
Middle - Peak let through current comparison downstream to tripping curve upstream (No Trip).

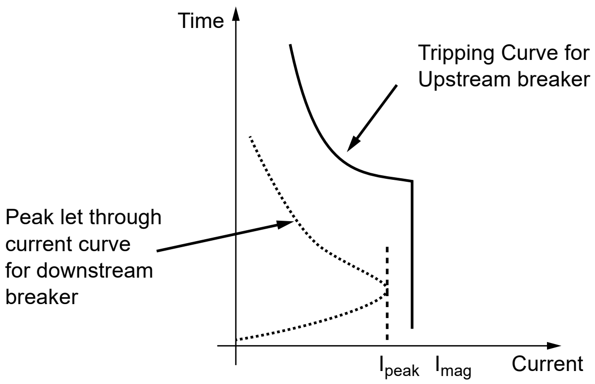
Figure 5.3.11
Bottom - Peak let through current comparison downstream to tripping curve upstream (Trip).



The diagram on the left shows a generic peak let-through current graph. On the two axes we have the short circuit current (I_{sc}) and the peak let through current (I_{peak}).

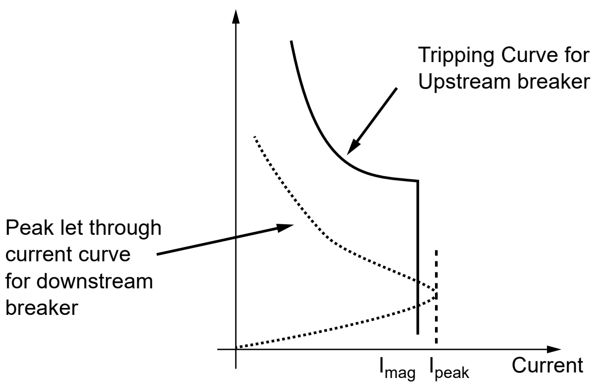
For any short circuit fault current (I_{fault}) we can determine the absolute peak current (I_p) that particular breaker will let through before fully tripping and clearing the fault.

Now that we can determine the peak let through current for the downstream circuit breaker we can use this information to determine what effect it will have on the upstream device.



The concept is similar in theory to the analysis on motor in-rush effects on circuit breakers. If the in-rush current is greater than the instantaneous or magnetic setting of the circuit breaker then it is possible that the breaker may class the in-rush current as a short circuit and trip. Consider the following diagram.

As we can see in this diagram, the peak let through current (I_{peak}) of the downstream device is less than the magnetic / instantaneous setting (I_{mag}) of the upstream device. Therefore, the upstream device will not open as the let-through current of the downstream device is not sufficiently high so as to trip it.



However, if we have the following scenario then there may be problems. In this instance, the current flowing through the downstream device continually rises such that its peak level (I_{peak}) is greater than the magnetic/instantaneous setting (I_{mag}) of the upstream device. The upstream device will detect the high current and class it as a short circuit, and is therefore likely to trip. In this scenario current selectivity is not guaranteed.

Current Selectivity is normally the second check made to determine if selectivity between two protective devices is achievable, and is generally taken into consideration in Selectivity tables.

Energy Selectivity and Enhanced Selectivity

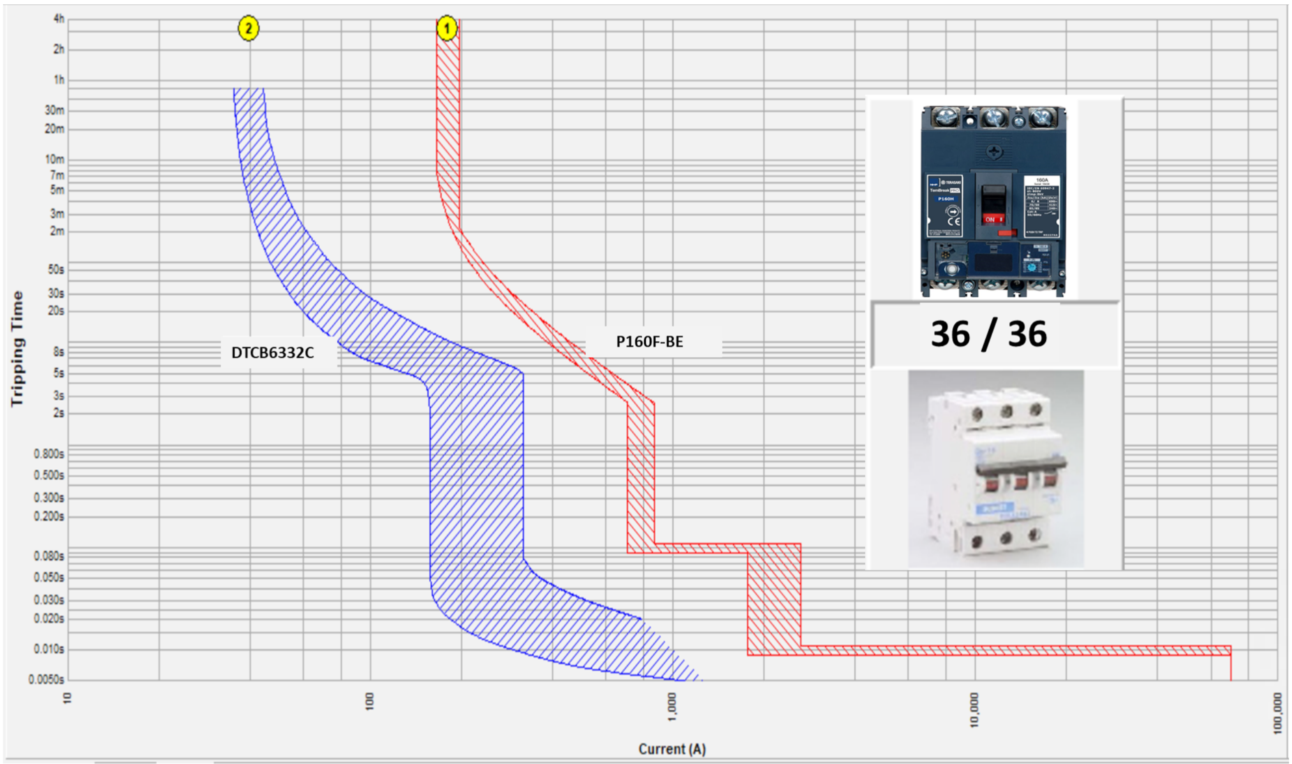


Figure 5.3.12
Enhanced Selectivity example
MCCB to MCB.

We saw previously that cascade uses an upstream device to assist the downstream device in clearing a fault current greater than the level that the downstream device can handle safely as a stand alone unit. In this case both devices will trip. Energy selectivity uses this factor to try and determine to what level the upstream device can back-up the downstream device without tripping.

Analysis of energy selectivity is an extremely fine science, and not something that can be calculated very easily. It involves complicated calculations using breaker peak let through and, more importantly energy let through data.

In general, the upstream device will be an MCCB that under relatively high fault currents will go through a stage of contact repulsion. If an arc forms at the contacts of the MCCB it creates a large (arc) impedance in the network and dissipates a high level of energy. The value of this impedance is complex to calculate, but in basic terms it is significant enough to limit the resultant current in the system to a level more manageable by the downstream device.

Commonly, a number of tests are done by circuit breaker manufacturers for the most critical combinations of breakers, and then extrapolated across the whole range.

Consider the example shown in Figure 5.3.12.

The DTCB6 / 32 A MCB is rated at 6 kA. That means that if we state Total (T) Selectivity then the DTCB6-32 A MCB will interrupt a fault before the MCCB only up to 6 kA.

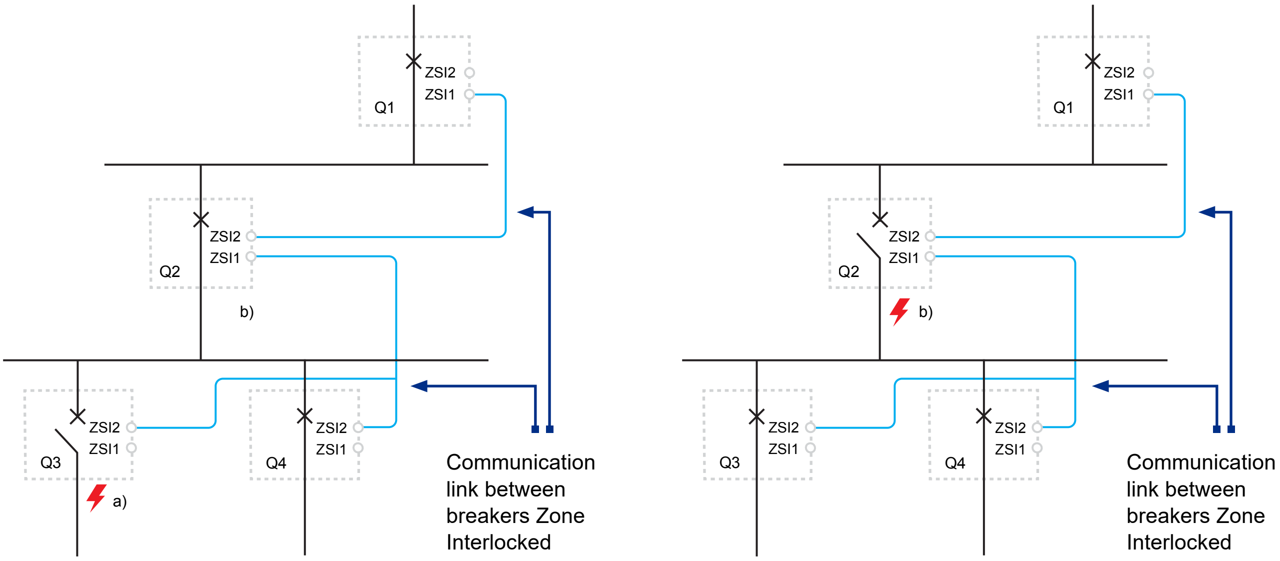
However, in cascade discussions we have seen that MCCBs can back-up MCBs to help them clear faults larger than their breaking capacities. In Enhanced Selectivity, not only does the MCCB back-up the MCB but the MCB also clears the resultant fault current before the MCCB can fully unlatch. Therefore, for faults up to 36 kA the MCB will trip before the MCCB.

In essence the MCCB is backing up the MCB to clear faults larger than its breaking capacity (6 kA), and the MCB is assisting the MCCB by is using its fast operation to clear the resultant fault before the MCCB can operate. This is the basic concept of enhanced selectivity.

Consider the amount of energy and force that would be required to push a large car or four wheel drive vehicle say 100 metres. Then consider the force and energy required to push a motorcycle the same distance. Also consider the acceleration and top end speed achieved by each vehicle. Similarly when considering the likelihood of achieving selectivity between two devices, speed of operation and volume of the devices is a fair indication of the probability of a high selectivity level being reached in a “rule of thumb” determination.

5.4 Zone Selective Interlocking

Zone interlocking is a communication scheme used with MCCBs and ACBs to improve the level of protection in a low voltage power distribution system.



In multi layered protection systems circuit breaker settings may be very similar based on expected maximum demands and load behaviours during cycling and peak demand periods. In these applications Zone Selective Interlocking may be employed to ensure that during a fault event, only the device immediately upstream of the fault is allowed to operate to isolate the line fault.

A communication 'signaling cable' is connected between the downstream and upstream devices, allowing the circuit breakers to 'indicate' at high speed to each other the location of a detectable short circuit, with the closest circuit breaker to the fault initiating a 'no intentional delay' trip.

Effectively the circuit breaker 'closest' to the fault temporarily overrides its normal short circuit 'time delay' setting and initiates a 'no delay' trip. The result is that the circuit breaker will clear the short circuit sooner, reducing the exposure of the switchboard to the 'normal' higher level thermal and magnetic stress.

Zone interlocking uses a two-wire scheme to monitor short circuit phase faults that occur in the 'short time delay trip area' between devices in separate zones. When an irregular condition i.e. such as a fault, occurs in the 'short time delay trip area', the circuit breaker closest to the fault sends a 24 V DC blocking signal to the upstream circuit breaker, ensuring system 'selectivity'. The device closest to the fault is given the opportunity to clear the fault ensuring minimal disruption in service to other areas within the facility.

This connection may or may not inhibit the tsd and/or tg time delay of the circuit breakers depending on the location of the short-circuit fault.

In this example we see the location of the fault is Q3. Devices Q1 and Q2 also see the fault current passing through the system however Q3 sends the blocking signal to both devices upstream to maintain their time delay settings and Q3 itself maintains its Minimum Delay Setting (the last breaker in the line should always be set to minimum time delay on STI) and will interrupt in "say 50 msec".

If the fault is at Q2 however only Q1 is affected by the fault current passing so the block is initiated as with the previous example. Upon interruption supply will of course be lost to Q3 and Q4 in this case.

When the Zone Selective Interlocking function is activated on a circuit breaker, it inhibits its time delay settings and has an almost instantaneous trip time.

When it is not activated, the circuit breaker operates according to the trip time delay settings.

In Practice

Figure 5.4.1
Typical breaker selection.

The understanding of manufacturer's "frame size breaks" is important to have a general guide as to physically what is possible in selectivity real terms. Reticulation maximum demand allowances for feeder systems can make full selectivity at all high prospective levels difficult without either lowering expectations or increasing frame sizes of upstream devices. Hopefully this text has given a greater appreciation of the issues involved.

Generally selectivity figures need not be calculated, they are available from most manufacturers in table format.

It is still very important to do an extensive time-current selectivity analysis at the design stage of any electrical distribution system to ensure selectivity is achieved under overload or low level short circuit conditions. It is also very important to understand the difference in the time current characteristic curve shapes, tolerances and limitations so that the time current selectivity may be met prior to full design implementation.

Difficulties may be experienced with certain designs in meeting AS/NZS3000 requirements however a better understanding of the possibilities and capabilities of protection devices may assist in this area.

There are numerous software packages available from circuit breaker manufacturers that assist Electrical, Protection or Commissioning Engineers to do this task accurately and efficiently. One example of this is NHP's TemCurve Selectivity Analysis Software, which contains the (tripping) characteristic curves for all Terasaki circuit breakers as well as complementary devices such as low and high voltage fuses.

To determine the selectivity level in the short circuit region it is very important to refer to the tables supplied from manufacturers. These tables take into consideration Current Selectivity and Energy Selectivity (Enhanced).

The tables are a quick and easy guide to what selectivity you are likely to achieve with a particular combination of circuit breakers.

Zone Selective Interlocking is normally only utilised in very large projects, and so is not commonly applied.

Tabular Combinations

Selectivity / Cascade Tables

Typically, manufacturers will produce tables showing tested combinations between different breakers and their behaviour with regards to selectivity and cascading at their consistent limits of fault current. MCCBs are tested against MCCBs as though in a distribution system and the results recorded and published to assist safety and design integrity according to the installation standards.

As an example, the combination MCCB-D 630 upstream and MCCB-C 400 downstream gives us 10 kA selectivity. This means that for faults up to 10 kA the MCCB-C will trip, and MCCB-D will remain closed. For faults above this level, both devices may trip (see cascade tables below). For selectivity at all levels up to this figure, breaker time current settings must also demonstrate time and current separation.

Cascade tables are set up similarly with the resultant number normally being the highest fault current that the two devices can offer safe interruption on a fault. Some typical cascade levels might look like the tables below.

Practical Example

Selectivity and Cascade Examples

From the tables we can see that the resultant cascade level between MCCB-D630 and MCCB-B 250 in series is 40 kA. This means that the MCCB-D will back up the MCCB 250B to interrupt a 40 kA fault which is above its breaking capacity of 36 kA however both breakers may open. In the case of the MCCB to miniature breakers, because of their difference in volume and therefore reaction speed to short circuits, the back-up given by MCCBs is significant, approaching protection given by some fuses.

Moulded Case Upstream, Moulded Case Downstream

MCCB to MCCB	MCCB-A 160 36 kA	MCCB-B 250 36 kA	MCCB-C 400 50 kA	MCCB-D 630 50 kA
MCCB -A 1 18 kA	-	25	36	40
MCCB -B 250 36 kA	-	-	40	40
MCCB -C 400 50 kA	-	-	-	50
MCCB -D 630 50 kA	-	-	-	-

Moulded Case Upstream, Miniature DIN Downstream

MCCB to MCB	MCCB-A 160 36 kA	MCCB-160 50 kA	MCCB 250 36 kA	MCCB 250 50 kA
MCB 6 kA 6-63 A	36	36	36	36
MCB 10 kA 10-40 A	36	50	36	50
MCB 6 kA 50-63 A	36	50	36	50

Moulded Case Upstream, Miniature DIN Downstream

MCCB to MCB	MCCB-A 160 36 kA	MCCB-160 50 kA	MCCB 250 36 kA	MCCB 250 50 kA
MCB 6 kA 6-63 A	36	36	36	36
MCB 10 kA 10-40 A	36	50	36	50
MCB 6 kA 50-63 A	36	50	36	50

Moulded Case Upstream Moulded Case Downstream

MCCB to MCCB	Upstream	MCCB-B 250 36 kA	MCCB-C 400 50 kA	MCCB-D 630 70 kA
MCCB -A 160 36 kA	20-125 A	30	36	36
MCCB -B 250 36 kA	40-160 A	-	25	36
MCCB -C 400 50 kA	To 400 A	-	-	10
MCCB -D 630 50 kA	To 630 A	-	-	-

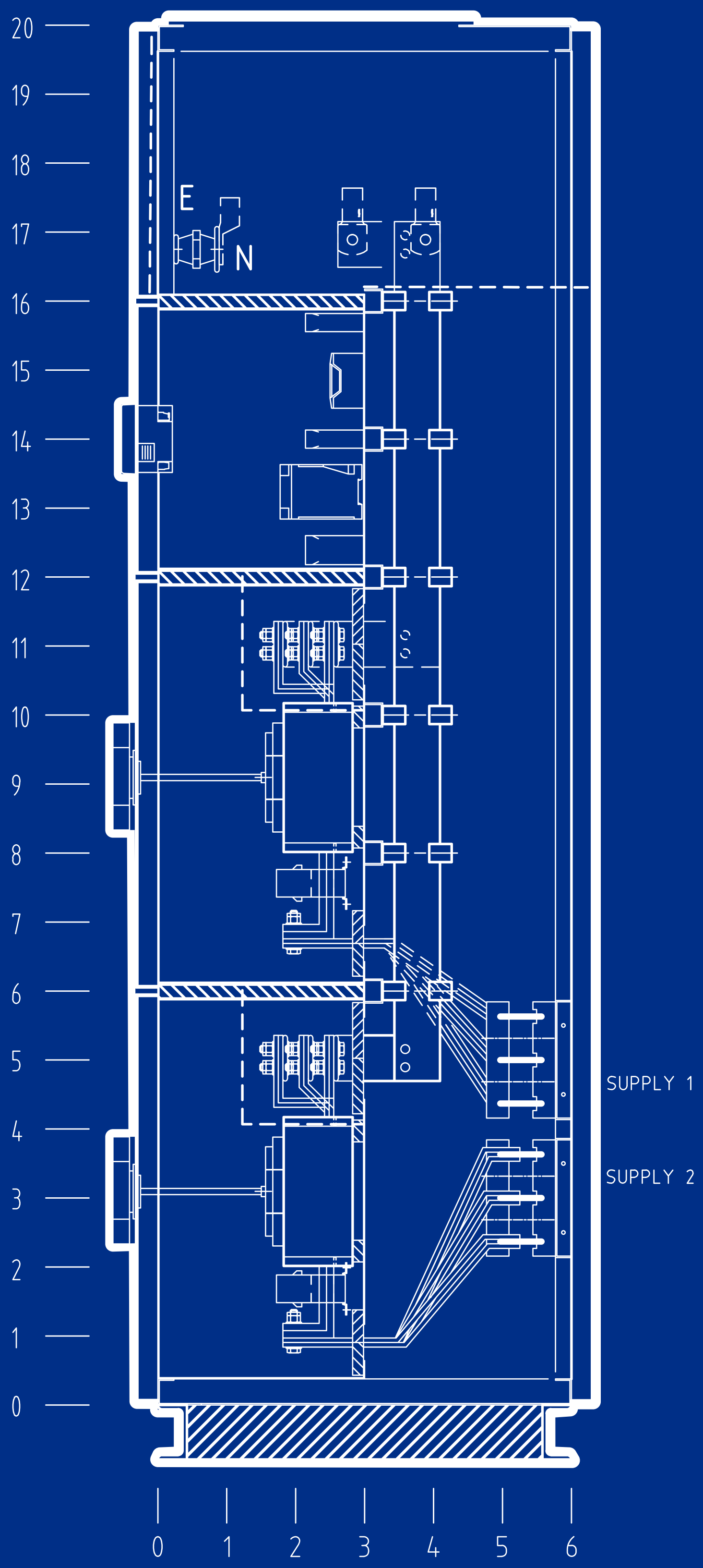
Summary

Provided the characteristic curves for both circuit breakers do not overlap we can see from the Selectivity tables that the P250FTM250 MCCB will trip (open) before the B800NBE800 MCCB for short circuit currents up to and including 36 kA, so ensuring Selectivity on a time / current basis. The instantaneous portions of the curves also ensure that for “impulse” currents the behaviour of the breakers is determined by their magnetic release points.

For short circuit values above the magnetic setting points, are the “no plot” tested performance levels of the breakers. Selectivity is assured up to the breaking capacity of the downstream device.

For fault levels above the breaking capacity of the P250FTM250 (36 kA) the B800NBE800 MCCB must back it up, and it will do so for short circuit currents up to 65 kA, so ensuring Cascade (back-up) protection is assured.

Based upon our “probability” determination, selectivity would be assured for 99.9 % of the expected fault scenarios. Should a bolted fault occur, a “safe” disconnection would still occur. The important issue of safety and reliability would still be met.



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