WHITE PAPER

Residual current devices (RCDs)

Protection against earth faults

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1. Introduction

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Figure 1. Load current (green) normally flows from source through load and back to source, passing through the Residual Current Device (RCD) two times and in opposite directions. In case of an earth fault, a residual current (red) flows from source to ground through a human body, e.g., when touching a live part, and then back to the source, bypassing the RCD on the way back. The resulting current imbalance is detected by the RCD, which immediately switches power off.

For many years, people have been injured in electrical accidents at home and in industry. In Australia and New Zealand as well as in global markets, electrical safety authorities have advocated the wide use of residual current devices (RCDs), also known as safety switches or earth leakage devices, as an effective means to provide protection against the threat of electric shock.

RCDs can provide protection for people against fatal electric shocks due to earth leakage and can also provide some protection against fire in installations.

The Australian and New Zealand Wiring Rules, AS/NZS 3000, require active conductors to be protected by one or more devices that automatically disconnect the supply in the event of overcurrent, before such overcurrent reaches a magnitude or duration that could cause injury to people or damage the installation due to excessive temperatures or electromechanical stresses.

AS/NZS 3000 also requires additional protection in most final sub-circuits by residual current devices to automatically disconnect the supply when an earth leakage current reaches a predetermined value.

In a fault free circuit, currents are flowing from the source (i.e., the substation transformer) to the load and back, in a loop (shown green in figure 1) that could include one or more phase (L1, L2, L3) or the neutral conductor (N). In case of an earth fault, an additional current loop is formed (red in figure 1), in which current flows back to source either through the ground or through a grounding conductor, such as, e.g., the protected earth (PE). Beside earth faults, other electrical faults may occur, such as overload or short-circuit (both referred to as overcurrent faults in AS/NZS 3000), overvoltage, arc fault, etc. Dedicated protection devices are recommended against these faults, which is beyond the scope of this RCD white paper.

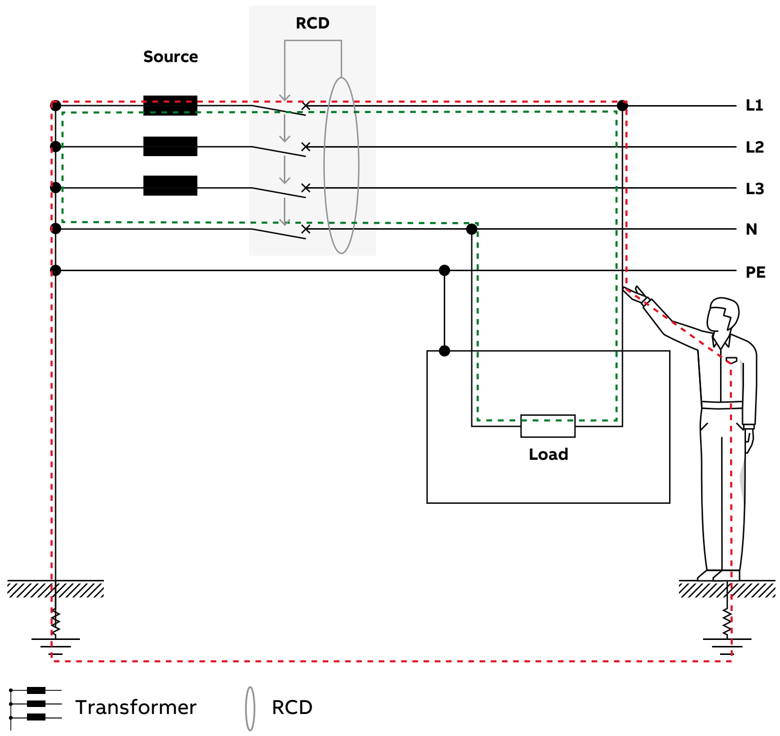

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Figure 1.

2. History

The development of the first RCD is not clearly defined to when, where and by whom. It is acknowledged that the early RCD designs were used by electrical utility companies as a means of identifying 'energy theft', where electrical energy was unsafely and illegally taken from the network active and utilizing the earth as a return conductor, bypassing electricity meters and conventional protection.

ABB introduced the first low sensitivity RCD in 1953 and followed with a high sensitivity device in 1956. After further development residual current devices were adopted as a safe and reliable means of protecting people against electric shocks. In Australia and New Zealand, the introduction of mandated residual current protection on certain final sub-circuits in the wiring rules has seen electrical fatalities reduce by about 50% when comparing 1990-1999 with 2000-2009[1]. Subsequent editions of the wiring rules has increased the mandatory requirements of residual current protection in final sub-circuit protection providing even greater safety and saw the electrical fatalities reduce by a further 50% from 2000-2009 to 2010-2019[2].

Electrical safety authorities report the electrical fatalities in Australia and New Zealand has shown a decrease over a 20-year period from an average (three years) of 1.70 deaths per million people in 2000-2001 to 0.34 deaths per million people in 2019-2020[3], coinciding with the mandated use of RCDs in both countries.

3. The three layers of earth fault protection

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Figure 2. The three layers of earth fault protection. RCDs are involved in fault protection by automatic disconnection and in additional protection

Fault protection to meet electrical safety standards can be defined in layers of protection. The highest level of protection is only achievable in the frame of a safety approach consisting of three layers: basic protection, fault protection and additional protection. Many of the earth fault requirements of the Australian and New Zealand Wiring Rules, AS/NZS 3000 are identical to that of the requirements of the IEC 60364 series of standards.

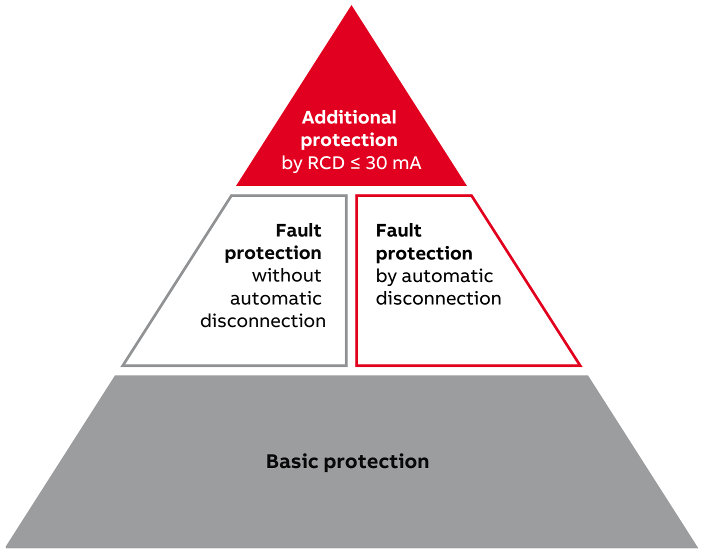

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Figure 2.

1 Source: Electrical Regulatory Authorities Council (ERAC) Accident statistics Report 2009-2010
2 Source: Electrical Regulatory Authorities Council (ERAC) Accident Statistics Report 2011-2019
3 Source: Electrical Regulatory Authorities Council (ERAC) Accident Statistics Report 2011-2019

3.1 Basic Protection

The first and most basic form of protection is to prevent accidental contact with live parts. The Wiring Rules require protection to be provided against dangers that may arise from contact with parts of the electrical installation that are live in normal service. This can be achieved by passive measures like insulation, barriers or enclosures, obstacles or placing out of reach. Basic protection shall be designed and constructed according to climatic conditions, presence of water, mechanical stresses, etc.

Basic protection could be sufficient for the purpose unless there is a fault in the insulation somewhere, or if the protection is removed intentionally, for example during installation or maintenance work, then failing to disconnect and de-energize the circuit undergoing maintenance. Any contact with only one hazardous live part is dangerous because a body would generally be in simultaneous contact with earth potential (e.g., by the feet standing on the floor). This provides an electrical circuit with a path back to the source, i.e. the substation transformer of the distribution grid.

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Figure 3. Basic protection.

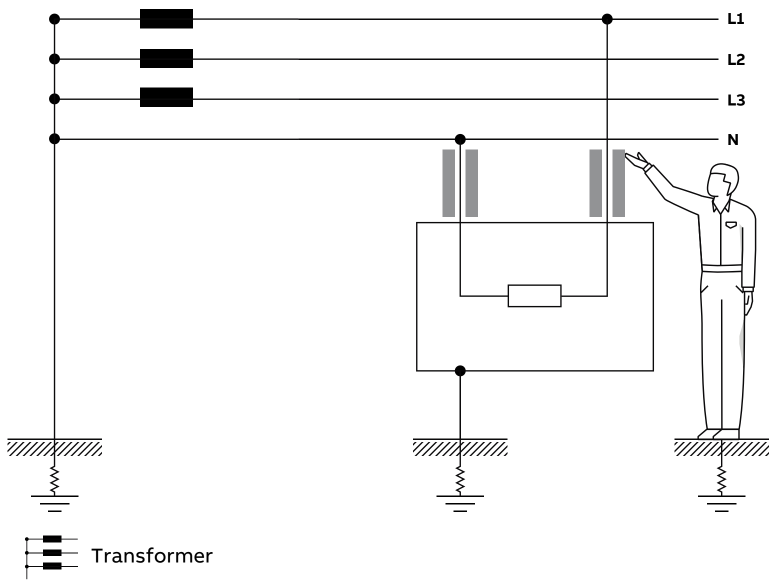

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Figure 3.

3.2 Fault protection

In case of insulation failure, fault protection is required to prevent electric shock. This is either done by a second, independent layer of insulation (double insulation), or by enclosing the live parts in a grounded metallic housing (schematically shown in Figure 1 and Figure 5 as a rectangular box around the load and connected to the PE conductor). A protective device shall automatically switch off the supply, in the event of a fault of negligible impedance between line conductors and exposed-conductive-parts. To provide double or reinforced insulation, it is necessary to use electrical equipment, known as class II equipment. Typical examples are sheathed cables consisting of an outer insulating sheath, covering one or more conductors that are in turn individually insulated, or totally insulating enclosures or panelboards; (depicted by the grey contours in Figure 4). In the case of a protective device, known as fault protection by automatic disconnection of supply, or also as indirect contact protection, all exposed conductive-parts (e.g. accessible metallic parts) must be connected by the protective earthing conductors (PE) to each other (equipotential bonding) and to the main earthing terminal of the installation.

Fault currents can flow from live parts to the grounded enclosure and then to source; See Figure 5. It is mandatory to automatically disconnect the supply in this case, which could be achieved by an RCD of medium sensitivity (for instance, 300 mA). In some cases, the fault current could flow through conductors, i.e., through a low impedance path, and it may reach values sufficient to trip Miniature Circuit Breakers (MCBs) and/or fuses. In the case shown in Figure 5, the ground is part of the reclosing loop, raising its impedance to values that may lead to currents not able to be detected by MCBs or fuses. Electrical equipment to be protected by automatic disconnection is equipped with a PE terminal (a third pin in many plugs) and is known as class I equipment.

Another fault protection method is protection by extra low voltage (ELV) or safety extra low voltage (SELV), in systems having a voltage not greater than 50 V AC, or 120 V DC, supplied by a specified safety source. Equipment protected by extra low voltage is known as class III equipment. Typical examples include low power electronic appliances, such as a mobile phone charger or a laptop.

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Figure 4. Fault protection by double or reinforced insulation.

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Figure 5. Fault protection by automatic disconnection of supply (electric shock is prevented).

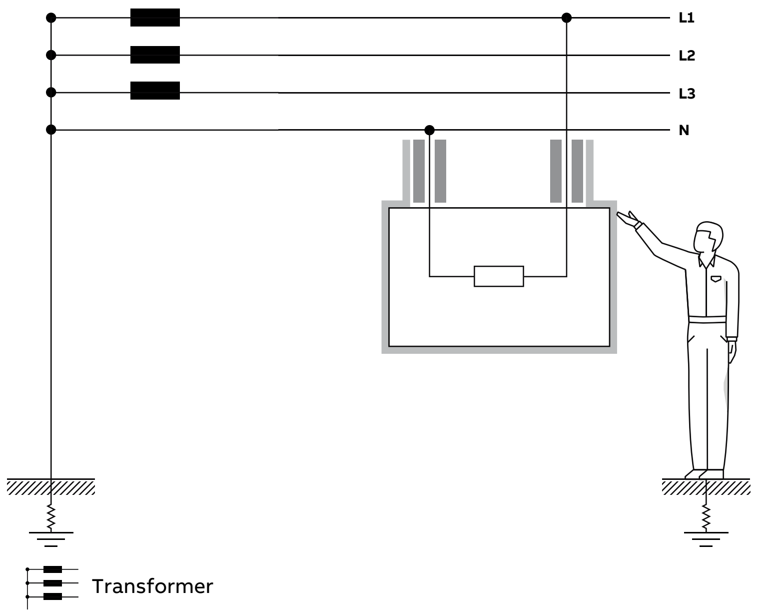

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Figure 4.

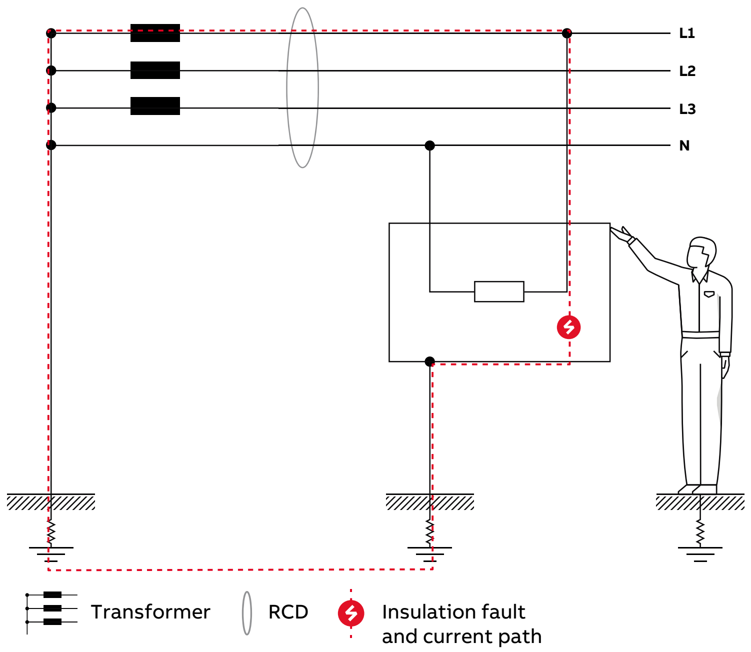

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Figure 5.

3.3 Additional protection

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Figure 6. Residual currents (red) flow from source to ground, e.g. when touching a metalwork in condition of double failure (internal insulation fault and loss of PE connection, i.e., of proper earthing), and back to the source around the RCD. The resulting imbalance is detected by the RCD, which immediately switches power off.

According to Australian and IEC standards, the double level of protection against electric shock - basic protection and fault protection - is mandatory almost everywhere. In many common applications, particularly final sub-circuits, a third level of protection, known as additional protection, is required in case of failure of both basic protection and fault protection; See Figure 6. The failure of basic and fault protection may happen due to carelessness by users, e.g. voluntarily removing the enclosure of an appliance, or due to broken insulation, or loss of PE connection, immersion in water, etc. If supply is not disconnected beforehand, electric shock is very likely as soon as a live part is touched, as indicated in Figure 1. An RCD with high sensitivity (e.g., 30 mA or less) is recognized in AC electrical systems as additional protection against electric shock.

As shown in Figure 1, when touching a live conductor, a residual current will flow through the body to ground, circumventing the RCD on the return path, which will disconnect power (more details in Section 6). It is important to note that, since the ground is part of the fault loop, a high impedance leads to very low currents (several mA) compared to the operating current of an overcurrent protection (MCB or fuse) which can be in the range of tens, hundreds, or thousands of amps. Because of this, overcurrent protection cannot provide additional protection.

The main difference between a device used for fault protection and a device used for additional protection is that a fault protection device offers circuit protection against electric shock in low impedance faults, where additional protection offers circuit protection with rapid circuit interruption for high impedance faults at low mA levels, lowering the risk of injury. Additional protection devices, like RCDs, cannot eliminate electric shock, however they can operate quickly enough and at a low enough current level to limit the damaging effects of the electric shock on the human body and prevent serious injury or death.

The use of RCDs with a rated residual operating current not exceeding 30 mA is a key protection element for increasing safety in low voltage (LV) electrical circuits, even though it can't be the only means of protection and does not replace the need to apply other protective measures specified for basic protection and fault protection.

Additional protection by an RCD rated up to 30 mA doesn't depend on an earthing system and is not related to the requirements for fault protection. For instance, a 30 mA RCD may be used to additionally protect class II equipment that does not need RCDs for fault protection. Additional protection by RCDs rated up 30 mA is also mandatory under certain conditions as defined in the wiring rules.

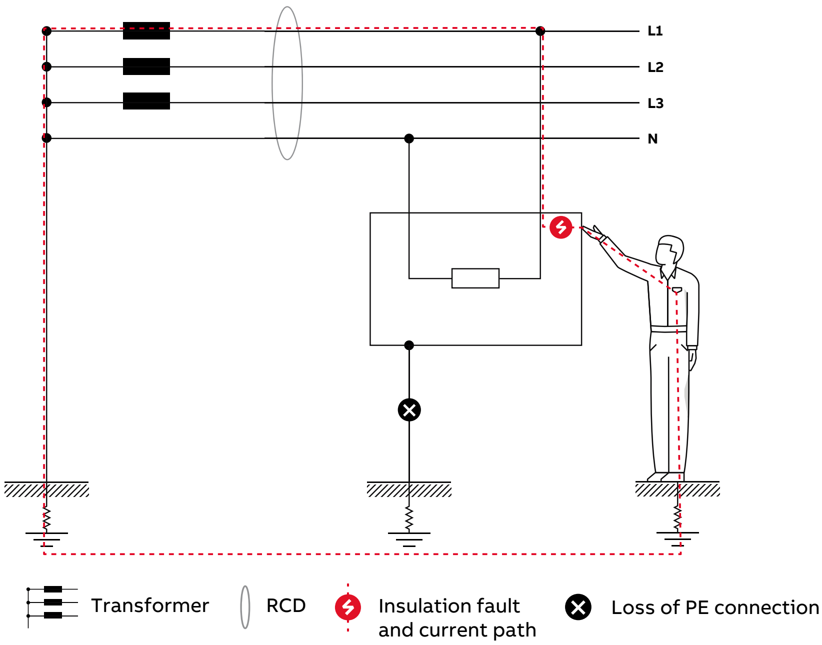

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Figure 6.

4. Effects of electric current on the human body

Electricity causes a 'shock' in the human body because it is an outside force that interferes with the internal electricity generated by the nervous system. As the human body consists primarily of water, it is essentially conductive. Any voltage that may be applied to the body can interfere and affect the normal function of the system. The higher the voltage, the worse the effect. An electric shock is the pathophysiological effect of an electric current through the human body. It effects the muscular, circulatory and respiratory functions and can also cause severe burns.

Injuries to people caused by current flow through the human body are:

- **muscular contraction:** the muscles affected by the current flow involuntarily contract, making letting go of conductive parts difficult. Very high currents often do not usually induce muscular contraction because when the body touches such currents, the muscular contraction is so strong that the involuntary muscle movements may throw the victim away from the conductor.
- **respiratory arrest:** if the current flows through the muscles controlling the respiratory system, the involuntary contraction of these muscles alters the normal respiratory process, and the victim may die due to suffocation or suffer the consequences of traumas caused by asphyxia.
- **ventricular fibrillation:** the most dangerous effect is due to the influence of the external currents with the body's physiological ones which, by generating uncontrolled contractions. This can induce alterations of the normal cardiac cycle. This anomaly may become an irreversible phenomenon and potentially fatal as it may persist even when the cause of the electric shock has been removed.
- **burns:** due to the direct heating effect of the current passing through the human body.
- An Australian Standard Technical Report, AS/NZS 60479.1 'Effects of current on human beings and livestock', provides detailed information based on research that the danger to persons depends mainly on the magnitude and duration of the current flow. This standard is based upon the international standard IEC 60479.1.
- A conventional risk map is shown in Figure 7, identical to the information included in AS/NZS IEC 60479.1, shows the time/current zones of effects of an AC current (15-100 Hz) flowing through a typical path from left hand to feet. Note that this current path will include the heart. Each point on the risk map is representative of a body current on the horizontal axis, and of a duration of the exposure on the vertical axis.

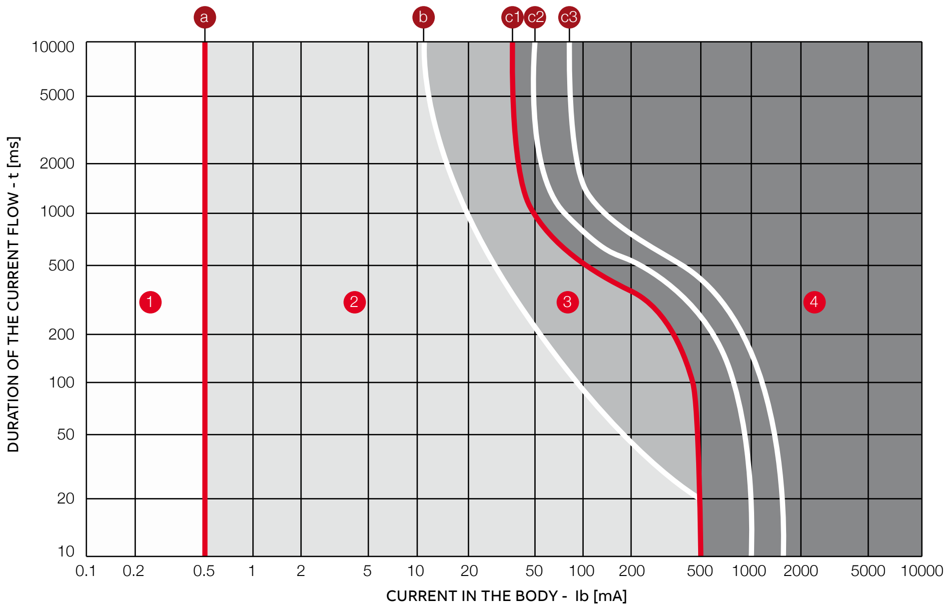

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Figure 7.

The time/current zones and the current boundaries for the different physiological effects of the pathway from hand to feet are indicated in the following table.

Table 1: Effects of alternating current on the human body

Zone	Effects
1	Usually no reaction
2	Usually no harmful physiological effects
3	Usually no organic damage to be expected. Likelihood of cramp-like muscular contractions and difficulty in breathing; reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time
4	In addition to the effects of zone 3, the probability of ventricular fibrillation increases up to about 5% (curve c2). 50% (curve c3) and above 50% beyond the curve c3. Pathophysiological effects such as cardiac arrest, respiratory arrest and severe burns may occur, increasing with current magnitude and time

Table 1

4.1 Ventricular fibrillation limit

As indicated in Figure 7, ventricular fibrillation and other pathophysiological effects that can cause death may occur in Zone 4, above curve c3. The ventricular fibrillation limit can be defined by Zone 4, above curve c1, so the operating characteristic of RCDs with a rated residual operating current of 30 mA is below this critical value. For this reason, 30 mA RCDs are mandated for people protection in various standards to avoid ventricular fibrillation.

5. Types of RCDs

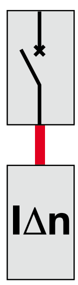
The following devices are all RCDs, equipped with additional features, offering cost effective solutions in different applications.

5.1 Residual Current Circuit Breaker (RCCB)

This device is essentially a mechanical switch with the residual current tripping characteristic attached to it. It will break the circuit only when there is a leakage current flowing to earth. The tripping time is such as to minimise the risks for human life.

As RCCBs are unable to detect or respond to an overcurrent or short circuit, they must be connected in series with an overcurrent device such as a fuse or MCB (Miniature Circuit Breaker). This gives the RCCB and the rest of the circuit the protection required to respond to an overcurrent or short circuit.

In summary, RCCBs provide earth leakage protection, however a major point to remember when applying them is that they must always be installed in conjunction with an appropriately rated Short Circuit Protective Device, like an MCB or fuse.

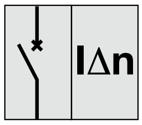


5.2 Circuit Breaker with Overload protection (RCBO)

The RCBO is a residual current device that has an MCB embedded in it. The RCBO is the equivalent of a separate MCB and RCCB. The main functions that an RCBO provides are:

a) Protection against earth fault currents
b) Protection against overload and short-circuit currents

The best way to use an RCBO is to use one on each circuit, this way if one circuit exhibits a fault it will not affect the other circuits. As the price of these devices is dropping year by year, the RCBO is an effective way of protecting lives and the installation.



5.3 Residual current relay (earth leakage relay)

This kind of residual current device has been designed to satisfy the requirements of industry. They suit three-phase circuits and high current loads. The residual current threshold and tripping delay is often adjustable, thus allowing selectivity among different circuit breakers.

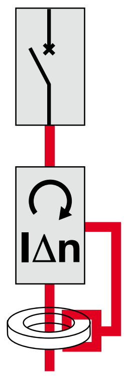
An earth leakage relay works in combination with a circuit breaker that opens the circuit in the case of a circuit breaker ground fault.

Phase and neutral conductors pass through a toroidal transformer, creating a magnetic field proportional to its current. In normal situations the vector sum of the currents is zero. In case of a fault, the toroidal transformer detects the imbalance and sends a signal to the relay and compares it with the preset threshold value. The output contact of the relay is turned on when the fault value detected is higher than the preset threshold and lasts more than the preset tripping time value.

An earth leakage relay can be classified according to AS/NZS IEC 62020 and is suitable for "monitoring" the circuit and providing information about the network's insulation. AS/NZS 3000 requires RCDs for additional protection to be a fixed setting device, therefore earth leakage relays with adjustable settings are not permitted for up to 30mA additional protection applications.

According to Annex M of AS/NZS IEC 60947-2, the manufacturer of residual current relays must check and guarantee protection performance for the entire chain, composed of toroidal transformer + relay + shunt trip + circuit breakers. In addition, they can be used only with circuit breakers certified by the manufacturer, who is responsible for the tripping time, considering the entire chain of components.

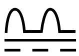
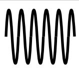
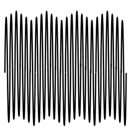
The devices according to this standard are tested by the factory in a "ready to use" configuration and they can make the installers' work easier.



5.4 Types of waveforms detected by RCDs and their classification

Residual current protective devices are distinguished from one another in respect of their suitability for detecting different forms of residual current.
The following table gives the RCD classification according to the waveform of the earth leakage currents:
- Type AC, sensitive to alternating current only
- Type A, sensitive to alternating and/or pulsating current with DC components
- Type F, with rated frequency of 50 Hz or 60 Hz are intended for installations when frequency inverters are supplied between phase and neutral or phase and earthed middle conductor and can provide protection in case of alternating residual sinusoidal current at the rated frequency, pulsating direct residual currents and composite residual currents that may occur.
- Type B to provide protection in case of alternating residual sinusoidal currents up to 1,000 Hz, pulsating direct residual currents and smooth direct residual currents
- Different types of loads can generate residual currents with a variety of waveforms. For this reason, various RCD types are available to allow the most appropriate selection of protection. It should be noted the types of RCD relate to the residual current waveform and not the supply voltage.

The Australian and New Zealand wiring rules recognize the following types of RCD: Type AC, Type A, Type F and Type B.

Current waveform	Proper functioning of residual current protective devices of type				Tripping current
	AC	A	F	B	
	■	■	■	■	0.5 to 1.0 IΔn
	–	■	■	■	0.35 to 1.4 IΔn
	–	■	■	■	Current delay angle 90°: 0.25 to 1.4 IΔn
	–	■	■	■	Current delay angle 135°: 0.11 to 1.4 IΔn
	–	■	■	■	max. 1.4 IΔn + 6 mA
	–	–	■	■	max. 1.4 IΔn + 10 mA
	–	–	■	■	0.5 to 1.4 IΔn
	–	–	–	■	0.5 to 2.0 IΔn
	–	–	–	■	Current frequency 150 Hz 0.5 to 2.4 IΔn
	–	–	–	■	Current frequency 400 Hz 0.5 to 6 IΔn
	–	–	–	■	Current frequency 1000 Hz 0.5 to 14 IΔn

5.4.1 Type AC RCDs

Type AC RCDs are suitable for systems where loads have a sinusoidal earth current. They have resistance to impulse leakage currents up to a peak of 250 A (8/20 wave form) such as those that may occur due to overlapping voltage impulses on the mains (e.g.: switching of fluorescent lamps, X-ray equipment, data processing systems and SCR controls).
Type AC RCDs are designed to detect these sinusoidal waveforms having a frequency equal to the power frequency, i.e 50 Hz. Type AC RCDs used to be the most common type, for networks supplied in AC (hence the name) supplying classical electric loads with a resistive, inductive, or capacitive impedance, generally without electronic components. The currents (including earth leakage) and voltage are generally sinusoidal in shape. Typical loads include tungsten & halogen lighting, ovens and heaters without electronic control.

5.4.2 Type A RCDs

Type A RCDs also have resistance to impulse currents up to a peak of 250 A (8/20 wave form) and perform with the characteristics of a Type AC, with the additional capability of being able to detect residual currents that are only partially sinusoidal, or a pulsating DC. These current wave forms are typical of networks supplying power electronic components, such as diodes and transistors. With the increased adoption of electronic appliances, such as dimmers, computers and television sets, currents and voltages in the network have experienced a progressively higher contribution from switched mode power supplies etc, where thyristors control the power supply by alternately switching the current flow on and off through powered appliances. This explains the only partial sinusoidal nature of earth leakages in networks with a significant quantity of electronic loads.

Type A RCDs will detect residual currents with an AC waveform, pulsating DC waveform or a smooth direct current of up to 6 mA.

Australian standards have recognized the increased use of electronics, renewables and emerging technologies by end users in Australia, and an amendment to the wiring rules in 2021 mandated RCDs used for protection against electric shock comply with the requirements of a Type A RCDs. This will exclude Type AC RCDs from both the Australian and New Zealand markets in new installations. This regulation will take effect from April 2023.

5.4.3 Type B RCDs

In addition to detecting residual current waveforms of the Type A RCD, a residual current protective device of Type B can detect smooth DC residual currents. Type B RCDs are recommended for use with drives and inverters for supplying motors for pumps, lifts, textile machines, machine tools etc., since they can detect a continuous fault current with a low level ripple and have tripping values defined up to 100 kHz.

Type AC and Type A RCDs comply with AS/NZS 61008/61009. Type B for RCDs are not mentioned in these reference standards and an international standard, IEC 62423, has been introduced in 2007, specifying additional requirements for Type B RCDs.

The standard, IEC 62423, should only be referred to together with AS/NZS 61008-1 (for RCCBs) and AS/NZS 61009-1 (for RCD-blocks and RCBOs), which means that Type B RCDs must also be compliant with all the requirements of AS/NZS 61008/9.

5.4.4 Type F RCDs

Type F RCDs are an extension of Type A and are recommended for loads with single-phase inverters and similar equipment (e.g. modern washing machines, air conditioners). For the Type F RCDs, additional tests have been added to those of a Type A, to simulate the ground fault in the presence of a single-phase inverter. These RCDs can detect residual currents with a harmonic content at frequencies higher than the power frequency, up to 1 kHz, typically found in networks with single phase power converters that modulate the power flow by shaping current and voltage according to very general waveforms.

The Type F RCD is characterised by a strong immunity to unwanted tripping, having resistance to impulse currents with a peak of 3,000 A (8/20 wave form). Type F RCDs can provide better protection with the increasing use of modern electronic appliances in domestic installations, where Type A RCDs could not properly cover them. It effectively fixes, in an “official” way, the problem of unwanted tripping with a non-selective RCD.

A Type F RCD can also detect smooth direct residual currents up to 10 mA.

5.4.5 Selective RCDs

It is a requirement of the standards and wiring rules that RCDs up to and including 30 mA must trip ‘instantaneously’, according to defined tripping times dependent on the residual current. Type S RCDs have the possibility to introduce a time delay in the operation of the device. This delay is used in providing selectivity or coordination between residual current devices installed upstream from each other, to avoid unwanted tripping in the event of a residual current fault.

Due to the internal time delay, Type S RCDs must not be used for people protection or have a sensitivity of 30mA or less, and are generally rated with a sensitivity of 300 or 500 mA or higher.

5.5 Choosing the right RCD

To choose the right type of RCD, two different aspects should be considered.

1) The type of protection required:

	Type of protection		
Type of RCD	**Protection against indirect contacts (if Idn is coordinated with ground system)**	**Additional protection (if Idn < 30 mA)**	**Protection against fire risk (if Idn < 300 mA)**
AC	■	■	■
A	■	■	■
F	■	■	■
B	■	■	■
A S (selective)	■		■
B S (selective)	■		■

2) The type of fault current wave form

	Types of wave form detected by RCDs				
Type of RCD	**Alternating current 50/60Hz**	**Alternating current up to 1000 Hz**	**Pulsating current with DC components**	**Multifrequency current generated by the single-phase inverter**	**Multifrequency current generated by the three-phase inverter**
aC	■				
A	■		■		
F	■		■	■	
B	■	■	■	■	■
A S (selective)	■		■		
B S (selective)	■	■	■	■	■

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Figure 8. Selected RCDs from ABB. Left to right: the bipolar (phase and neutral) F202, an RCCB; the tetrapolar (three phases and neutral) DDA 204, an RCD block; the bipolar (phase and neutral) DS201, a VI RCBO; the bipolar (phase and neutral) DSE, a VD RCBO, where the blue and white cable connect the power supply to the mains.

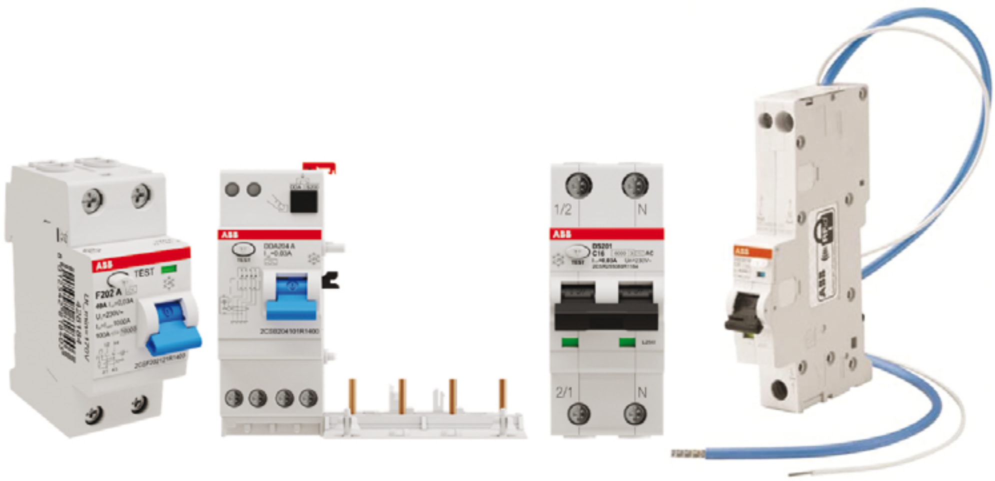

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Figure 8.

5.6 Voltage independent RCDs

Voltage independent (VI) RCDs use the energy of the earth fault current to trip the mechanism directly. In this type of RCD, the output from the sensing coil operates a specially constructed magnetic relay which then releases the RCD mechanism, independently of the mains voltage. Voltage independent RCDs normally use a polarised (field weakening) relay construction.

This operates by cancelling the permanent magnetic flux (which holds the relay ON) by the excitation flux (produced by the fault current). This can only occur in one half-cycle of the AC supply because the magnetic flux will be reinforced in the other half cycle. Operating times can vary from 20 to 120 ms at rated tripping current.

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Figure 9. Building blocks of VI (left) and VD (right) RCDs.

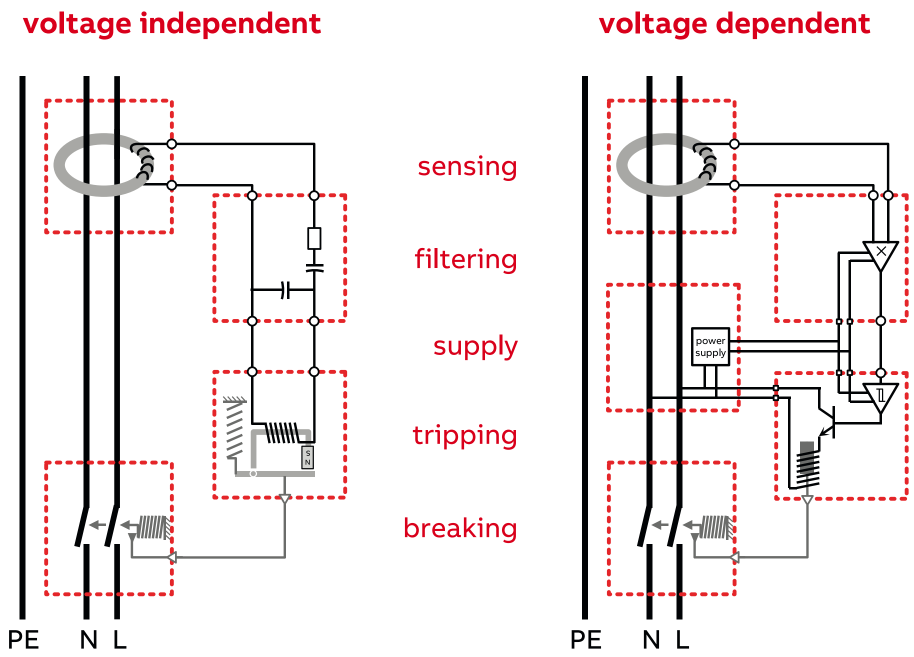

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Figure 9

5.7 Voltage dependent RCDs

Voltage dependent (VD) RCDs generally employ an electronic amplifier to provide an enhanced signal from the sensing coil to operate a trip solenoid or relay. RCDs of this type are defined as “voltage dependent” because they rely on a voltage source, derived from the mains supply, or an auxiliary supply, to provide the amplifier with power. The basic principle of operation is, however, the same as voltage independent RCDs.

Some Voltage Dependent RCDs utilize an additional conductor for a functional earth (FE) connection. The purpose of this conductor is not as a protective earth, but to provide an additional assurance of operation of the RCD in case the neutral connection is lost, depriving the RCD of the supply necessary to trip in the event of a residual current fault. The loss of neutral may happen for a variety of reasons such as mechanical damage to cables or loose connections.

5.8 Hi-immunity RCDs

High immunity RCDs are a special variation of the Type A RCDs. Through special design considerations and residual current processing circuitry with short delays, these RCDs provide the ability to overcome some high transient surge events up to 3000 A, waveforms exhibiting high rate of change peaks and momentary high frequencies. The hi-immunity RCDs can still operate within a time defined by the standards to be characterized as ‘instantaneous’, therefore they can be used in applications required for people protection with sensitivities up to 30mA.

5.9 Rated residual operating current IΔn

A key parameter for RCDs is the rated residual operating current. The tripping criteria is defined by standards and wiring rules according to applications. The RCD must trip if the residual current exceeds the rated value although the product standard states the device may trip any time after 50% of the rated sensitivity value. The rated residual current values for standard RCDs include 10, 30, 100, 300, 500 mA, 1 A.
The most common value required for RCDs in general final sub-circuit applications is 30 mA, which will prevent ventricular fibrillation in humans as described in section 4. It is noted according to the standards that a RCD with a rated sensitivity of 30 mA may trip anywhere in the range of 15 – 30mA.

5.10 Operating times of RCDs

The product standards for RCCBs and RCBOs defines the operating times required for these devices based upon the applied residual current. The tripping times defined in the standards for an RCBO is in the following table. The tripping times for RCCBs is identical.

AS/NZS 61009 defines a Type 1 RCBO as an RCBO with a maximum rated residual current of ≤0.01 A.

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Limiting values of break time and non-actuating time for Type AC and Type A RCBOs alternating residual currents (r.m.s. values)

Type	In A	IΔn A	IΔn	2 IΔn	5 IΔn	5 IΔn Or 0.25 A	5 A, 10 A, 20 A, 50 A, 100 A, 200 A, 500 A	IΔt	
General	Any	<0.03	0.3	0.15	-	0.04	0.04	0.04	Maximum break times
		0.03	0.3	0.15	-	0.04	0.04	0.04	
		>0.03	0.3	0.15	0.04		0.04	0.04	
S		>0.03	0.5	0.2	0.15		0.15	0.15	Maximum non-actuating times
		>0.03	0.13	0.06	0.05		0.04	0.04	
1		≤0.01	0.04	0.04	-	0.04	0.04	0.04	Maximum break times

5.11 Prevention of unwanted tripping

To prevent loss of supply due to unwanted tripping of RCDs, the AS/NZS 3000 wiring rules state the rated residual operating current shall be selected considering any leakage currents likely to occur during normal operation downstream of an RCD due to filters, natural capacitance, etc. Specifically, the wiring rules recommend the subdivision of electrical circuits so that any earth leakage current that may be expected to occur during normal operation of the connected loads will be unlikely to cause unnecessary tripping of the device.

Unwanted tripping of RCDs is sometimes referred to as ‘nuisance tripping’. In general a RCD trips due to an event it detects and interprets as an earth fault, essentially performing the task it is designed to do. Sometimes this tripping is not a real earth fault, and becomes a ‘nuisance’ due to the interruption of supply.

RCDs may operate at any value of residual current above 50% of the rated residual current according to the wiring rules and product standards. The wiring rules further recommend that the leakage current of a circuit does not exceed one-third of the rated residual current. Therefore, in the case of a 30 mA RCD, the expected leakage current should not be greater than 10 mA.

A phenomenon of accumulated leakage can affect some circuits, so the wiring rules recommend consideration be given to the number of socket-outlets protected on a circuit and the nature of the equipment likely to be connected to the socket outlets.

Many electronic appliances utilize switch mode power supplies that can exhibit a small leakage due to the capacitors connected to earth in their filtering circuits. The actual leakage can vary between products and manufacturers. A guide of possible leakage levels of various electronic products is shown in the following table.
Actual leakage from various equipment can vary between manufacturers and products and should be checked according to the manufacturers data, if available. The table below should only be used as a guide.

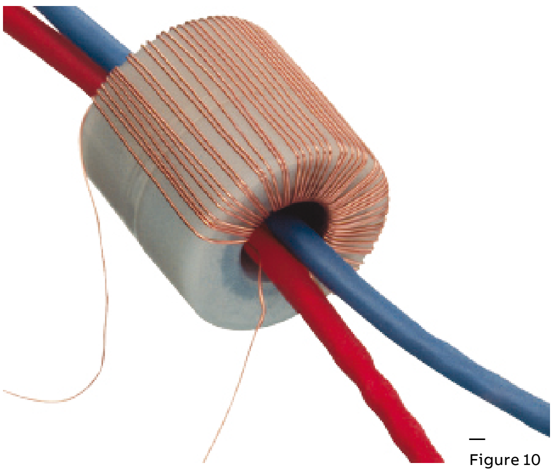
Appliances	**Earth leakage current**	
	From	**To**
Computers	1 mA	2 mA
Printers	0.5 mA	1 mA
Small portable appliances	0.5 mA	0.75 mA
Fax machines	0.5 mA	1 mA
Photocopiers	0.5 mA	1.5 mA
Filters	Around 1 mA	

6. RCD working principle

6.1 Residual current sensing

For any given installation, a residual current equals the difference of the currents flowing through the phase conductors and, where applicable, the neutral conductor. RCDs are required to trip for residual current values that are very small compared to the normal load currents flowing in the main conductors (mA compared to Amps). A smart way to approach residual current sensing is to directly measure the current imbalance. When a current significantly changes in time, such as in AC circuits, this can be achieved by a so-called differential transformer or core balance transformer. This is a special current transformer (CT) with all supply conductors as the primary windings (refer Figure 9 and Figure 10). In a normal circuit the magnetic fields of all conductors passing through the CT will cancel each other. If a current imbalance on the primary windings produces a magnetic field imbalance in the transformer toroid, this in turn produces a voltage on the secondary winding. This output voltage is a proportional measure of the intensity of the residual current.
In the case of Type F RCDs special provisions are necessary as magnetic properties are frequency dependent and the Type F must sense waveforms that are high in harmonic content and frequencies beyond 50 or 60 Hz.

Type B RCDs require additional sensing means due to the need to sense smooth DC components of the earth fault waveform as well as waveforms that are high in harmonic content and frequencies above 50 or 60 Hz. A smooth DC waveform provides a negligible output from a differential transformer, so Type B RCDs utilize a sensor to measure the rate of change of current whose output is analyzed to detect any smooth DC component.



— Figure 10

— Figure 10. A differential transformer to protect a network branch characterized by phase and neutral conductors (red and blue).

6.2 Test button

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Figure 11. RCD test circuit.

International and Australian Standards recommend periodically testing of installed RCDs. Testing is carried out by a suitable by-pass circuit that bridges one of the phases to neutral, or to another phase, without passing through the residual current sensor; See Figure 11. Consequently, a residual current is simulated when the test circuit is closed by operating a suitable test button. A functional RCD shall sense and process the simulated residual current, whose intensity is calibrated by a suitable test circuit resistance. Therefore, a properly functioning RCD will trip. Since the test signal is injected upstream, while the effects of testing are observed downstream, RCD testing effectively verifies that the whole sensing and tripping function of the RCD. ABB recommends the testing of RCDs every six months.

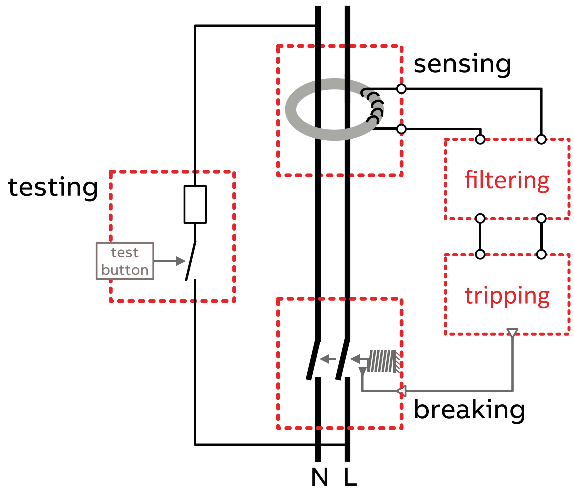

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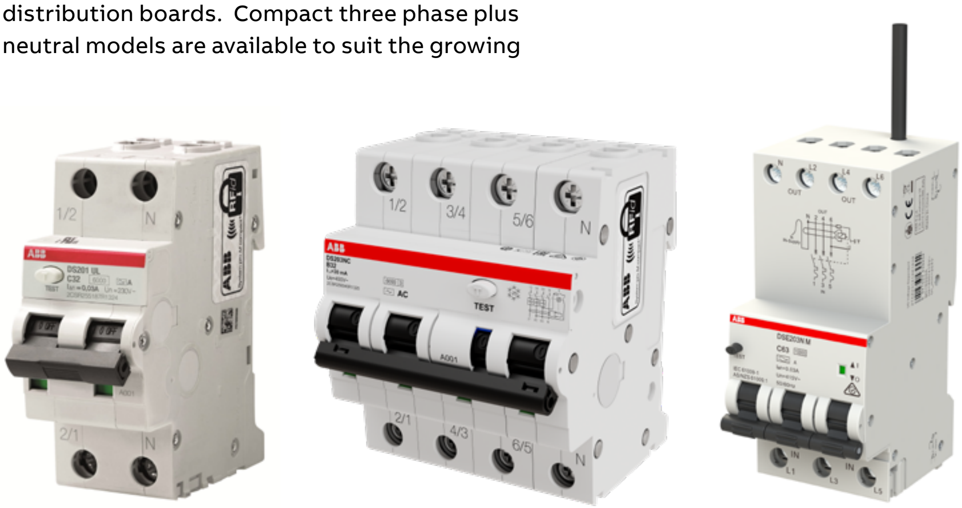
Figure 11

7. Further developments

Historical data has clearly shown the introduction of RCD technology and the mandated use of RCDs by regulations and wiring rules has had a dramatic impact on reducing electrical fatalities. The scope of RCD products is increasing with technology developments to provide RCD solutions for even wider applications to suit the needs of industry.

Models of RCBOs are more compact than earlier versions, saving space in consumer units and distribution boards. Compact three phase plus neutral models are available to suit the growing requirement to protect these loads. The increasing use of electronics has created harmonic disturbances on the network not tolerated by earlier RCDs, creating unwanted (nuisance) tripping issues.

ABB is at the forefront of RCD development as one of the world's leading suppliers of RCDs. The continuing commitment to research and development is allowing product development of the ABB RCD range to continue to expand.



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