

Why to Choose Type B Earth Leakage Protection for Safe and Efficient People Protection

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Executive summary

A wave of new electrical systems applications, including electrical vehicle (EV) charging stations and photovoltaic (PV) installations—plus the wider use of variable speed drives (VSDs) for motor control—are presenting new earth leakage protection challenges. This paper examines the principal types of earth leakage protection technologies available on the market today, and reviews applicable standards, proper usage and coordination rules as it pertains to electrical shock protection.

Introduction

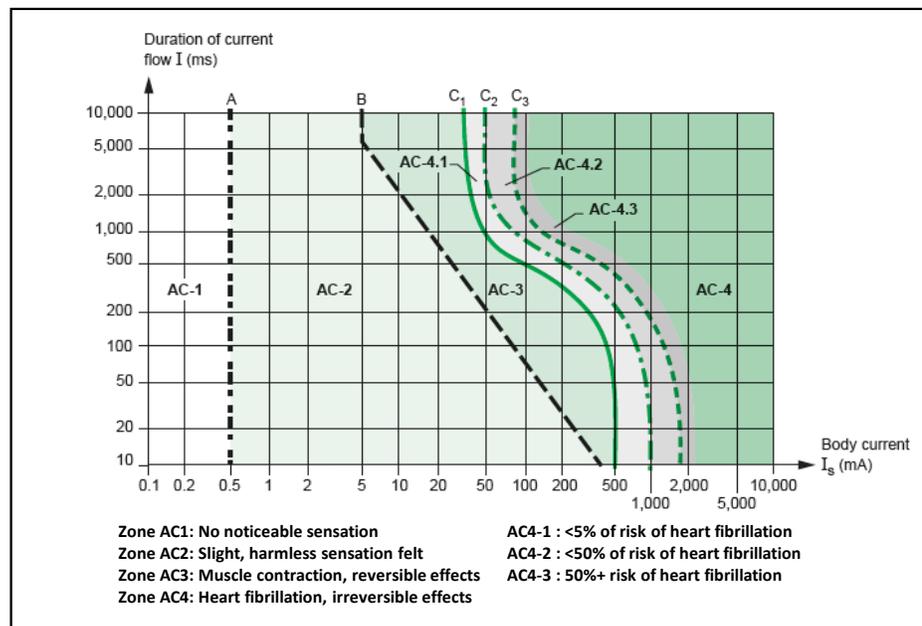
An electric shock results from the pathophysiological effect of an electric current through the human body. The current flow affects the muscular, circulatory and respiratory functions and sometimes results in serious burns.

The degree of injury risk for the victim is a function of the magnitude of the current, the parts of the body through which the current passes, and the duration of current flow.

IEC publication 60479-1 defines four zones of current-magnitude/time-duration, in each of which the pathophysiological effects are described (see **Figure 1**), for AC current. Any person coming into contact with live parts risks an electric shock. Curve C1 shows that when a current greater than 30 mA passes through a human being from one hand to feet, the person concerned is likely to be killed, unless the current is interrupted within a short time.

Figure 1

Time/current zones of effects of AC current on the human body when passing from left hand to feet (source IEC 60479-1)

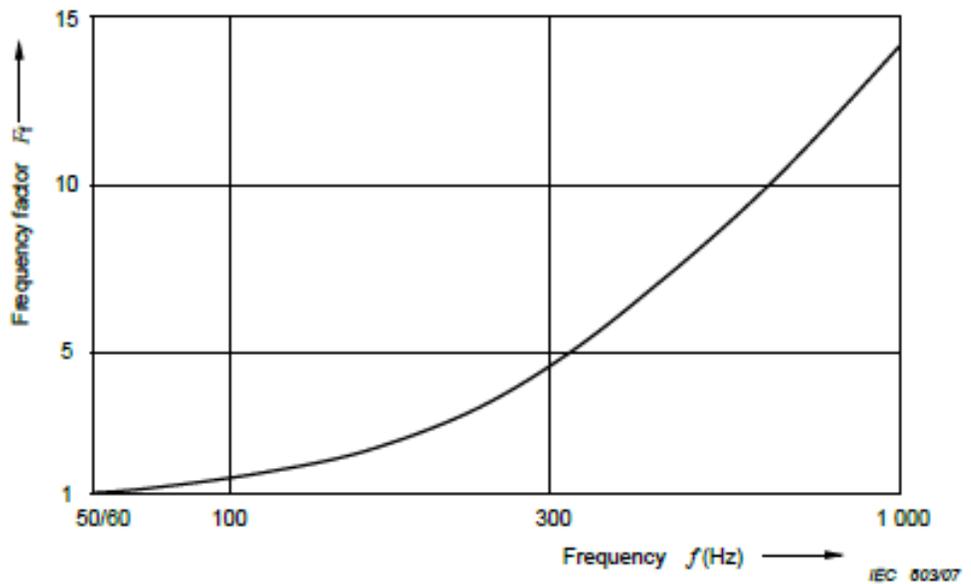


Protection against electric shock in electrical installations must conform with appropriate national standards and statutory regulations, codes of practice, and official guides and circulars. Relevant IEC standards include IEC 60364, IEC 60479, IEC 60755, IEC 61008, IEC 61009 series and IEC 60947-2.

If the current flowing in the human body is not purely 50Hz sinusoidal (e.g., pulsating DC, other frequencies, smooth DC), the thresholds defined in **Figure 1** are modified, according to the information provided in IEC 60479-1 and 60479-2. For example, in case of frequencies higher than 50 Hz, the threshold of ventricular fibrillation is modified according to the values in **Figure 2**.

Figure 2

Variation of the threshold of ventricular fibrillation within the frequency range 50/60 Hz to 1 000 Hz.

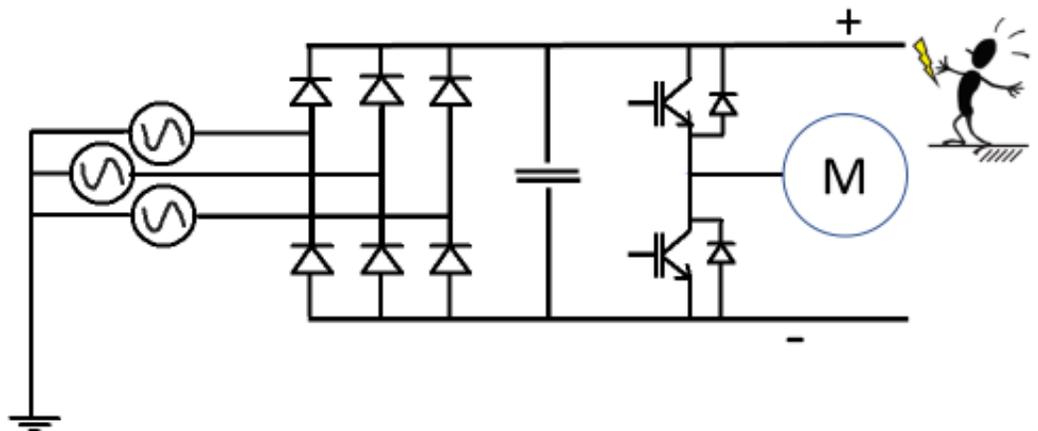


Pure DC residual current

In some applications, the load connected to the AC electrical installation can create residual currents which are more complex. For example, even on a 50 Hz AC electrical installation, the residual current may contain a smooth DC component, or frequencies higher than 50 Hz, or a combination. For example, such applications may be motor supplied by a 3-phase drive, electric vehicle (EV) supply equipment, or a photovoltaic inverter.

Figure 3

Example of application with DC residual current



These applications require a specific residual current device (RCD), which ensures protection in case the residual current contains such a waveform. This particular RCD is defined as a type B RCD and complies with the International Standard IEC 62423.

Residual Current Device (RCD) Types

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

Excerpt from IEC 60755:2017 § 5.2.10.1 describing type AC

The International Standard IEC 60755 defines four types of RCDs for AC applications. These types, which address the various kinds of residual current waveforms, are known as type AC, type A, type F and type B. All these devices are intended to be used within AC supply systems.

Type AC residual current devices

In most cases, the expected fault current is of the same frequency and waveform as the supply (i.e., sinusoidal 50 Hz), either because a fault may occur only on the supply conductors themselves, or because the load is resistive or linear. Residual current devices intended to detect sinusoidal residual currents are defined by IEC standards as type AC and are marked with a following standard symbol:



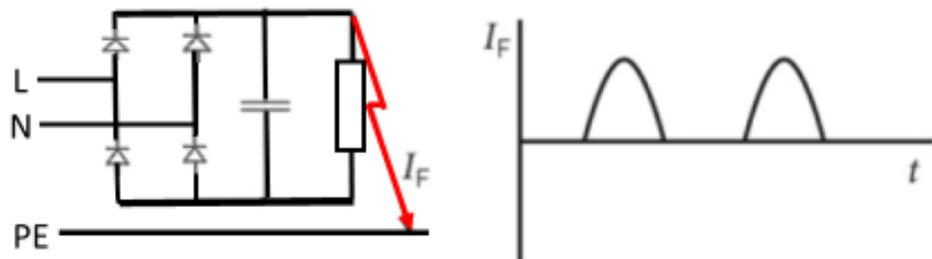
RCDs of type AC are used in many countries for general purposes applications.

Type A residual current devices

In some cases, the expected fault current could contain a pulsating DC waveform, because the fault current flows through a rectifier, as shown in **Figure 4**. Residual current devices able to detect such waveforms are known as type A RCDs.

Figure 4

Example of application which may create type A fault current and corresponding waveform (I_F)



Such devices are able to detect pulsating DC residual current and to withstand superimposed smooth DC residual current up to 6mA. In addition, a type A RCD is also able to detect the sinusoidal residual currents detected by a type AC RCD. Type A devices are defined in IEC standards and are identified by the following symbol:



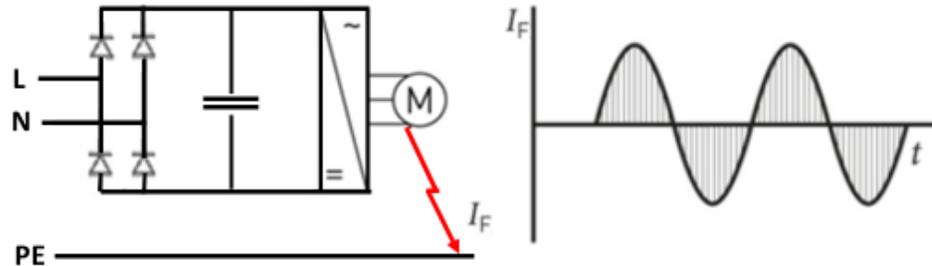
Type A RCDs are used in case the application creates pulsating DC residual current. For example: single-phase devices with a rectifying circuit like cooking plates.

Type F residual current devices

In other cases, the expected fault current may contain composite residual currents, with frequencies that range from only a few hertz up to 1000 Hz, as shown in **Figure 5**. In this example, the RCD supplies a load containing a single-phase motor drive and the waveform of the residual fault current is defined as a composite residual current. Residual current devices able to detect such waveforms are known as type F RCDs.

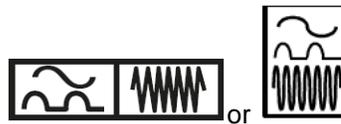
Figure 5

Example of application which may create type F fault current and corresponding waveform (I_F)



These devices are also able to withstand smooth DC residual current of up to 10 mA superimposed on the residual current. In addition, a type F RCD is also able to detect all the residual currents detected by a type A RCD.

Type F residual current devices are defined in IEC 62423; they are identified using the following standard symbol (which also denotes that a type F RCD complies with the requirements for type A):



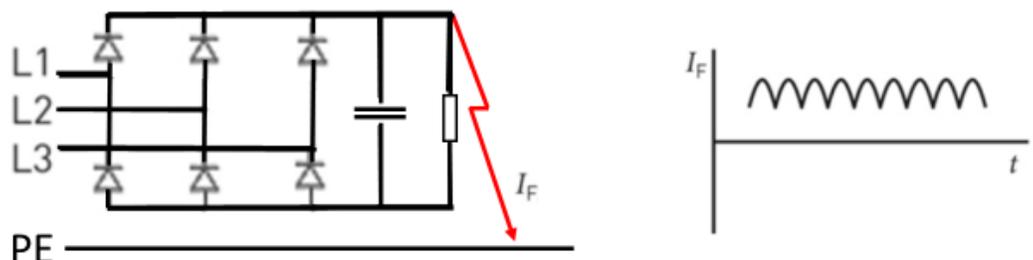
Type F RCDs are used in the cases where the application may create composite residual current. For example, single-phase devices containing a motor controlled by a variable speed drive, like a single-phase heat pump or an air conditioner.

Type B residual current devices

The waveform of a residual current can also demonstrate characteristics such as frequencies higher than 50 Hz or 60 Hz, non-sinusoidal waveform, waveforms resulting from rectifying circuits with six pulse bridge, as shown in **Figure 6**, or even smooth DC. This is the case, for example, when an RCD supplies a motor with a three-phase variable speed drive. Residual current devices able to detect such waveforms are known as type B RCDs.

Figure 6

Example of 6 pulse bridge application which may create type B fault current and corresponding waveform (I_F)



Such devices are able to withstand smooth DC residual current of 10 mA superimposed on a residual current. In addition, a type B RCD can detect all the residual currents detected by a type F RCD.

Type B residual current devices are defined in IEC 62423 in the following manner:

“An RCD for which tripping is ensured as for type F and, in addition:

- for residual sinusoidal alternating currents up to 1 000 Hz;
- for residual alternating currents superimposed on a smooth direct current of 0,4 times the rated residual current ($I_{\Delta n}$) or 10 mA whichever is the highest value;
- for residual pulsating direct currents superimposed on a smooth direct current of 0,4 times the rated residual current ($I_{\Delta n}$) or 10 mA, whichever is the highest value;
- for residual direct currents which may result from rectifying circuits, i.e.
 - two-pulse bridge connection line to line for two-, three- and four-pole devices;
 - three-pulse star connection or six-pulse bridge connection for three- and four-pole devices;
- for residual smooth direct currents.

The above specified residual currents may be suddenly applied or slowly increased independently of polarity.”

Type B RCDs are identified by one of the following standard symbols:



Type B RCDs are used in cases where the application may create smooth DC residual current or contain frequencies higher than 50 Hz. For example, three-phase devices containing a motor controlled by a three-phase variable speed drive. This is the case for certain types of three phase air conditioners, or pumps, or when supplying an electric vehicle or when medical equipment requiring a high precision of movement is used.

Figure 7

In this summary of RCD types, it can be seen that a type B RCD is also type F, type A and type AC

Type	AC			
	AC	A	F	B
I fault				
Load				
	linear	single phase rectifier	single phase frequency converter	3 phase rectifier

For more details regarding the possible faults created by various loads, refer to **Appendix A** in the back of this white paper.

How type B RCD technology works

Type A and Type AC RCD architecture

The internal design of type AC or type A RCD typically consists of the following core components (see **Figure 8**):

- a summation current transformer,
- an electronic circuit for signal processing (filtering and/or tripping decision),
- a trip unit,
- a latching mechanism
- electrical contacts.

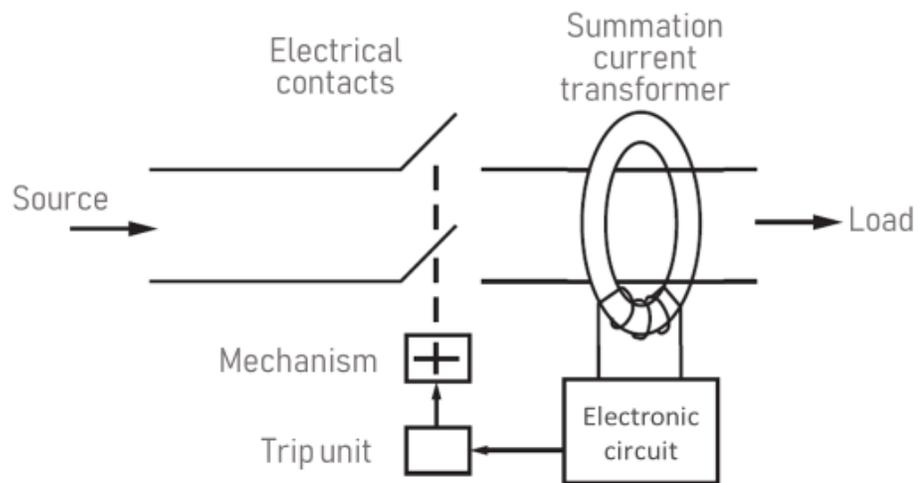


Figure 8
RCD architecture

Alternative residual current flowing in the primary winding generates a magnetic flux variation in the summation current transformer, thus inducing a voltage in the secondary winding. When the voltage is higher than a defined threshold, it will trigger the trip unit which activates the latching mechanism to open the contacts for protection.

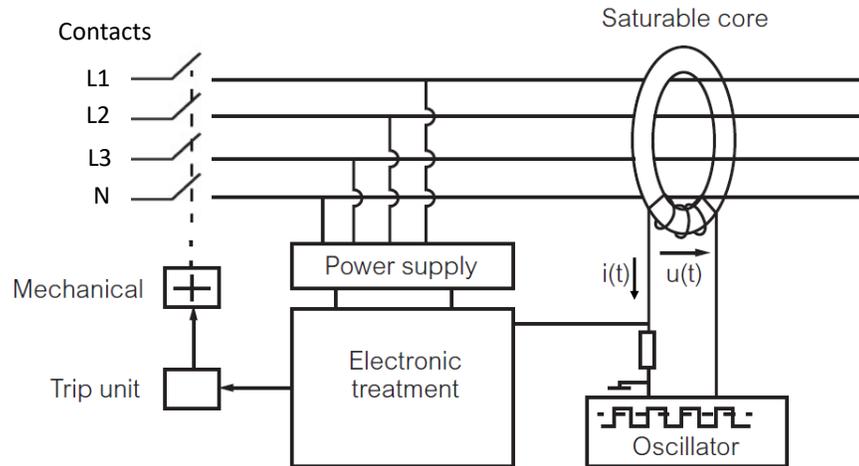
This well-known design has certain limitations, however. These devices cannot detect smooth DC current because the DC current does not create magnetic flux variation.

Fluxgate technology principle:

In order to detect DC residual current, a “fluxgate” technology can be used to stimulate a saturable core via a high frequency square wave voltage $u(t)$ on the secondary winding (see **Figure 9**). This technology allows DC current detection and is commonly used in type B RCD.

Figure 9

The principle of “fluxgate” for DC current detection

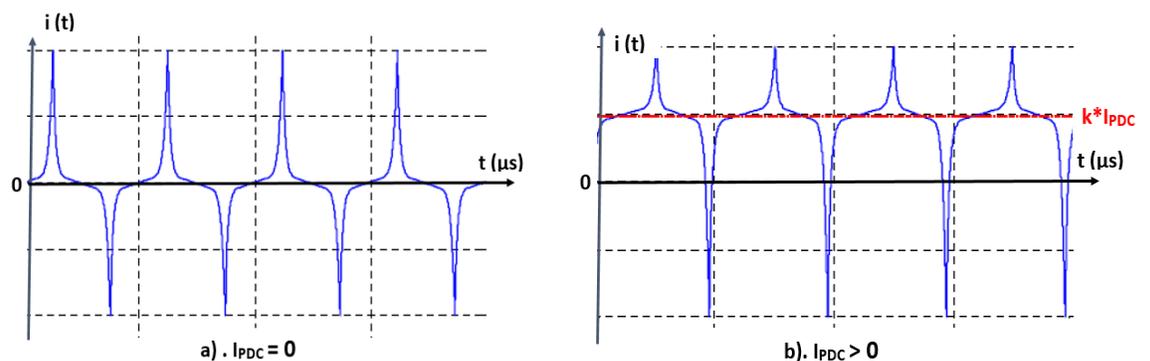


When no primary residual current exists, the current $i(t)$ in the secondary winding is symmetrical with a high peak value due to the saturation behavior of the core (see **Figure 10**, left side).

When a DC primary residual current is present, the magnetic state of the saturable core is changed and triggers a waveform modification of the secondary current $i(t)$. Since $i(t)$ is rendered no longer symmetrical, the device presents a DC component proportional to the primary DC current. By filtering and measuring the secondary current, the primary DC residual current is measured thus allowing for the detection of smooth DC earth leakage current (see **Figure 10**, right side).

Figure 10

$i(t)$ current waveforms
 a). no DC primary current
 b). with DC primary current



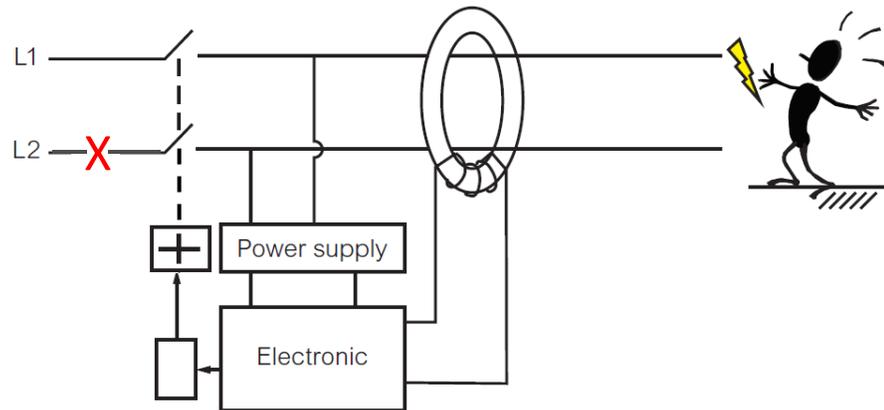
Type B RCD Architecture

In order for smooth DC current detection to occur, an electronic circuit has to stimulate the summation core and extract the primary residual current. The electronic device is, under normal circumstances, supplied by all line cables. But in case of voltage loss and when there is only one line available, the electronic device

will lose its power supply and the residual current detection can no longer be ensured despite an existing safety risk (see **Figure 11**).

Figure 11

The risk of non-protection when a loss of line voltage occurs



To mitigate this risk, the EN 62423 standard requires that type AC and type A protection are ensured by a voltage independent residual current protection.

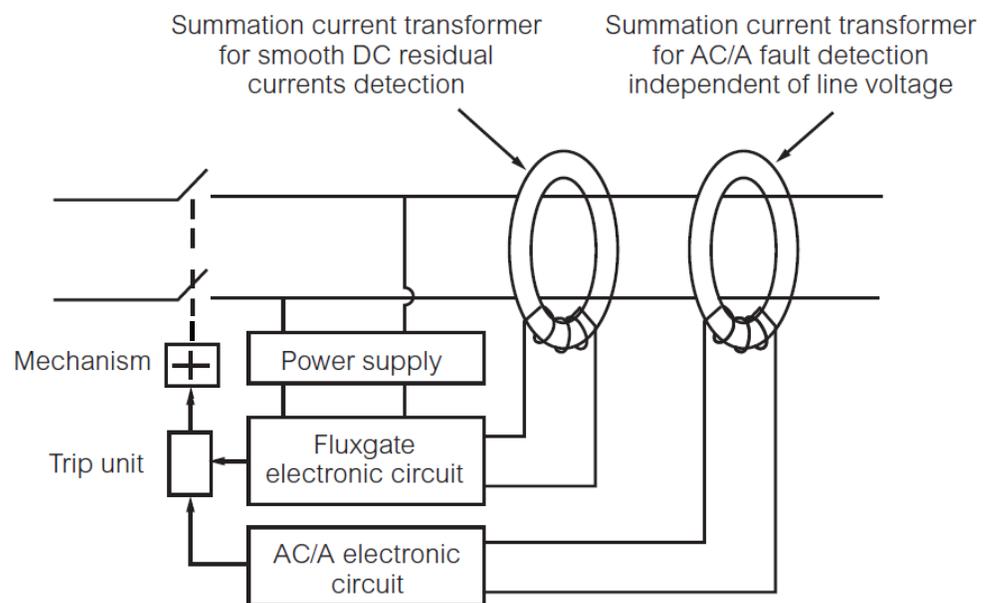
Since applications in electrical distribution do not generate smooth DC residual current when only one supply line is available, this voltage independent type AC and type A protection is enough to ensure electrocution protection in this situation.

Type B RCDs are usually designed with two residual current detection systems:

- one system with the voltage dependent fluxgate technology for smooth DC current detection,
- one system with voltage independent technology capable of type AC and type A fault detection. This second system ensures people protection even in case line voltage is lost (see **Figure 12**).

Figure 12

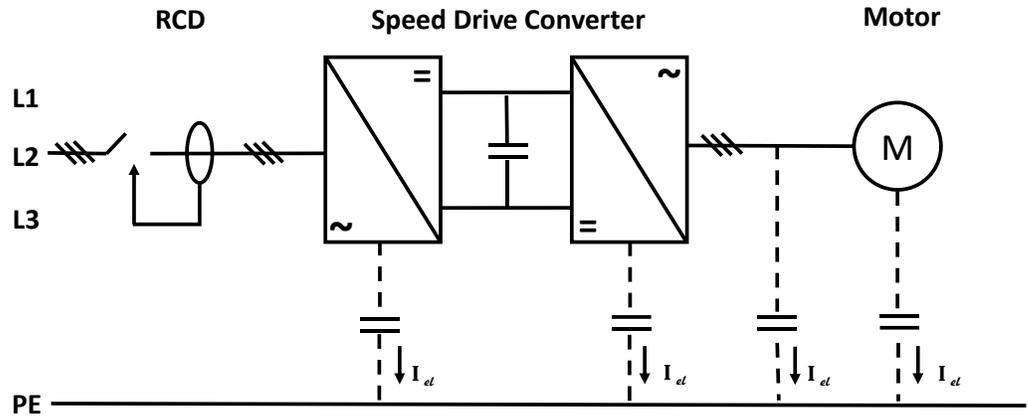
General architecture of RCD type B with 2 detection systems



High frequency: Key factor for service continuity and protection

Switching mode power equipment use is gaining in popularity due to its compacity and energy efficiency benefits. But switching mode implementations generate high levels of dv/dt, and, therefore, substantial high frequency earth leakage current in the circuits.

Figure 13 below demonstrates an example of a speed drive power converter:



I_{el} = Earth Leakage Current

Under normal operation, high frequency leakage current flows through cable stray capacitors and equipment EMC filter capacitors. As the impedance of capacitors decreases with frequency, the leakage current will be proportional to the switching frequency of the converter for the same voltage level:

$$I_{el} = 2\pi f * C * U = k * f$$

This capacitive earth leakage current is not dangerous because it is non-energetic, but it could cause unwanted tripping of protection devices (RCD's).

Another factor to be considered is the frequency curve of ventricular fibrillation threshold as illustrated in the **Figure 2** (on page 3). We can see that the human body is less sensitive to high frequency current than to network frequency and the safety threshold will increase substantially at higher frequency. **Figure 14** illustrates the ventricular fibrillation threshold and capacitive earth leakage on the same graph.

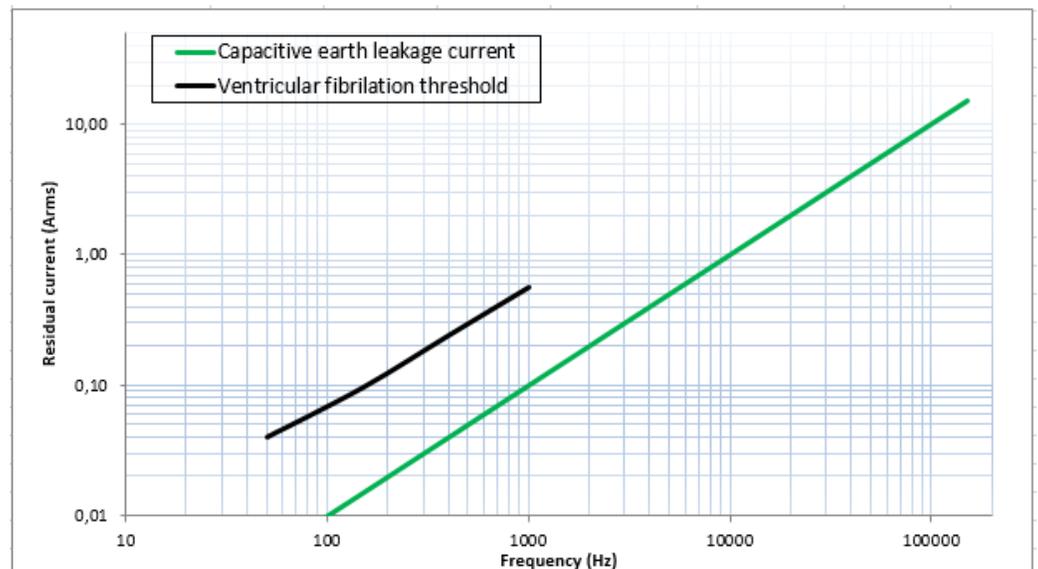


Figure 14

Capacitive earth leakage current with switching mode equipment

The tripping threshold of the RCDs needs to be below the safety (black) curve (as prescribed by IEC 60479-2) to ensure protection of humans, but it needs to be higher than the curve of capacitive earth leakage current to avoid any unwanted tripping.

Thus, Schneider Electric has designed a Super Immunity (SI type) RCD which strikes a balance between the safety curve and the unwanted tripping curve (see **Figure 15**). This device is particularly useful for applications characterized by high frequency switching mode converters (such as variable speed drive, UPS, PV, EV, medical equipment, Switch Mode Power Supply - SMPS, and electronic ballast lighting, for example). The type SI RCD also provides protection against network transient disturbances, lightning induced overvoltage, lightning induced current, and radio frequency (RF) waves.

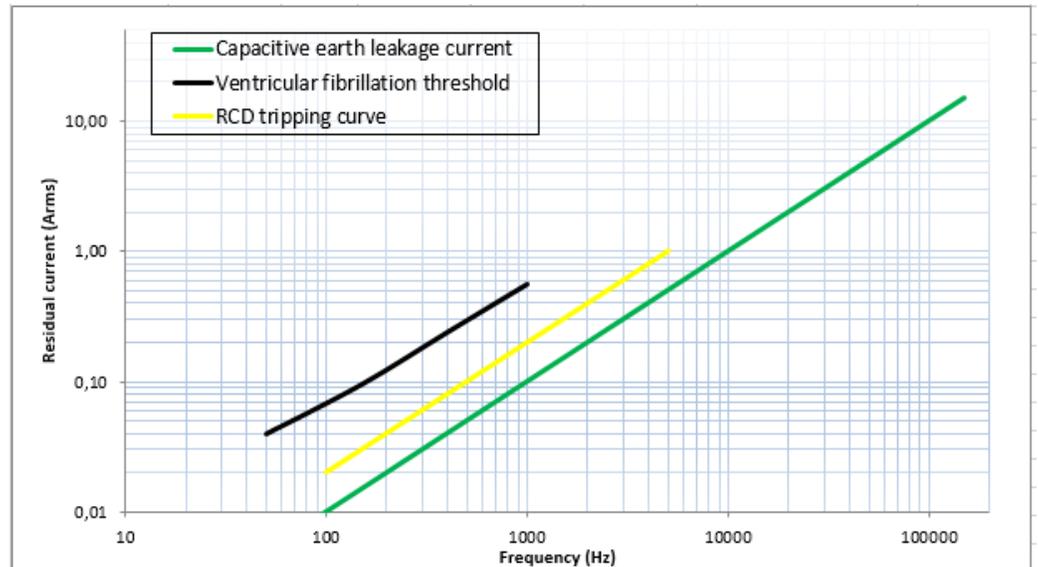


Figure 15

*Tripping curve of
Schneider Electric SI
RCD*

Figure 16 below provides a summary of the performance characteristics of the Schneider Electric SI type RCD.

Disturbance type	Rated test wave	Immunity SI type
Continuous disturbances		
Harmonics	@ 1 kHz	Earth leakage current = $8 \times I_{\Delta n}$
Transient disturbances		
Lightning induced overvoltage	1.2 / 50 μ s pulse (IEC/EN 61000-4-5)	4.5 kV between conductors 5.5 kV / earth
Lightning induced current	8 / 20 μ s pulse (IEC/EN 61008)	3 kA peak
Switching transient, indirect lightning currents	0.5 μ s / 100 kHz "ring wave" (IEC/EN 61008)	400 A peak
Downstream surge arrester operation, capacitance loading	10 ms pulse	500 A
Electromagnetic compatibility		
Inductive load switchings (fluorescent lights, motors, etc.)	Repeated bursts (IEC 61000-4-4)	5 kV / 2.5 kHz 4 kV / 400 kHz
Fluorescent lights, thyristor-controlled circuits, etc.	RF conducted waves (level 4 IEC 61000-4-6) (level 3 IEC 61000-4-16)	30 V (150 kHz to 230 MHz) 250 mA (1 kHz to 150 kHz)
RF waves (TV& radio, broadcast, telecommunications, etc.)	RF radiated waves 80 MHz to 3 GHz (IEC 61000-4-3)	30 V / m

Figure 16

*Immunity to nuisance
tripping tests for
Schneider Electric SI
type RCDs*

A note on Type B+ RCDs

Type B+ RCDs are available on the German market and are designed to protect against fires caused by high frequency ground fault current. The frequency tripping curve of the type B+ 30mA is illustrated in **Figure 17**.

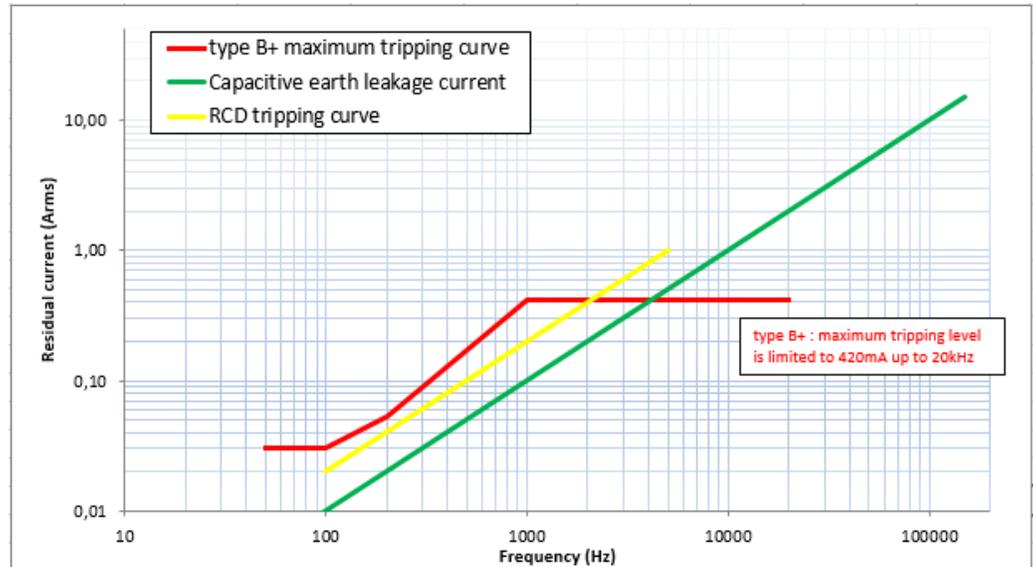


Figure 17

Tripping curve of RCD type B+

The frequency tripping curve of the Type B+ is more sensitive to high frequency capacitive earth leakage current, so these devices are not recommended for use when circuits are equipped with switching mode converters or in situations where unwanted tripping needs to be avoided.

The high frequency leakage current results from either stray or EMC filter capacitors under normal working conditions. Capacitive leakage currents are not dangerous and cannot generate any electrical fire. In the case of a ground fault, the earth leakage current will not be of a single frequency but will be composed of different frequencies (mainly network frequencies and high frequencies linked to switching mode equipment in the circuit). Such a composite fault scenario is interpreted as a Type F RCD by the IEC 62423 standard. Since standard Type B RCDs complies with the requirements of the Type F RCD, the ground fault situation for fire protection is generally covered without having to resort to a Type B+ RCD.

Application examples

Illustrated below are three examples of environments where Type B RCDs are appropriate to implement:

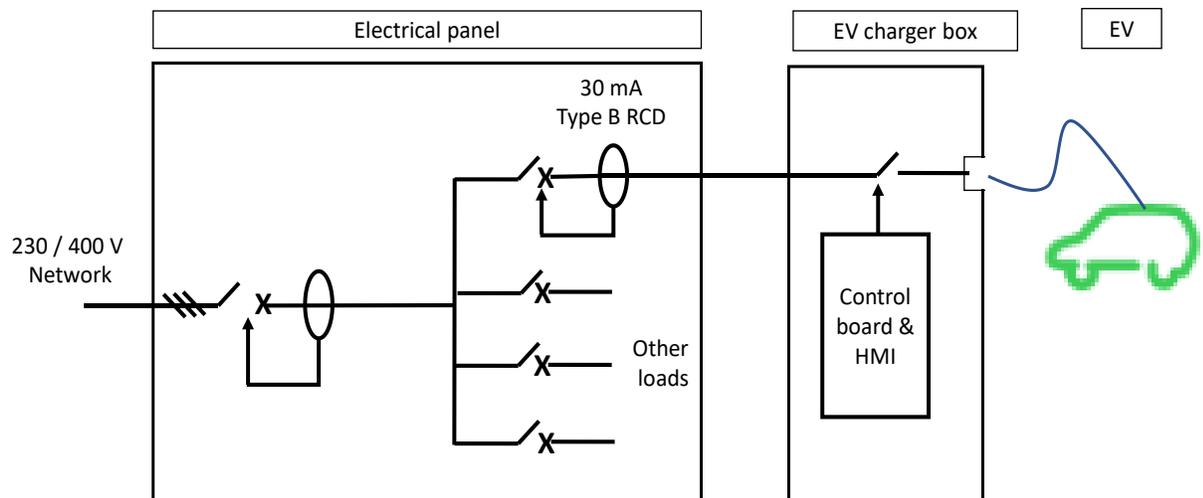
- Electric vehicle (EV) chargers** - Within an electrical vehicle, the AC/DC conversion process ensures that charging of the electrical vehicle occurs within the confines of the electrical vehicle itself. Electrical vehicle manufacturers state that, in the case of a 3-phase charger, DC current leakage can occur. The same phenomenon is replicated in the case of a single-phase charger with boost stage.

The electrical vehicle cannot be fully isolated and therefore a proper protection against DC residual current is needed in the system. The protection can be accomplished either with a 6mA detection device (Residual direct current detecting device, RDC-DD) inside the charger or with a Type B RCD either inside the panel board or inside the charger itself.

The Type B RCD ensures better continuity of service and protection because it will detect DC current and its tripping value is much higher than 6mA DC. The IEC 62643 requires that RCD trips for DC residual current not greater than 60mA. This value is lower than the ventricular fibrillation threshold in DC. Type B RCD will also detect earth leakage current at frequencies higher than 50/60Hz which is not the case with a 6mA RDC-DD.

Figure 18

Example of EV charger box protected by 30mA Type B RCD



- Photovoltaic systems** - In the case of a 3-phase photovoltaic application, DC/AC converters are present. Therefore, a Type B RCD is recommended to protect people against electrocution in case of use of an inverter (unless it is doubly isolated).
- 3-phase drives** – When a 3P+N drive is used, there is a risk of creation of earth leakage at various frequencies, including DC. Therefore, a Type B RCD can provide protection. For example, a crane that is powered on, via a mobile panelboard, needs the protection of a 30mA Type B RCD. As a second example, an elevator, if there is no risk of direct contact between the user inside and the lift machinery electrical system, will need a 300mA Type B RCD for the protection of the lift against indirect contact.

[See example on following page of installation of a lift \(elevator\) in TT network](#)

Figure 19

Example of elevator in TT network

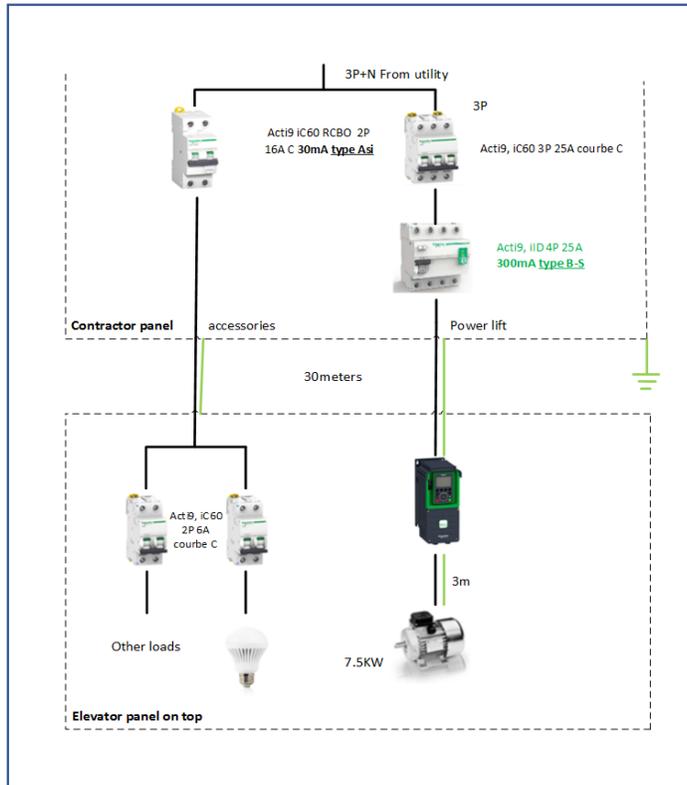


Figure 20

Relevant standards as they apply to RCD applications

	Application	International standard
	Electrical vehicule	IEC60364-7-722: RCD B type 30mA or RCD A type 30mA + 6mA DC detection
	Photovoltaic systems	IEC60364-7-712: RCD B type unless the invertor provides isolation between AC and DC side
	Power drives (ex: cranes, lift, HVAC, manufacturing line)	IEC61800-5-1 IEC 62477-1 RCD B type if power drive may create DC residual current
	Hospitals	IEC 60364- 7-710: RCD B type shall be used if the fault current could contain DC residual current
	Secured network/UPS	IEC 62040-1: RCD B type for 3 phases UPS

Coordination and selectivity

Selective-tripping coordination is achieved either by time-delay or by a subdivision of circuits. Such approaches avoid the tripping of any RCD, other than the device immediately upstream of a fault position.

The general specification for achieving total selective tripping coordination between two RCDs is as follows:

- The ratio between the rated residual operating currents must be greater than or equal to 3
- Time delaying of the upstream RCD

For RCDs with rated residual current strictly higher than 30 mA, the RCD standards define a selective RCD, also known as type S. Such devices are delayed and are able to withstand a residual current during a specified time, without tripping. Type S residual current devices are able to withstand 2 times $I_{\Delta n}$ for a period of 60 ms without tripping.

Discrimination is achieved by exploiting the several levels of standardized sensitivity: 30 mA, 100 mA, 300 mA and 1 A and the corresponding tripping times, as illustrated in **Figure 21**.

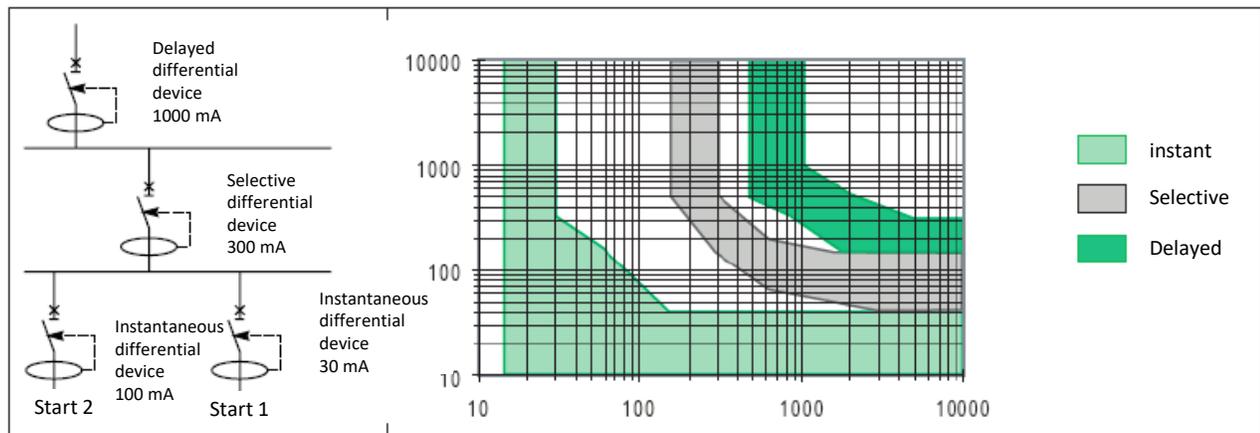


Figure 21

Architecture of installation with selectivity between RCDs

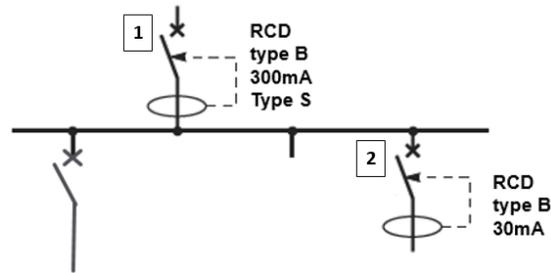
Coordination of Type A and B RCDs

When there is a possible DC residual fault current, a Type B RCD shall be used for protection against electric shocks. In this case, when any residual fault current occurs in any other part of circuits, the upstream RCD should not be blinded by the DC residual current and should ensure its normal protection function.

For example, in the circuit of **Figure 22**, the 30mA Type B RCD at level 2 could have a maximum DC tripping threshold of $2 \cdot I_{dn}$, according to RCD product standard IEC 62423. Therefore, the 30mA Type B RCD B could let pass through almost 60mA of DC residual current without tripping and the upstream RCD would not lose any of its performance despite the presence of this high level of DC residual current. That's why it's sometimes recommended that a Type B RCD be used at level 1 to avoid any blinding effect by DC current, as shown in **Figure 22**.

Figure 22

Coordination between
Type B RCDs

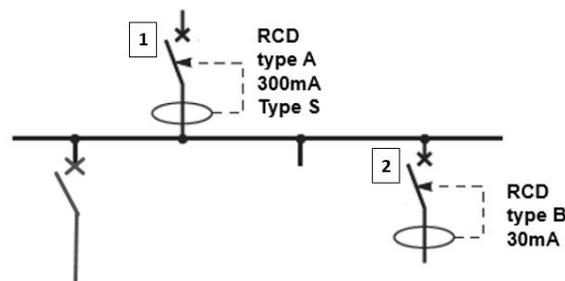


Regarding Type A RCDs, the Schneider Electric models with sensitivity above or equal to 300mA are qualified to be immune to DC residual current up to a level of 60mA. It is the case of Acti9 iLD Acti9 Vigi, NG125 Vigi and NSXm. See catalog pages for more information.

Figure 23 illustrates that Schneider Electric 300mA type A RCDs can be used upstream a 30mA Type B RCD without risk of blinding: Type A protection of the device is guaranteed even in case of a 60mA smooth DC residual current. If the smooth DC residual current reaches the value of 60mA, the 30mA type B RCD will trip.

Figure 23

Coordination between
Type A and Type B
RCDs



Conclusion

Residual current or earth leakage current refers to the fault current from an electrical installation to the ground. When the fault current passes through a person, it will result in injury, burns, shock or electrocution. A Residual Current Device (RCD) is used to detect these currents and disconnect the circuit from the source automatically when the values of these residual currents exceed the pre-defined limits.

Depending on the nature of the loads to be protected, the residual current may be pure alternating AC current at 50/60Hz or more complex waveforms with a combination of frequencies and even DC current. The proper functioning of the RCD is ensured only if the type of RCD is matched to the type of residual current expected. Selection of the proper RCD type must be based on knowledge of the nature of residual currents that can be present in the AC circuit.

As modern electrical installations have grown more sophisticated and complex, and as new applications such as 3-phase variable speed drives, electric vehicles, and photovoltaic gain a mainstream presence, the importance of Type B RCDs has increased significantly. Type B RCDs provide good levels of protection to assure both human safety and system availability in modern electrical installations.



About the authors

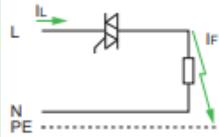
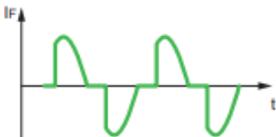
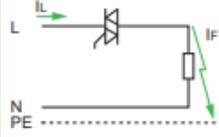
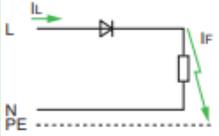
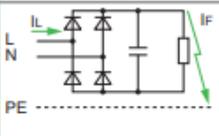
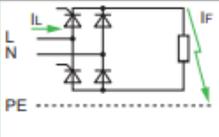
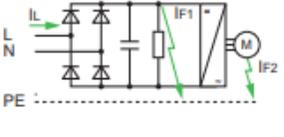
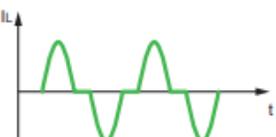
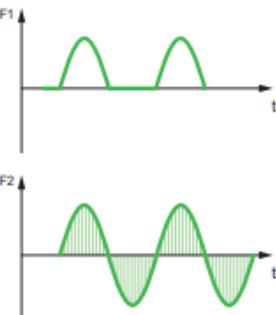
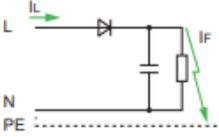
Natacha Lucius holds an engineering diploma from ENSTA (Ecole Nationale Supérieure des Techniques Avancées in Paris). She has been working 12 years for Schneider Electric in R&D and project management. She is currently offer manager for Residual Current Devices. She drives solutions to improve the safety of electrical devices and also takes a lead in educating customers on potential electrical dangers and possible solution to promote safety.

Marc Paupert holds an electrical engineering diploma from INSA Lyon (Institut National des sciences Appliquées). He has worked at Schneider Electric for more than 25 years in R&D for earth-leakage protection design and specification for applications. He is a senior expert about people protection against electric shock. He is involved in IEC standardization, focusing on the physiological effects of current for RCD specifications and installation rules evolutions.

Jean-François Rey holds an engineering diploma from ENSAM (Ecole National Supérieure d'Arts et Métiers) and from SUPELEC (Ecole Supérieure d'Electricité). After 20 years in Research and Development for Electrotechnical Devices, including design, laboratory, and project management, he is a Standardization Manager and involved in IEC and CENELEC standardization bodies, focusing on product standards and installation standards.

Simon Tian holds a Ph.D. in Electrical Engineering from Ecole Normale Supérieur de Cachan, France. He has worked at Schneider Electric for more than 25 years in R&D for advanced power protection including earth-leakage protection, arc fault protection and connected monitoring/control devices. He's presently Senior Offer Architect for final distribution protection devices.

Appendix A: Possible fault current in electronic loads and suitable RCD types

	Circuit diagram with fault location	Shape of line current I_L	Shape of earth fault current I_f	RCD tripping characteristic
1	Phase control 			AC, A, F, B
2	Burst control 			AC, A, F, B
3	Single-phase 			A, F, B
4	Two-pulse bridge 			A, F, B
5	Two-pulse bridge, half controlled 			A, F, B
6	Frequency inverter with two-pulse bridge 			F, B
7	Single-phase with smoothing 			B

8	<p>Frequency inverter with two-pulse bridge and PFC</p>				B
9	<p>Two-pulse bridge between phases</p>				B
10	<p>Frequency inverter with two-pulse bridge between phases</p>				B
11	<p>Three-phase star</p>				B
13	<p>Frequency inverter with six-pulse bridge</p>				B

Appendix B: Reference Standards

A number of standards either directly or indirectly impact the selection, installation and maintenance of RCD devices. Below is a summary of relevant applicable standards:

IEC 60755:2017 ed 1.0 (Group Safety Publication) - A general standard defining all types of RCD that also addresses general safety requirements. This standard cannot be used for certification purposes.

IEC 62423:2009 ed 2.0 – Addresses Type B RCDs for household and similar applications. This standard defines the requirements, identification criteria (via markings) and testing procedures for Type B Residual Current Circuit Breakers (RCCBs) and Residual Current Circuit Breaker with Overcurrent Protection (RCBOs). This standard is viable for certification purposes.

Note: IEC 62423 requires that the RCD shall first comply to IEC 61008-1 (for RCCBs) and/or IEC 61009-1 (for RCBOs) in order to address AC type and A type faults.

IEC 61543 - Addresses electromagnetic compatibility (EMC) tests pertaining to immunity and emissions and represents the EMC general standard for RCDs.

Appendix C: Glossary

RCD: residual current devices

RCCB: residual current circuit breaker, also known as ID

RCBO: residual current circuit breaker with overcurrent protection combining an MCB and a RCCB in one device