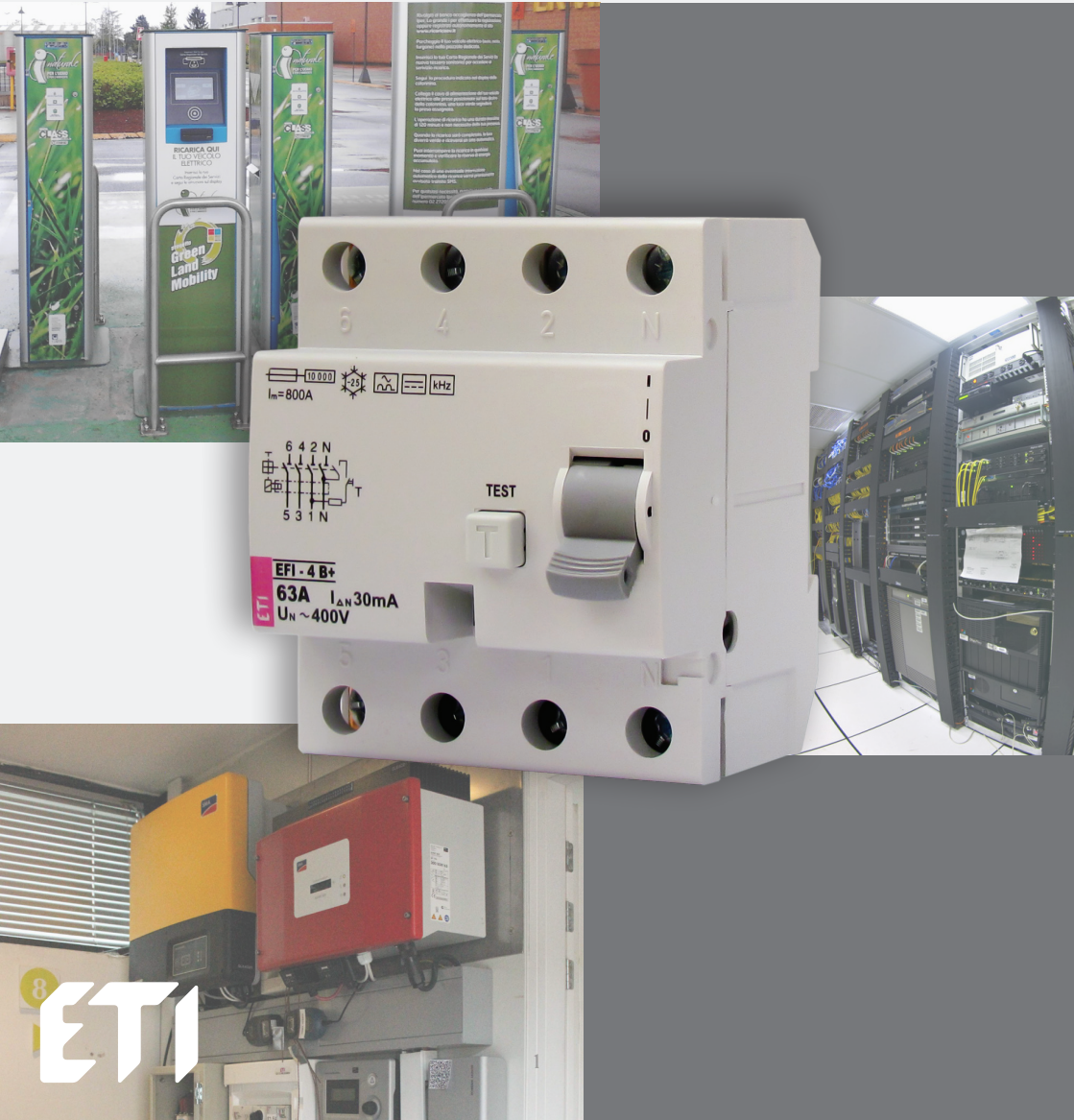


Residual Current Circuit Breakers Manual



8
ETI

Residual Current Circuit Breakers

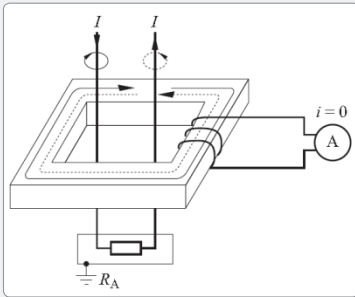
Introduction

Since security is becoming more and more important due to better protection for humans, animals and higher fire safety, additional protection is being constantly developed and improved. This is where the Residual Current Circuit Breakers RCCBs come in.

Use of RCCBs is recommended where an increased risk of electrical shocks can appear (bathrooms, other humid and wet rooms, children's rooms, workshops...). Protective residual current circuit breakers can be used in all systems, electrical installations, where neutral conductor (N conductor) and earth conductor (PE conductor) are separated. In old installations, in certain countries, where neutralization is still used, wherein the N and PE conductors are joined, such protection switch cannot be used.

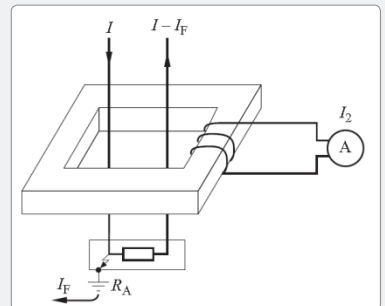
Residual current devices are a commonly established way of protection against indirect contact with live parts, fires and direct contact with live parts in different types of installations. Performance is primarily related to grounding systems known as TT, TN and IT systems.

Operating principle of RCCB switches



In the case when the sum of incoming and outgoing currents through the primary winding is equal to 0, on the secondary side of the transformer the current will not be induced and the device will not switch off.

In the case, when the sum of incoming and outgoing currents through the primary winding is not equal to 0 and varies for the value of fault current I_F , current I_2 is induced on the secondary winding and it triggers the RCCB through the relay.



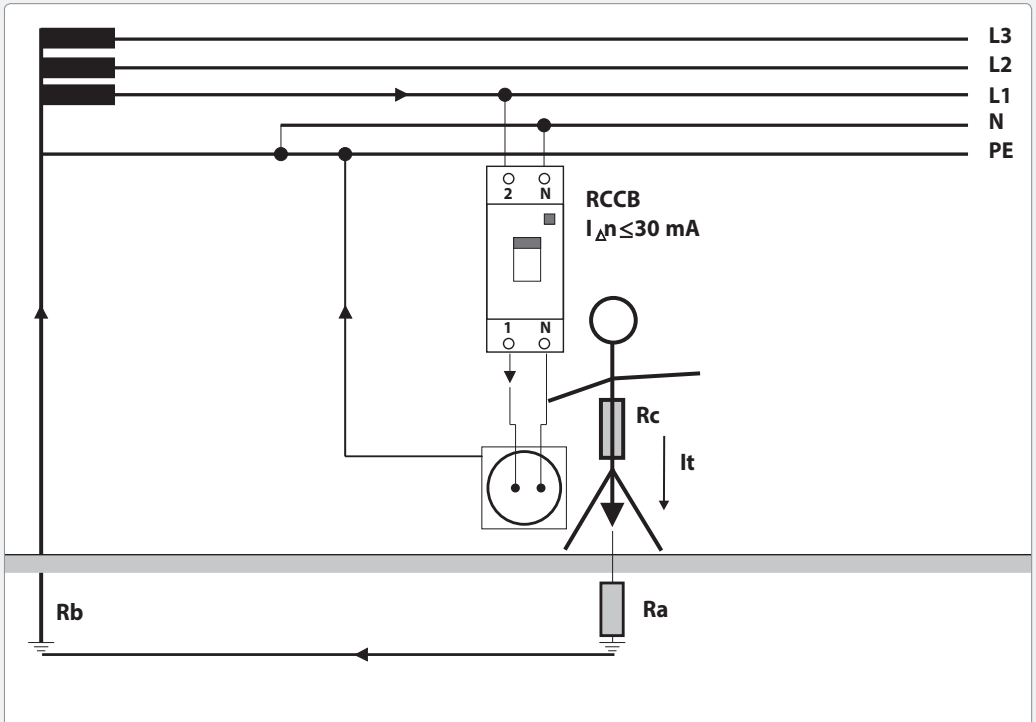
According to the sensitivity, there are three types of RCCBs for different protection as follows:

- ✎ $\leq 30\text{mA}$: Protection against direct contact with live parts - “additional protection”
- ✎ $\leq 100\text{mA}$: Protection against indirect contact with live parts - “basic protection”
- ✎ $\leq 300\text{mA}$: fire protection

Technical requirements for residual current circuit breakers are prescribed in international standard IEC 61008 and European standard EN 61008. Main criteria for selection are as follows:

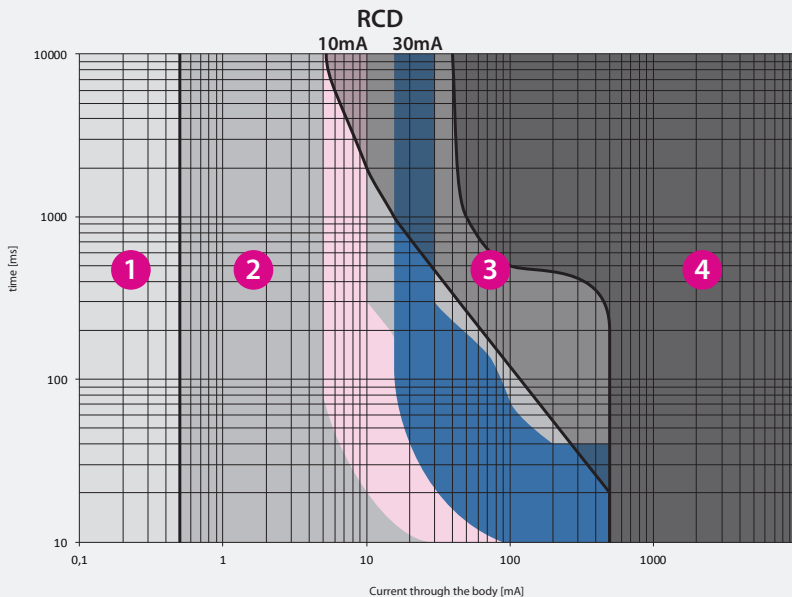
- ✎ Number of poles: 4 -pole , 2-pole
- ✎ Rated current : 16A , 25A , 40A , 63A , 80A , 100A , 125A
- ✎ Rated Residual Current: 10 mA , 30 mA , 100mA , 300mA , 500mA ,
- ✎ Breaking times: instantaneous, short-time delayed , selective
- ✎ Type of residual current:
 - pure sinus residual current, 50/60Hz: AC type
 - pure sinus and pulsating direct residual current, 50/60Hz: A type

Protection against direct contact with live parts - “additional protection”



Direct contact occurs when a human body directly touches live parts. If we assume that the resistance of human body is approximately $1\text{ k}\Omega$, which of course depends on conductivity of human skin, then if we touch voltage of 230V , 230mA of current flows through our body. Such a current can already be life-threatening.

Influence of the current on human body:



1: Area where influence is imperceptible

2: Area where there is no detectable adverse effects and muscle contraction

3: Area where muscle contraction can be detected, but there is no danger to the heart

4: Where you start having heart problems.

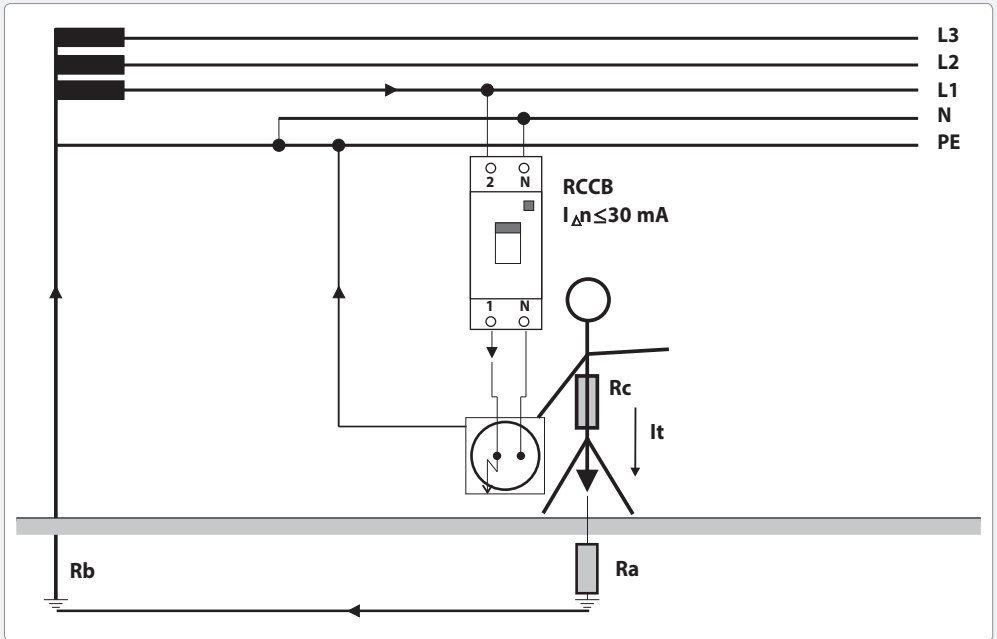
As you can see all RCCBs with rated residual current equal or less than 10mA are under the limit where influences on human body can occur. Because of that, they are especially suitable for use in bathrooms, children rooms, schools, hospitals, kindergartens...

RCCBs with residual current equal or less than 30mA are used for additional protection against electrical impacts.

Protection against indirect contact with live parts - “basic protection”

Indirect contact occurs when a human body does not touch directly live parts, but it touches conductive parts. In this case the RCCB must disconnect the supply, when the fault can cause a risk to humans due to the size and duration of the residual current.

This category is represented by all RCCBs with rated residual current more than 30mA.







Fire protection

According to standard IEC 60364-4-482 or HD 60364.4.482 all electrical circuits in TN and TT systems must be protected with Residual Current Circuit Breakers with rated residual current of less than 300mA, except busbar systems.

Residual current circuit breakers - RCCBs

Residual current circuit breakers differ on types of sensing the residual current and tripping times.

Levels of tripping currents compared to rated residual current:

Type of residual current	Current wave-form	AC Type RCCB	A Type RCCB	B, B+ Type RCCB	Value of tripping current
Sinusoidal AC residual current		✓	✓	✓	$0,5 \dots 1,0 I_{\Delta n}$
Pulsating DC residual current		✗	✓	✓	$0,35 \dots 1,4 I_{\Delta n}$
Delay angle	90°	✗	✓	✓	$0,25 \dots 1,4 I_{\Delta n}$
	135°	✗	✓	✓	$0,11 \dots 1,4 I_{\Delta n}$
Pulsating DC residual current + smooth DC residual current of value 6mA		✗	✓	✓	$\max 1,4 I_{\Delta n} + 6\text{mA}$
Smooth DC residual current		✗	✗	✓	$0,5 \dots 2,0 I_{\Delta n}$

Above table shows data about levels of tripping currents compared with rated residual current and in relation with different types of RCCBs. It is clearly seen that B and B+ types operate in all possible forms of fault currents.

All conductive parts of protected equipment must be grounded. According to touch voltage U_L and rated residual current $I_{\Delta n}$ there can be maximum values of earthing resistance as follows:

UL	$R_{E \max}$								A
	50 V ~				25 V ~				
$I_{\Delta n}$	0,03	0,1	0,3	0,5	0,03	0,1	0,3	0,5	
$R_{E \max}$	1660	500	166	100	830	250	83	50	Ω




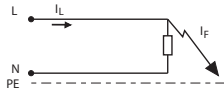
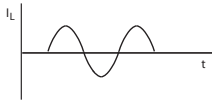
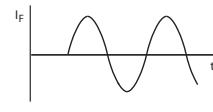
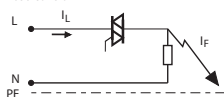
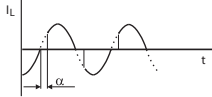
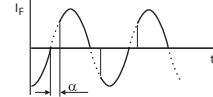
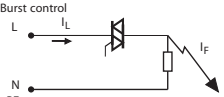
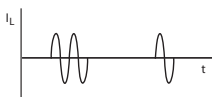
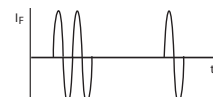
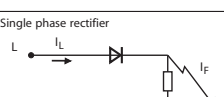
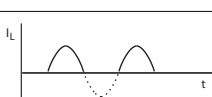
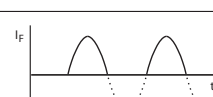
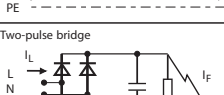

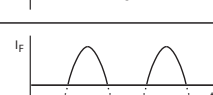
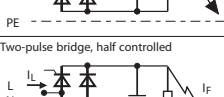
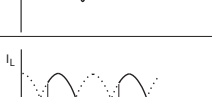

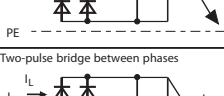
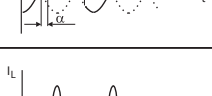
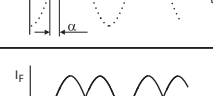
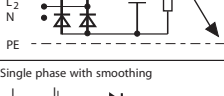


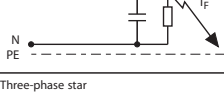
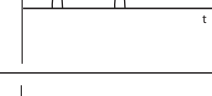
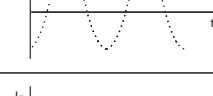
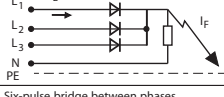
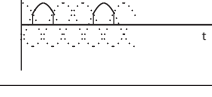
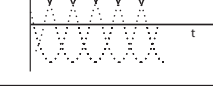
Tripping time must be shorter than 40ms.

Types of RCCB according to the form of residual current

According to the fact, that there can appear different forms of residual currents in the circuits, depends what kind of rectifier circuit is used, it is necessary to select a proper type of the RCCB.

Overview of possible errors in the rectifier circuit and appropriateness of the selected RCCB.

AC A B, B+

	Connection	Normal mains current	Fault earth current			
1	Single phase 			✓	✓	✓
2	Phase control 			✓	✓	✓
3	Burst control 			✓	✓	✓
4	Single phase rectifier 				✓	✓
5	Two-pulse bridge 				✓	✓
6	Two-pulse bridge, half controlled 				✓	✓
7	Two-pulse bridge between phases 				✓	✓
8	Single phase with smoothing 					✓
9	Three-phase star 					✓
10	Six-pulse bridge between phases 					✓

Selection of the Correct Type of RCCB

Simple household installations without electronic components

Household installations with electronic components (LCD TV, computers, printers, wash machines, ...)

Surge current proof 3kA (8/20 μ s).
High immunity against unwanted tripping
For S: ensuring selectivity in case of serially connected RCD's



AC type - Instantaneous

$I_n = 25, 40, 63, 80 \text{ \& } 100\text{A}$
 $I_{\Delta n} = 30, 100, 300, 500\text{mA}$
2p & 4p

A type - Instantaneous

$I_n = 25, 40, 63, 80 \text{ \& } 100\text{A}$
 $I_{\Delta n} = 30, 100, 300, 500\text{mA}$
2p & 4p

A type – K/G (short-time delay) & S (selective)

$I_n = 25, 40, 63, 80 \text{ \& } 100\text{A}$
 $I_{\Delta n} = 30, 100, 300\text{mA}$ for K and $I_{\Delta n} = 100, 300\text{mA}$ for S
2p & 4p

K/G – short time delay: time delayed min. 10ms and max. 40ms

S – selective: time delayed min. 40ms and max. 150ms

B type – Instantaneous (Tripping values are defined up to 1 kHz)

$I_n = 25, 40, 63\text{A}$
 $I_{\Delta n} = 30, 100, 300 \text{ mA}$
4p

B type – K/G (short-time delay) & S (selective)

$I_n = 25, 40, 63\text{A}$
 $I_{\Delta n} = 30, 100, 300\text{mA}$ for K and $I_{\Delta n} = 100, 300\text{mA}$ for S
4p

K/G – short time delay: time delayed min. 10ms and max. 40ms

S – selective: time delayed min. 40ms and max. 150ms

B+ type – Instantaneous (Tripping values are defined up to 20kHz and they

$I_n = 25, 40, 63\text{A}$
 $I_{\Delta n} = 30, 100, 300 \text{ mA}$
4p



Installations where 3f frequency converters and speed regulated machines are used (elevators, cranes...). PV systems on a.c. side, Charging stations for electric vehicles, UPS, computer data centres, X-ray devices...

Surge current proof 3kA (8/20µs) High immunity against unwanted tripping For S: ensuring selectivity in case of serially connected RCD's

Requirement for increased fire protection according to VDE 0664-400



Computer data centres

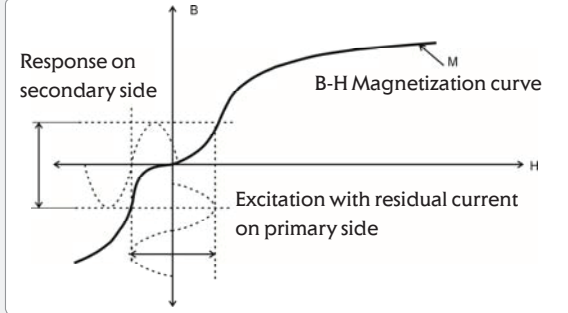


are below 420mA) according to VDE 0664-400

AC type

Residual current circuit breakers sensitive only to pure sinus signals are the most basic ones.

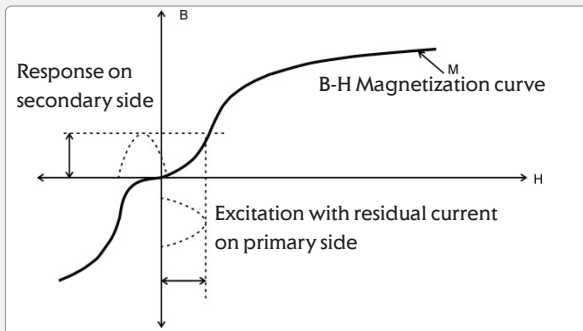
Operation mode of AC-type residual transformer:



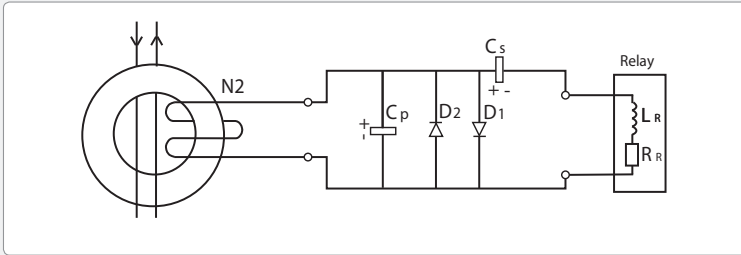
Above is shown a B-H magnetization curve of residual transformer. Magnetic field strength depends on excitation with residual current. Inside the core of the transformer appears a magnetic flux B , in accordance with the shape of B-H curve. Because of the height of magnetic flux, voltage is induced on secondary side which generates a switching current in switching relay.

A type

Operation mode when residual current appears as a result of half-wave oriented current:



As you can see, the response on secondary side is two times smaller, which means that we have to increase this signal in some way. This can be achieved with a special circuit on the secondary side of transformer, which is shown on the next page.



Electronic circuit is tuned to such a frequency to obtain the maximum mode of operation and the highest efficiency of the output signal on the secondary side of the transformer and thus an optimal operation of the tripping relay at the rated frequency. In general we can say that A type RCCB works perfectly for sinusoidal and pulsating DC residual currents for frequencies of 50Hz and up to the third harmonic frequency, while at higher frequencies up to 1 kHz and above, the sensitivity of the A type protection switch is falling.

At this point we should mention that functionality of RCCBs AC and A type is known as “voltage independent”, so they do not require a power supply for their functionality. To put it even more simply, in case of disconnection of the neutral conductor, RCCB still works properly and in accordance with all its prescribed technical specifications. This is particularly important for protection against indirect contact, ie. in providing “general” protection.

In conjunction with the international product standard for RCCBs the situation is as follows :

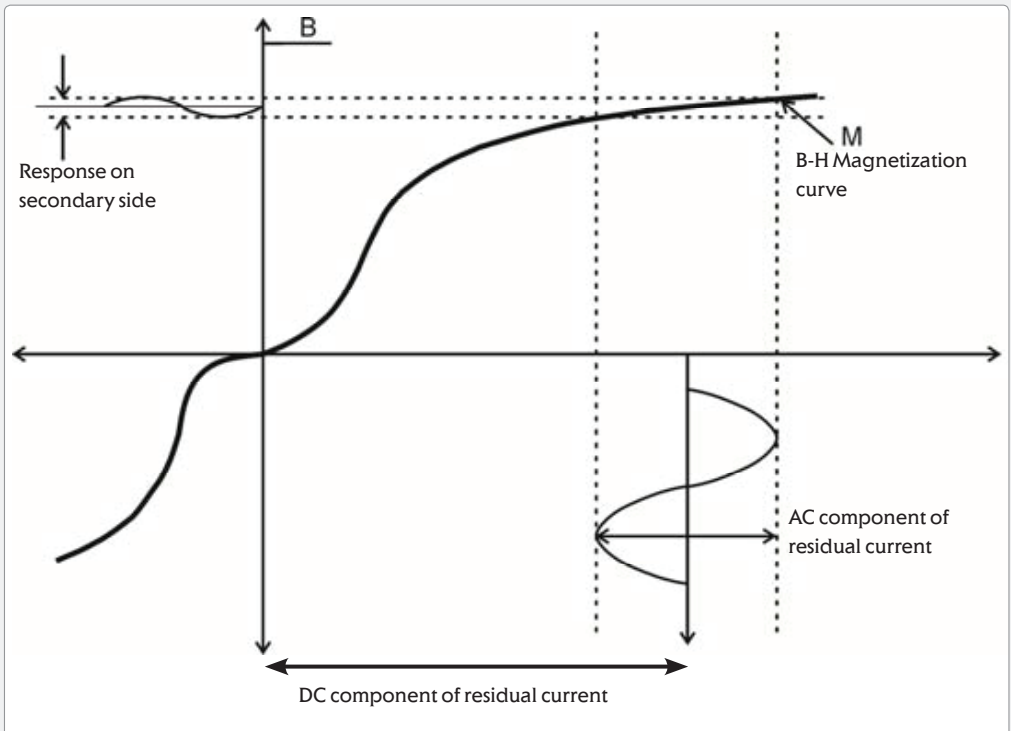
- ✦ IEC 61008, A and AC type are included, in addition to voltage-independent RCCB's are included also voltage-dependent RCCB's
- ✦ EN 61008, A and AC types are included as for IEC, voltage-dependent RCCB's are not included

The actual market situation shows that almost all RCCBs within the European Union as well as elsewhere in the world are voltage independent, therefore these switches do not use active electronic circuits that require power supply for their operation.

B type

B or B + type RCCBs are an upgrade of A type RCCBs, that also work in the event of the occurrence of pure DC component of residual current. This can occur especially in the case of use of variety conventional rectifiers, another option are inverters, such as a photovoltaic power plants, furthermore, in the case of frequency converters for speed regulation of asynchronous electric motors, and much more and more. In short, already in household appliances nowadays there are electronic controls, which in addition to pulsating DC currents, in case of errors can cause quite smooth DC component of the electric current. This phenomenon is even more common in recent times in the case of small photovoltaic plants on the roofs of family houses, which are increasingly used PV technology for their own use. Inverters in PV systems are usually without isolating transformers and in the case of faults in the electronic circuit occurrence of DC component of the current very much possible.

What happens in conventional AC or A type of protective residual current circuit breaker in the event of the occurrence of a direct current:

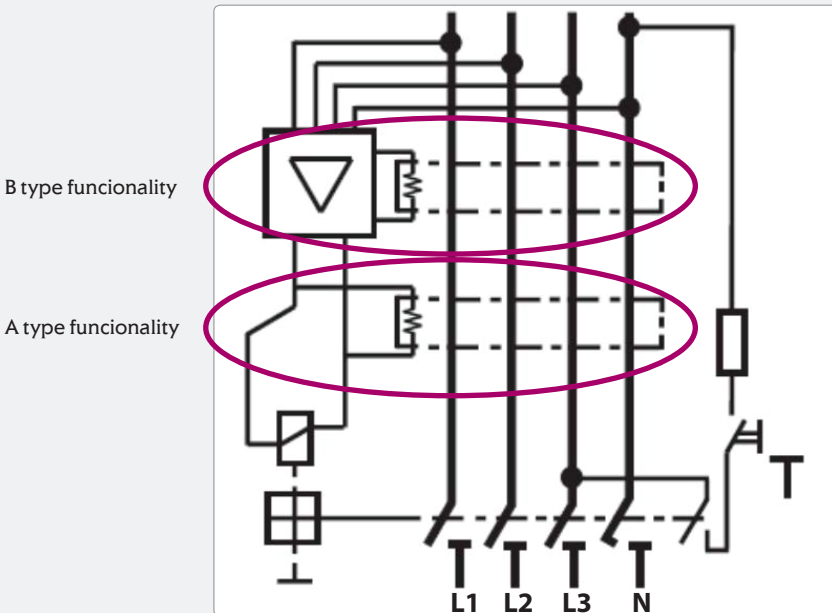


It is clear that the residual transformer does even not detect pure DC current, so therefore AC or A type of protective switch is not sensitive on smooth DC residual currents. An even greater problem is shown in figure on the previous page, which shows the situation in the case of the occurrence of a residual AC current, which is superposed on a smooth component of DC current. In this case, the core of the residual transformer goes in saturation, although if adequate size of AC components of the residual current is a response on the secondary side too small to cause actuation trigger of the relay. So, in the case of saturation of the core due to DC current, the switch does not operate even in an alternating regimen. In this case we use the term that the switch is “blinded”.

The problem of “blindness” of AC and A type of switch is already partly being recognized in the applicable standard 61008 in such a way, that it is intended to test with DC current of value 6mA at which the switch must still work properly. However, this test does not solve the problem at higher values of DC currents.

The only solution for this problem is the use of B or B+ type of protective switches. Additionally, it should be explained that, in addition to the DC sensitivity, B and B+ type also cover sensitivity at higher frequencies up to 1 kHz and more.

At first glance, the B type of RCCB does not differ from AC or A-type, but look into the product reveals the essence of the technical differences between A or AC and B type. The basic idea lies in the fact that B type must meet all the characteristics of A type according to standard 61008. Because of this, basic structure comes from the A type. In B type is additional current transformer and a complex PCB, which provides a sensitivity to the smooth DC residual current. Below is a schematic view of an electrical circuit inside the RCCB.



As mentioned above, the operation for A type is carried out as in classical A type RCCB and it is, in addition to other technical characteristics according to standard 61008, voltage independent. Operation of the B type regime, at smooth DC currents and at higher frequencies, up to 1kHz, is provided with an additional current transformer, as shown on the previous page. There are also visible connections between the PCB for B type and the individual phase conductors. Those connections are used for power supply for PCB. Commercially acceptable variants are those which provide functionality of B type at minimum phase voltage of 50V. In general, in case of a complete power failure, B type RCCB must still act as A type RCCB.

Standards:

- ✎ IEC / EN 61008-1 basic standard for AC and A type RCCB
- ✎ IEC / EN 62423 additional requirements for B type (up to 1 kHz)

B+ type   

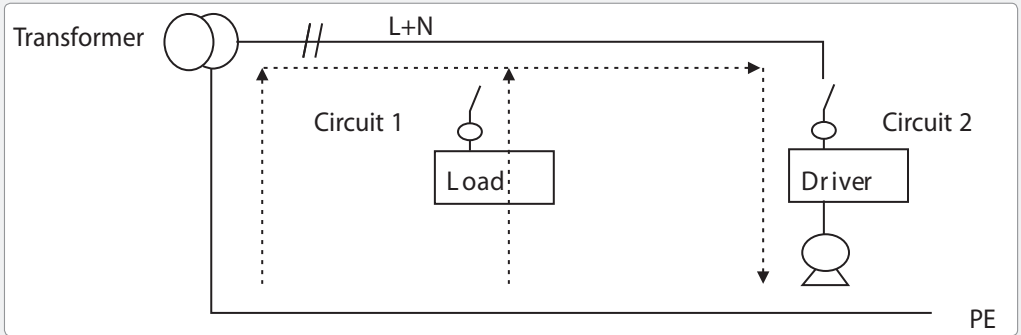
Similar to B type RCCB the B+ type RCCB also completely conforms with standard 61008. Unlike the basic B type, B+ type works at frequencies up to 20kHz, where the tripping value should always be lower than 420 mA.

Standards:

- ✎ IEC/EN 61008-1 basic standard for AC RCCB type A and type
- ✎ IEC / EN 62423 additional requirements for B type (up to 1 kHz)
- ✎ VDE 0664-400 additional requirements under the German standard for B + type (up to 20kHz)

Function of RCCB at higher frequencies

The occurrence of high-frequency residual currents is expanding with increasing use of power electronics and frequency converters for motor drivers. It was discovered that high-frequency residual currents may also cause "blindness" or unwanted tripping of A or AC type of RCCB.



Above is a simple example of two circuits; circuit 1 includes a consumer that does not cause high-frequency interference and circuit 2 includes a frequency converter that can cause high-frequency interference. The capacitance between the users, cables and conductor PE causes high-frequency currents that are flowing through the conductor PE and are superposed with the supply current.

You may encounter two problems:

- ✖ In the circuit 1, the current may occur, that has superimposed components, of which levels, forms and frequencies are not determined. At fault such a current can cause either so-called "blindness" or unwanted tripping of the RCCB.
- ✖ In the circuit 2, in a normal situation (no faults) constant current through the conductor PE can occur, whose frequency, form and level are not known or defined. At fault, either on a motor, converter or filter, residual current occurs, which can have a significantly higher frequency. RCCB, which is built into such a circuit, must provide protection even at frequencies that are different from 50/60Hz
- ✖ In the circuit 2 a high frequency AC leakage current or smooth DC leakage current can occur as in example, shown in the table on page 7.

In the event that high frequency of residual currents or smooth DC residual currents are expected, due to the above described possible problems, the use of B or B + type of RCCB is required.

RCCB type according to tripping time

According to tripping time we divide RCCB's in 3 different types:

- ✗ instantaneous,
- ✗ short time delayed,
- ✗ selective.

Table below shows the differences in tripping times for those 3 types

Value of residual current	RCCB type	Tripping time t_a
$I_{\Delta n}$	Instantaneous	$t_a \leq 300\text{ms}$
	Short time delayed - K	$10\text{ms} \leq t_a \leq 300\text{ms}$
	Selective - S	$130\text{ms} \leq t_a \leq 500\text{ms}$
$2 \times I_{\Delta n}$	Instantaneous	$t_a \leq 150\text{ms}$
	Short time delayed - K	$10\text{ms} \leq t_a \leq 150\text{ms}$
	Selective - S	$60\text{ms} \leq t_a \leq 200\text{ms}$
$5 \times I_{\Delta n}$	Instantaneous	$t_a \leq 40\text{ms}$
	Short time delayed - K	$10\text{ms} \leq t_a \leq 40\text{ms}$
	Selective - S	$50\text{ms} \leq t_a \leq 150\text{ms}$

Instantaneous type

In some countries this type is also known as the general type. As the name says, this RCCB trips simultaneously with the appearance of residual current. As a result unwanted tripping can appear in the case of storms, the transient response of switching maneuvers... This type corresponds with standards IEC 61008-1 and EN 61008-1.

Short time delayed type – K type

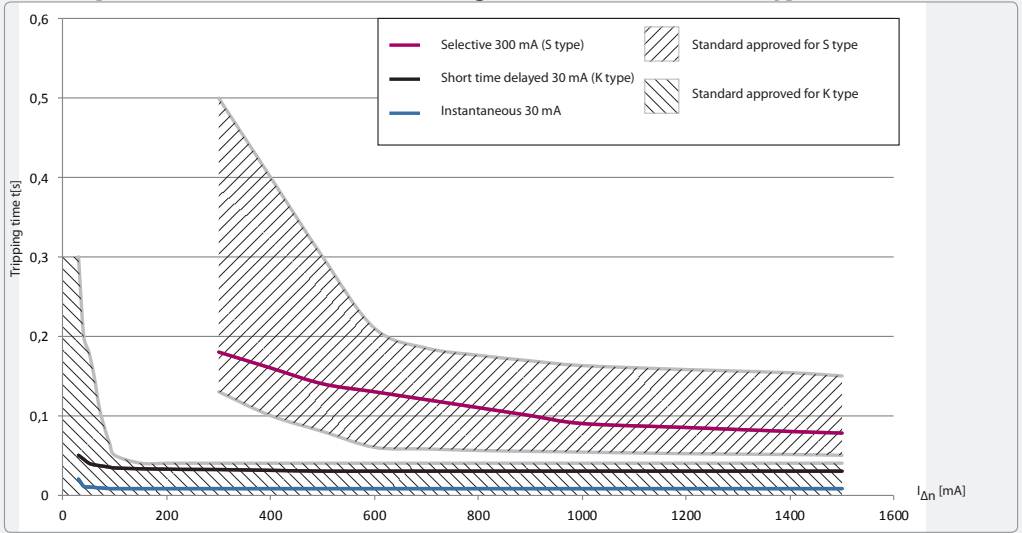
If we want to avoid unwanted tripping when residual current occurs, we must use short time delayed type RCCB named K-type, which is sometimes also called high immune or super resistant RCCB. As type K is not specifically described in the standard 61008-1, this RCCB falls under instantaneous type according to that standard.

Selective type – S type

In order to achieve selective disconnection in the case of more RCCBs connected in series, there must be an S-type RCCB installed at the beginning of the installation. This RCCB type has a prescribed tripping delay in such a value, that all instantaneous RCCBs trip before it does.

Selective residual current circuit breakers are also more resistant to surge currents (8/20), whereby the value by the standard 61008 should not be less than 3kA.

Time dependence of the size of the leakage current for the various types of RCCB:

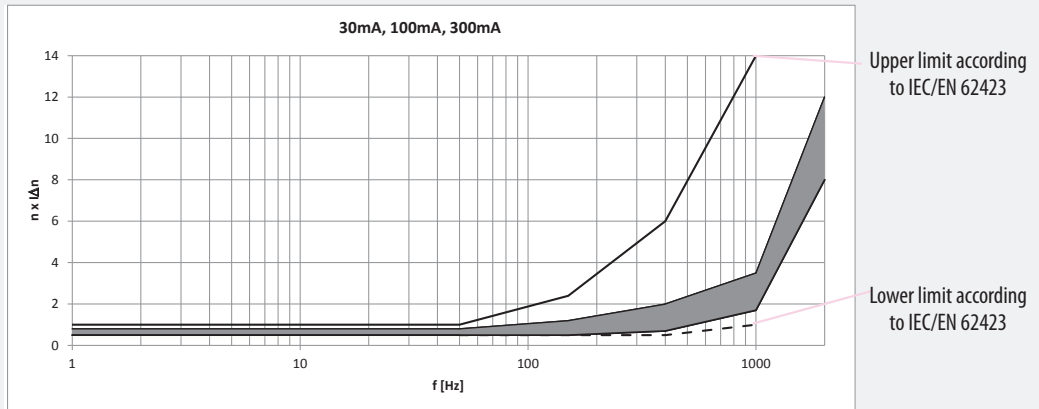


Tripping characteristics for B and B+ type of RCCB

Tripping characteristics of B and B+ type differ because the former is defined as a multiple of rated residual current as a function of frequency, and the latter is specified as maximum residual current at different frequencies and is independent of the rated residual current of RCCB.

Maximum frequency for B type, where the tripping values of residual current are still defined, is 1 kHz.

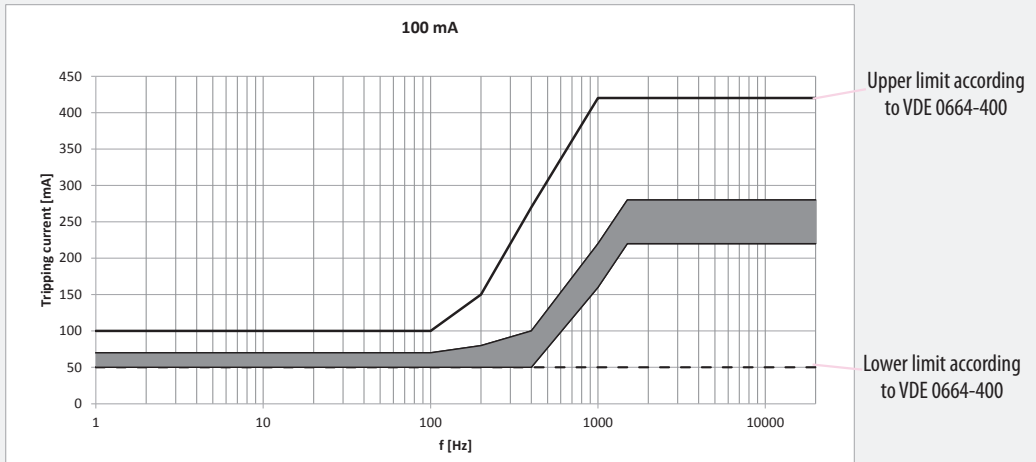
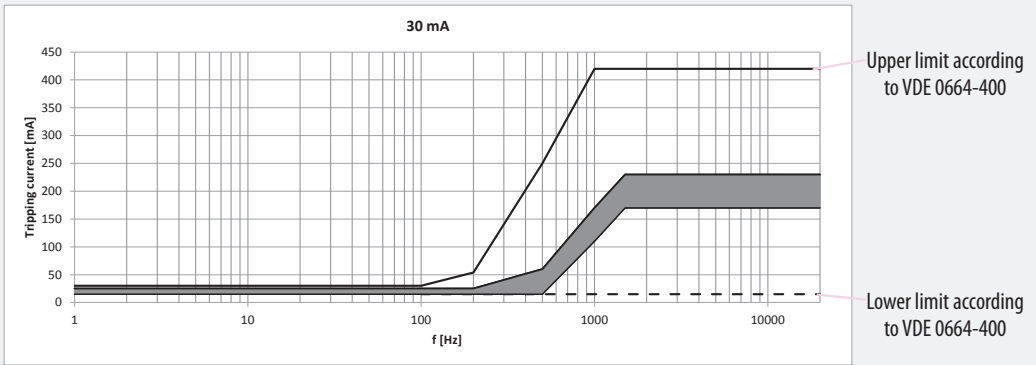
Tripping characteristic for B type RCCB:

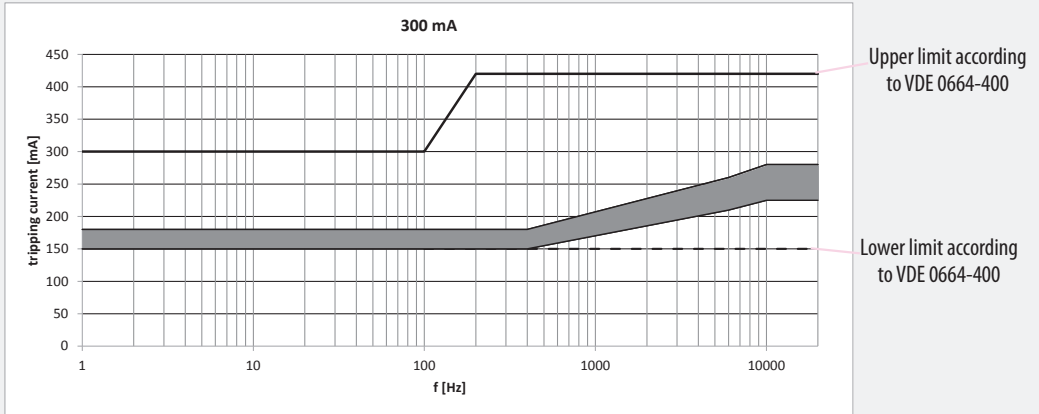


According to IEC / EN 62423 the specified tripping area at frequency of 50 Hz is between 0.5 times and 1 times of rated residual current. At the frequency of 1 kHz the tripping area is limited between 1 time and 14 times of rated residual current. As you can see, our B type achieves tripping current less than 14 times of rated residual current, even at a frequency of 2 kHz, which is shown by the shaded area in the graph.

B + type is made in accordance with VDE 0664-400. In this standard it is prescribed, that the tripping value, at any frequency, should be higher than 0.5 times of the rated residual current. The upper tripping value is limited to 420mA.

Current tripping value in dependence of the frequency of the residual current:



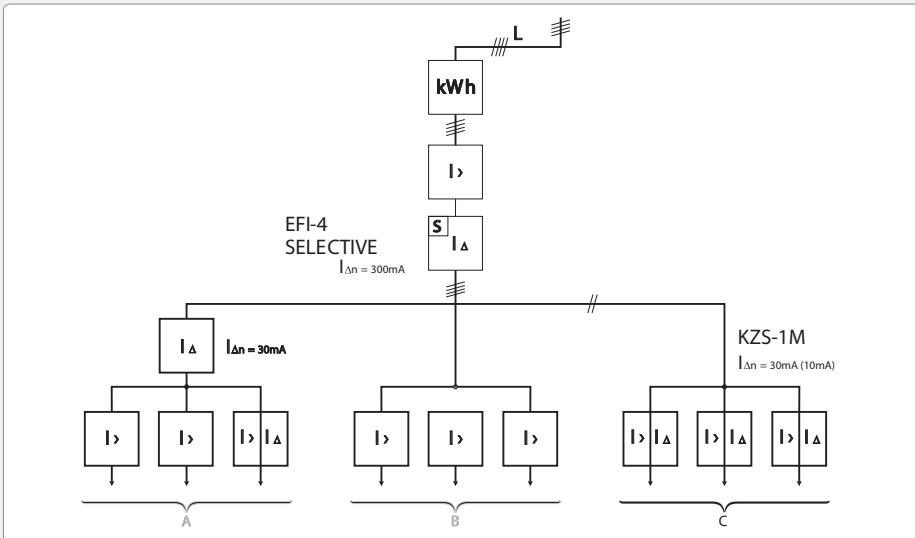


Applications to use RCCB

Use of RCCB in installations

Classic installation in residential and similar conditions includes installation of only one RCCB, positioned immediately after the main fuse. This RCCB provides only the main protection. The problem of such an installation is that, when an error occurs or in the case of occurrence of residual current on one of the lines, the entire installation will be without power. This is from the modern life perspective and the requirements for power availability inadmissible.

Today, modern installation requires the use of several different residual current devices, as shown below. Consumers in the installation are divided into several groups.



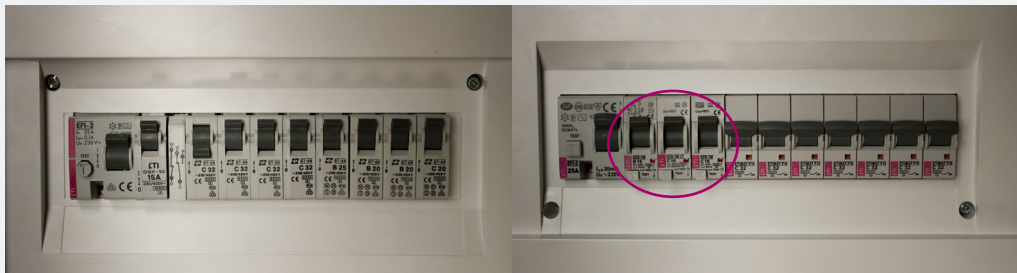
Group A: consumers who require a high degree of protection (30mA): kitchen, living room...

Group B: consumers, where the possibility of touching live parts is lower: lighting

Group C: consumers who require a high level of protection and the availability of electricity: children's rooms, bathrooms, home workshops... In this case each line requires additional protection of 30mA or even 10mA.

As we can see, the optimal choice is to place a selective type RCCB as the main RCCB and additionally protect all the individual lines either with RCCB or RCBO.

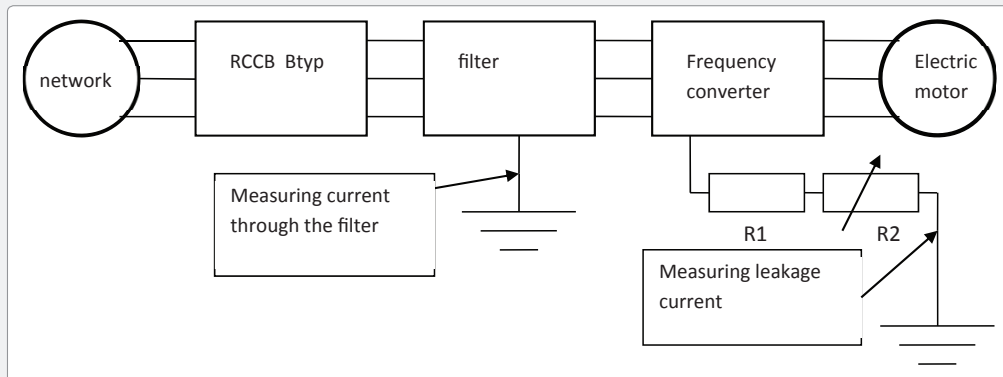
A classic example of renovation of an old distribution board:



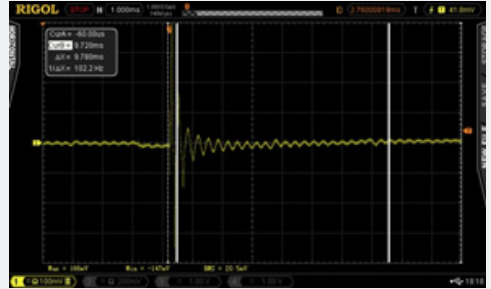
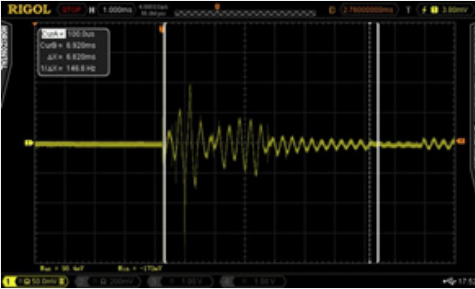
The left side shows an old distribution board, consisting of a classic RCCB with instantaneous tripping and 8 MCBs. On the right side the new type of distribution board is shown, which besides a selective RCCB includes additional protection, solved with 3 x KZS-1M (1M RCBO). This way we have improved our protection yet retained the same amount of space required.

Use of B type of RCCB

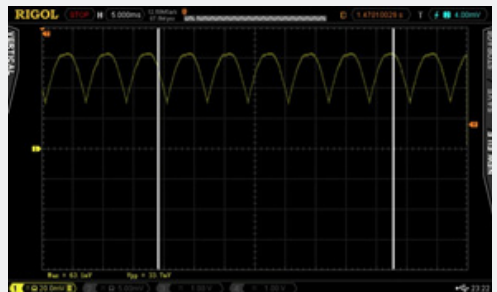
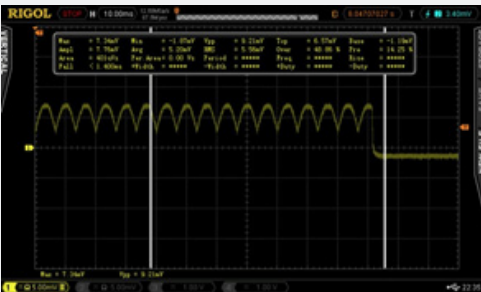
In this section, we will show the use of B-type residual current circuit breakers in connection with the inverter and asynchronous motor. Picture below the wiring schema with which was carried out a few measurements of the possible occurrence of leakage currents and residual currents with DC component.



The first set of measurements was carried out in order to measure the actual shape and value of the current through the grounded filter when you turn on the complete circuit. At turning on may occur, due to charging capacitors in the filter, to inrush current (or residual current), which could result in to the unwanted tripping of RCCB B-type. Pictures below show the actual measured residual current at the time of switching ON. There have been measured two measurements with different filters.



The second set of measurements was carried out on the basis of simulation of fault on the inverter. From his DC-link, we carried out a connection to earth through changing resistors and thus set the current fault. We measured the shape and the current value shown in the pictures below. It is very clear to see the DC component, on which is superposed AC current. This is exactly that residual current on which can react only B-type of RCCB.



Such and similar results will be obtained if we deal with other typical areas of application of B-type. These are, in addition to frequency converters, also: photovoltaic systems, charging stations for electric vehicles, in short, all systems containing converting AC to DC and back.

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