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Residual Current Protective Devices

BETA Low-Voltage Circuit Protection Technology Primer

Answers for industry.

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Foreword

Whether for protecting, switching, monitoring or measuring – BETA low-voltage circuit protection devices perform a wide range of functions for all applications in the area of electrical installation engineering. They are suitable for use in residential buildings, non-residential buildings or industrial applications and thus allow you to maintain control over all electrical circuits.

This is especially important when it comes to selecting and installing the appropriate residual current protective device. With this primer, we provide you with an instrument that makes it easy for you to adapt the respective residual current protective device perfectly to the requirements of the electrical installation in question. Apart from general information on residual current protective devices, it contains important details regarding installation and use. You can therefore be assured that you will always choose the right device.

Your team
BETA Low-Voltage Circuit Protection

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Residual current operated circuit breaker (RCCB)

5SM3
- Type AC and Type A
- I_n = 16 to 125 A
- $I_{\Delta n}$ = 10 mA to 1 A
- 2-pole (1+N) and 4-pole (3+N)
- N connection at left and right
- SIGRES for severe environmental conditions
- **K** and **S** version
- Version for 500 V
- 50 to 400 Hz version

SIQUENCE universal current-sensitive residual current operated circuit breaker (RCCB)

5SM3
- Type B, type B+
- I_n = 16 to 80 A
- $I_{\Delta n}$ = 30, 300 and 500 mA
- 2-pole (1+N) and 4-pole (3+N)
- **K** and **S** version

SIQUENCE RCCB with overcurrent protection (RCBO)

5SU1
- Type B, type B+
- I_n = 100 to 125 A
- $I_{\Delta n}$ = 30, 300 mA and 1A
- 4-pole
- Circuit breaker characteristic C and D
- Rated short-circuit capacity 10 kA
- **K** and **S** version

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RC unit for combination with a miniature circuit breaker

5SM2
- For mounting on a miniature circuit breaker
- Combined electric shock and line protection
- Type AC and Type A
- I_n = 0.3 to 100 A
- $I_{\Delta n}$ = 10 mA to 1 A
- 2, 3 and 4-pole
- **K** and **S** version

RCCB with overcurrent protection; combination units (RCBO)

5SU1
- Combined electric shock and line protection
- Type AC and Type A
- I_n = 6 to 40 A
- $I_{\Delta n}$ = 10 to 300 mA
- Circuit breaker characteristic B and C
- Rated short-circuit capacity 4.5 kA, 6 kA and 10 kA
- 1+N-pole, 2-pole
- N connection at right and left

Differential current monitors (RCM)

5SV8
- Residual current monitoring
- Type AC and type A
- $I_{\Delta n}$ = 0,03 to 30 A
- Response time 0.02 to 10 s
- Summation current transformer 20 to 210 mm

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Introduction

When dealing with electricity, safety has top priority. Every electrician must be particularly conscientious when safety is concerned and must apply the required protective measures correctly. In consumer's installations, residual current protective devices must be given unreserved preference over alternative protective equipment.
In addition to protection in cases of indirect contact, residual current protective devices with rated residual currents up to 30 mA also provide "additional protection" in cases of direct contact. Fires caused by ground-fault currents can also be prevented at a very early stage.

In many cases, the erection standards require the use of residual current protective devices. Electricians should therefore make sure that they are fully informed about residual current protective devices.

In addition to information on the protective effect of residual current protective devices, an understanding of how the devices function is also conveyed.
In order to optimally adapt the use of residual current protective devices to the requirements of the electrical installation, the functionality of the different versions of residual current protective devices is discussed and the user is given practical installation and application tips.

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1. Protection through residual current protective devices

The basic prerequisite for use of a residual current protective device in order to automatically disconnect the power supply as a protective measure is that an appropriately grounded PE conductor is connected to the components and equipment to be protected. Current can then pass through a human body only when two faults occur (interruption of the PE conductor in addition to a fault in the insulation) or when there is unintentional contact between live parts.

1.1 Additional protection (protection against direct contact) with $I_{\Delta n} \leq 30$ mA

Direct contact is understood to mean direct contact of a human body with a live part. When a human body touches live parts, two resistors connected in series determine the intensity of the flowing current – the internal resistance of the human body R_m and the transfer resistance of the location R_{st} (Figure 1).

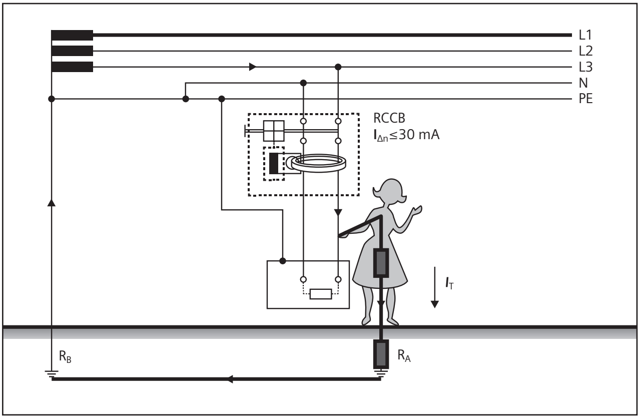


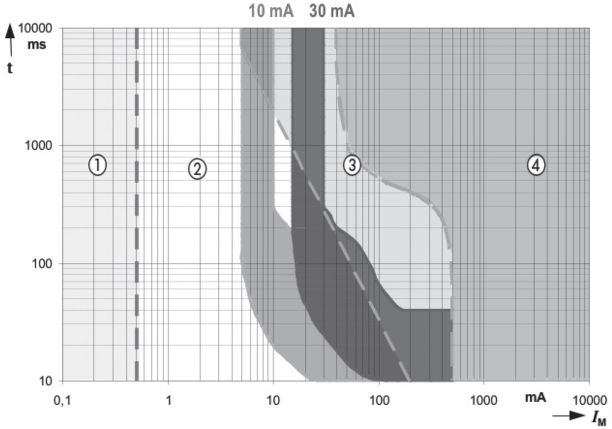
Figure 1: Additional protection: Residual current protection device with $I_{\Delta n} \leq 30$ mA in the TN system

In order to consider the accident properly, the worst case scenario where the transfer resistance of the location is near zero must be assumed.

The human body's resistance is dependent on the path of the current and the transfer resistance of the skin. Measurements have shown e.g. approximately 1,000 Ω for the flow of current from hand to hand or from hand to foot.

Under these assumptions, a touch voltage of 230 V results in a dangerous shock current of 230 mA. Figure 2 shows the current intensity/exposure time curves in relation to the physiological reactions of the human body. Dangerous current intensities and exposure times are those which reach as far as Area 4, as they can cause death due to cardiac fibrillation. Figure 2 also contains the tripping ranges of residual current protective devices with rated residual currents of 10 mA and 30 mA. The maximum permissible tripping times according to IEC 61008-1 / EN 61008-1 are shown. As can be seen from the tripping curves, residual current protective devices do not limit the intensity of the residual current but provide protection due to fast disconnection of the power and therefore a minimal time of exposure to the current.

Protection against direct contact (additional protection) with $I_{Dn} \leq 30$ mA



Area ①: Exposure is normally imperceptible.

Area ②: Medically damaging effects and muscle cramps do not normally occur.

Area ③: Muscle cramps can occur. There is normally no danger of cardiac fibrillation.

Area ④: Cardiac fibrillation can occur.

Figure 2: Effects of 50/60 Hz alternating current on the human body

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The tripping curve of residual current protective devices with a rated residual current of $I_{\Delta n} \leq 10$ mA is in Area 2 below the release limit. Medically damaging effects and muscle cramps do not usually occur (see Figure 2). They are therefore especially suitable for sensitive areas such as bathrooms.

Residual current protective devices with a rated residual current of $I_{\Delta n} \leq 30$ mA fulfill the conditions for additional protection against electric shock (see Figure 2):

– in the event of unintentional, direct contact with live parts (e.g. failure of the basic insulation, operation for other than the intended purpose, ineffective basic protection)

– in the event of carelessness on the part of the user (e.g. use of defective equipment, incorrectly repaired components and equipment)

– in the event of contact with defective live parts (e.g. loss of protection against faults due to interruption of the protective conductor).

The use of residual current protective devices with a rated residual current of up to 30 mA has proven to be effective as additional protection in the event of failure of the basic protection precautions (protection against direct contact) and/or fault protection precautions (protection against indirect contact) as well as in the event of carelessness on the part of the user when using electrical equipment. However, this should not be the only way of providing protection against electric shock and does not replace implementation of a further protection measure as required by IEC 60364-4-41 or HD 60364-4-41.

The requirement for "additional protection" with residual current protective devices according to sections 411.3.3 and 415.1 of IEC 60364-4-41 or HD 60364-4-41 does not mean that how this protection is used is up to the user. This additional protection can be required in conjunction with other protection measures under certain external influences and in certain special areas.

In several parts of the standards of sections 4 and 7 of IEC 60364 or HD 60364, this additional protection is required or expressly recommended (see Appendix). Some important requirements are explained below in more detail as examples.

In the general applicable standard for protection against electric shock (IEC 60364-4-41 or HD 60364-4-41), the use of residual current protective devices with a rated residual current of ≤ 30 mA is required as additional protection for

– all socket outlets with a rated current of ≤ 20 A if they are intended for use by laymen and for general use
– final circuits for portable items of equipment used outdoors with a rated current of ≤ 32 A.

Note:

In IEC 60364-4-41 or HD 60364-4-41, two exceptions from these requirements are indicated but they are not usually applicable in the majority of applications.

The requirement of the standard for additional protection can be avoided only in the case of socket outlets which are only used by qualified electricians and persons who have received appropriate technical instruction (e.g. in electrical workshops) or if it has been ensured that the socket outlet is only used permanently for a "specific item of equipment".

In the standard DIN VDE 011-723:2005-06 "Requirements for special installations, locations or plants - classrooms with experimental equipment", type B residual current protective devices with a rated residual current of ≤ 30 mA must be used for supplying power to the experimental equipment and its circuits in TN or TT systems.

1.2 Fault protection (protection against indirect contact)

Indirect contact is understood to mean the contact of a human body with a not live but electrically conductive part. In these cases, the demand is for automatic disconnection of the power supply when a fault can pose a risk due to the intensity and duration of the touch voltage.

Residual current protective devices with rated residual currents of over 30 mA are also suitable for this purpose. In order to achieve the protective effect, the tripping conditions must be complied with. In addition, the dangerous touch voltage must not be present for an impermissible length of time, whereby account must be taken of the grounding resistance and the rated residual current.

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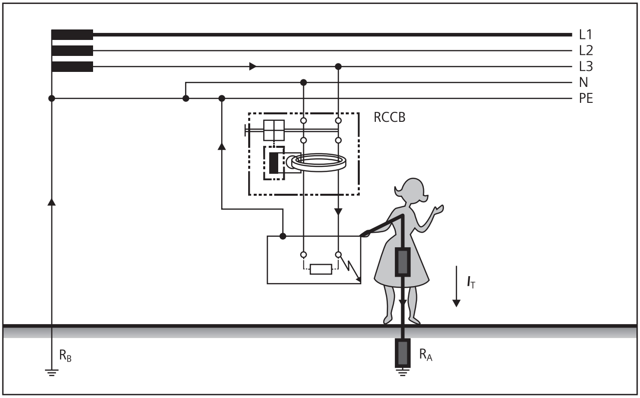

Figure 3: Fault protection in the TN system

1.3 Fire protection

For “locations exposed to fire hazards”, IEC 60364-4-482 or HD 60364.4.482 requires measures for the prevention of fires which can be caused by insulation faults. According to this standard, cables and lines in TN and TT systems must be protected by residual current protective devices with a rated residual current of $I_{\Delta n} \leq$ 300 mA. Exceptions are mineralized lines and busbar systems.

In applications in which resistive faults can cause a fire (e.g. radiant ceiling heating with panel heating elements), the rated residual current must be $I_{\Delta n}$ = 30 mA.

The fire protection provided by residual current protective devices, however, should not be limited to locations exposed to fire hazards but should always be provided.

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2 Residual current protective devices

2.1 Residual current protective device types

Residual current protective devices are distinguished from one another in respect of their suitability for detecting different forms of residual current (Figure 4).

Current waveform	Proper functioning of residual current protective devices of type				Tripping current
	AC	A	B	B+ kHz	
	•	•	•	•	0.5 to 1.0 $I_{\Delta n}$
	–	•	•	•	0.35 to 1.4 $I_{\Delta n}$
	–	•	•	•	Current delay angle 90°: 0.25 to 1,4 $I_{\Delta n}$
		•	•	•	Current delay angle 135°: 0.11 to 1,4 $I_{\Delta n}$
	–	•	•	•	max. 1.4 $I_{\Delta n}$ + 6 mA
	–	–	•	•	0.5 to 2.0 $I_{\Delta n}$

Figure 4: Classification of residual current protective devices into different types with tripping ranges

Residual current with different waveforms can occur, depending on which electronic switching takes place in the circuit. Since residual current protective devices differ in their suitability for detecting residual current waveforms, the relevant load input circuit must be taken into account when such a device is chosen.

Table 1 shows electronic circuits and their possible load and residual currents, along with the suitable types of residual current protective device in each case.

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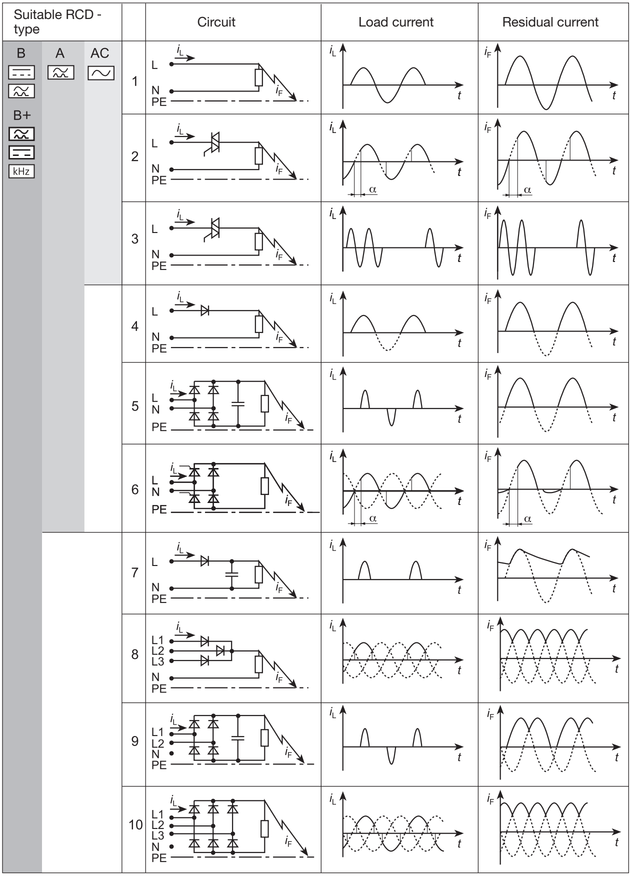

Table 1: Possible residual current waveforms and suitable residual current protective devices

2.1.1 Type AC

Residual current protective devices of type AC are suitable only for detecting sinusoidal AC residual currents (see circuits 1 to 3 in Table 1). This device type is not authorized in every country (e.g. Germany) for residual current protection and cannot carry the VDE mark of conformity.

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2.1.2 Type A

Residual current protective devices of type A detect pulsating DC residual currents in addition to sinusoidal AC residual currents.

This type of device is the most commonly used pulse current-sensitive RCCB in Germany. It can therefore also handle the residual current waveforms which can occur in the power supply units of single-phase loads with electronic components (e.g. ECG, dimmer switches). This type of residual current protective device is suitable for electronic equipment with input current circuits 1 to 6 in Table 1.

2.1.3 Type B

In addition to detecting residual current waveforms of type A, residual current protective devices of type B are used to detect smooth DC residual currents. Residual current protective devices of this type are suitable for use in three-phase AC systems with 50/60 Hz also upstream of input circuits 7 to 10 in Table 1 and can therefore be used for all the circuits shown. Tripping values defined up to 2 kHz.

2.1.4 Type B+ kHz

Like type B residual current protection devices, type B+ residual current protection devices are suitable for use in alternating current systems with 50/60 Hz for all input current circuits shown in Table 1. Tripping conditions for type B+ residual current protection devices are defined at up to 20 kHz and lie within this frequency range below a tripping value of 420 mA.

2.2 Classification of residual current protective devices

Residual current protective devices are classified according to their type (see Figure 5).

- **RCD** is the generic term for all types of residual current protective device.
- **RCCBs** are residual current operated circuit breakers without integral overcurrent protection.

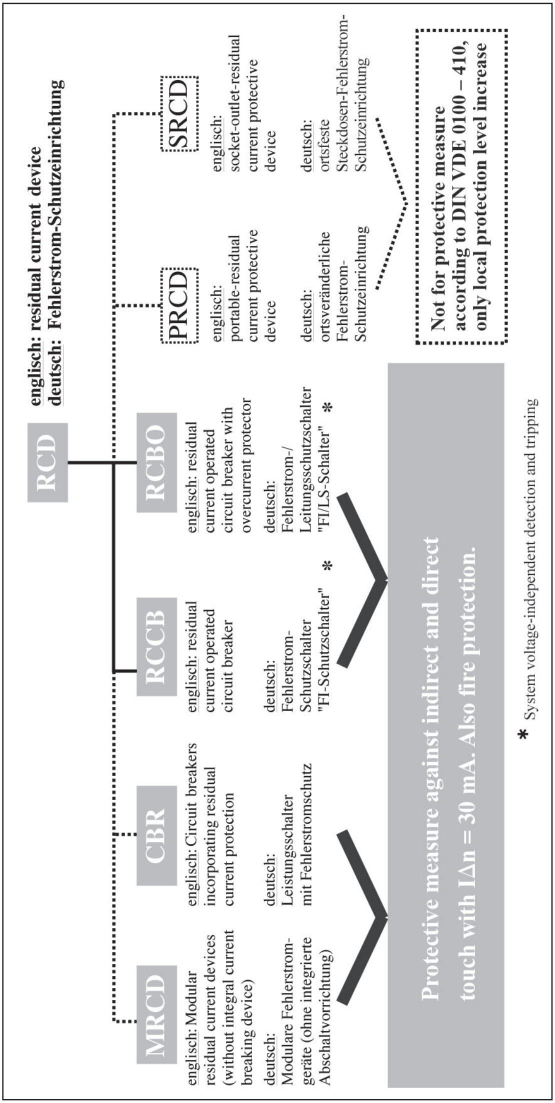

Figure 5: Classification of residual current protective devices (RCDs)

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– **RCBOs** are devices which feature an integrated overcurrent protection unit for overload and short-circuit protection in addition to protection against residual currents. Another model in this device group is the residual current unit (RC unit). The customer can then mount the circuit breaker versions suitable for a particular application (characteristic, rated current, switching capacity) on these RC units. Once assembled, these devices perform the same functions as an RCBO. The RC unit provides residual-current detection but has no contacts of its own; in the event of a fault, it trips the circuit breaker which opens the contacts and interrupts the circuit.

As regards their tripping conditions, only RCCBs and RCBOs which are independent of the supply voltage are approved for AC residual currents and pulsating residual currents (type A) in Germany and in most other European countries as a means of providing protection with disconnection of the supply. Only such RCCBs and RCBOs are permitted to bear the VDE mark of conformity.

– **CBRs** are circuit breakers with residual current protection in accordance with IEC 60947-2 or EN 60947-2, Appendix B. In this case, a residual-current detector is permanently installed on a circuit breaker, thus ensuring residual current protection.
– **MRCDs** are modular devices, i.e. residual current detection (via current transformers), evaluation and tripping (via circuit breakers) take place in separate modules (in accordance with IEC 60947-2 or EN 60947-2, Appendix M).

CBRs and MRCDs are especially intended for applications with higher rated currents (> 125 A).

– **PRCDs** are portable residual current protective devices which are integrated, for example, in connectors or in multiple socket outlets.
– **SRCDs** according to DIN VDE 0662 are non-portable residual current protective devices which are integrated in a socket outlet or form a single unit with a socket outlet.

PRCDs and SRCDs can be used to raise the level of protection for applications in which the required protection is ensured in some other manner. They are not permissible as devices providing protection with disconnection of the supply.

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2.3 Basic design and method of operation

2.3.1 RCCB type A

An RCCB of type A essentially consists of the following function groups:

- Summation current transformer for residual current detection
- Tripping circuit with components for evaluation and holding magnet tripping unit for converting the electrical measured variable into a mechanical latch release
- Latching mechanism with contacts

Note: With the exception of the tripping circuit, the design of the RCCB type AC is identical to that of type A.

The summation current transformer comprises all conductors of the circuit to be protected, including the neutral conductor. In a fault-free system, the magnetic effects of the current-carrying conductors are cancelled out in the summation current transformer. There is no residual magnetic field which could induce voltage onto the secondary winding of the transformer.

A residual magnetic field remains in the transformer core only if residual current is flowing, e.g. due to an insulation fault in the system to be protected (from the electrical point of view, downstream of the RCCB). This generates a voltage in the secondary winding, effecting disconnection of the circuit with the excessive touch voltage by means of the holding magnet tripping unit and the latching mechanism (Figure 5).

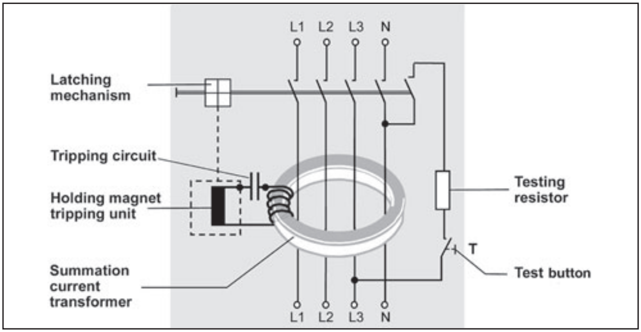

Figure 6: Schematic representation of an RCCB

In accordance with the device regulation IEC 61008-1 or EN 61008-1, for rated residual current, tripping must take place within 300 ms.

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In accordance with the product standard applicable in Germany, RCCBs must function independently of supply voltage and auxiliary voltage in all function groups (detection, evaluation, tripping) in order to achieve a consistently high level of reliability of the protection device.
The function of the trip element, which works independently of the supply or auxiliary voltage, is shown in Figure 7.

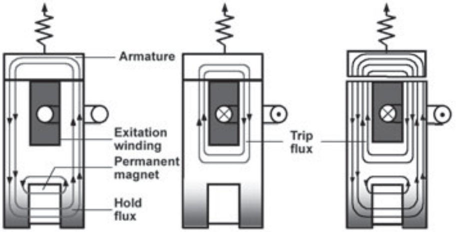

Figure 7: Operating principle of a holding magnet tripping unit

Immediately above the magnet lies a magnetic shunt whose primary task is to stabilize the permanent magnet's magnetic flux. On one pole core, there is an excitation winding, which is connected to the secondary winding of the summation current transformer. If there is a ground fault in the main circuit, a voltage is induced in the secondary winding of the summation current transformer. The left part of the illustration shows the rest position when the system is in a fault-free state. The permanent magnet drives a magnetic flux between two cores of magnetically soft material and stabilizes the armature through counteraction of a spring force. If a voltage is generated in the secondary winding of the transformer (middle part of the illustration), this voltage drives a current through the excitation winding. This generates a second magnetic flux. The effect of the permanent magnetic field is cancelled out in a half-wave by the second magnetic field (right-hand part of the illustration). This allows the spring to pull the armature from the pole face. The armature triggers the separation of the contacts by means of the latching mechanism. The transformer need only generate the small amount of energy needed to cancel out the holding flux, which trips the latch release of the energy store in the latching mechanism by means of the falling armature, and not the large amount of energy needed to open the contacts.

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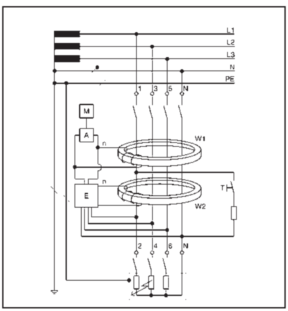
The functionality of the residual current protective device can be tested using the test button available on every device. Pressing the test button generates an artificial residual current which must trip the residual current protective device. In order to guarantee protection against dangerous shock currents, the reliability of the RCCB must be tested when the installation is put into operation and at regular intervals, at a minimum semi-annually (e.g. upon transition from daylight savings time to standard time).

2.3.2 SIQUENCE universal current-sensitive RCCB type B and type B+ kHz

This type of device has two detection systems. In accordance with the DIN VDE 0664-100 specification applicable in Germany, detection, evaluation and disconnection according to type A requirements take place independently of the supply voltage. For physical reasons, a voltage supply is required only for the detection of smooth DC residual currents. The voltage is supplied by all line supply cables.



A *Holding magnet tripping unit*
M *Mechanical components of the protective device*
E *Electronics for tripping in the case of smooth DC residual currents*
T *Test equipment*
n *Sekundärwicklung*
W1 *Summation current transformer for detection of the sinusoidal residual currents*
W2 *Summation current transformer for detection of the smooth DC residual currents*

Figure 8: Structure of a SIQUENCE universal current-sensitive RCCB type B and type B+

2.4 Features and applications

2.4.1 RCCBs

RCCBs are residual current protective devices without integrated protection against overcurrent (overload and/or short-circuit). A corresponding overcurrent protective device must therefore be assigned to them for overcurrent protection. The expected operational current of the circuit can be used as a basis for assessing the level of overload protection needed. The overcurrent protective device must be selected according to the information provided by the manufacturer of the residual current protective device.

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In order to meet these requirements regarding the availability of the electrical installation (see section 3.1.2), final circuits are to be divided up among several residual current protective devices.
If the protective device trips in the event of a fault or if manual disconnection is necessary, all the circuits downstream from the RCCB are disconnected from the power supply, whereby the line conductor and the neutral conductor are disconnected. This is an advantage when a search for a fault is carried out in an installation with fault-laden neutral conductors.
If residual current operated protective devices with a rated residual current of 30 mA or less are used for additional protection, fault protection is to be provided with an upstream selective residual current protective device with a higher rated residual current or with an overcurrent protection device. The protective device must be installed at the beginning of the circuit.

2.4.2 RCBOs (type AC /type A)

Residual current operated circuit breakers with overcurrent protection (RCBOs) include residual current detection and overcurrent protection in one device and thus enable a combination of electric-shock protection, fire protection and line protection in one device. The use of RCBOs has a series of advantages:

- Each circuit is assigned its own RCBO. If the device is tripped due to a residual current, only the affected circuit is disconnected. This is done in the same way as it has been for years when the circuit-breaker exclusively assigned to a circuit trips due to overcurrent.
- Due to division of the circuits, the user profits from increased operational safety and equipment availability because leakage currents produced by electronic equipment, such as parts of power supply systems, for operating reasons do not add up to produce non-permissible values and exceed the tripping value of the RCBO.
- Planning is simplified in that demand factors as in the case of loads on residual current operated circuit breakers do not have to be taken into account. The RCBO protects itself against overload.
- In the event of a fault, disconnection of all poles from the power supply takes place. All live parts are thus reliably disconnected from the supply and troubleshooting is simplified.

These advantages led to a note in DIN VDE 0100-410 recommending the use of RCBOs as additional protection in final circuits for outdoors and for socket outlets.

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The requirements indicated in 3.1.2, namely that the circuits in an electrical installation must always be divided up among several residual current protective devices, can also be complied with optimally by using RCBOs. In the following comparison of the different methods of installation, the differences are described.

<u>Installation with a central RCCB</u>
Figure 9 shows a frequent type of installation with a central RCCB, downstream of which several miniature circuit breakers are connected for each outer conductor.

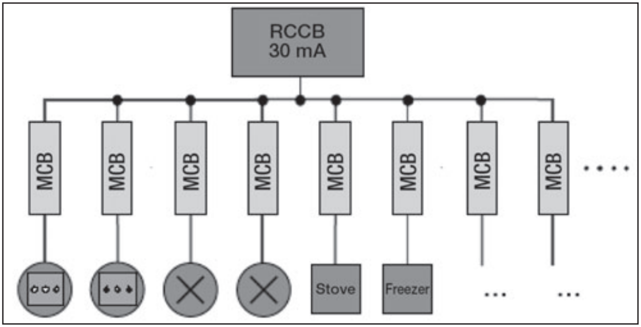

Figure 9: Installation with a central RCCB and several miniature circuit breakers for branches

The RCCB provides electric-shock protection and fire protection as well as the additional protection with $I_{\Delta n} \leq 30$ mA against direct contact as required for certain circuits (e.g. in bathrooms). The miniature circuit breaker prevents damage due to overloads or short-circuits. If the RCCB is tripped in one of the downstream circuits due to a ground fault, all other circuits, even the fault-free circuits, are disconnected from the voltage supply. Operation of these parts of the installation can only be resumed after the fault has been eliminated. In the case of this type of installation, the following factors must be taken into account:

– For correct dimensioning of the installation in respect of the residual current operated circuit breaker (RCCB), it must be ensured that the RCCB is not overloaded due to excessively high load currents (see section 3.5).
– In the de-energized state, the single-pole miniature circuit breakers only disconnect the line conductor from the power supply. The neutral conductor remains connected to the load side.

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Installation with RCBOs
Figure 10 contains an example of a future-oriented installation, which meets all the requirements of the installation regulations and planning stipulations.

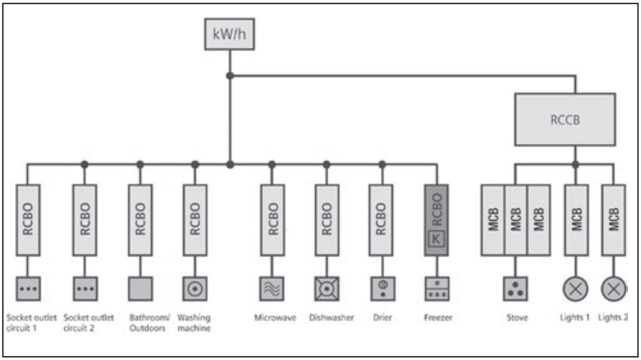

Figure 10: Example of an installation with RCBOs

Each individual socket-outlet circuit now has its own RCBO, which provides complete fault, fire and line protection as well as additional protection against direct contact. In the event of a fault, only the affected circuit is disconnected from the supply.
In order to obtain increased safety against inadvertent disconnection from the supply, e.g. due to lightning overvoltages, the use of a super resistant RCBO, type **K**, is recommended for protection of socket-outlet circuits for refrigerating equipment. If RCBOs with a rated residual current of 30 mA or less is used, the additional protection and fault protection can be provided with the same RCBO. The RCBO must be installed at the beginning of the circuit to be protected.
As an option, a selective RCCB with $I_{\Delta n}$ = 300 mA can be connected upstream of the entire installation. This RCCB protects installations with branches against faults and fire.
If the stipulations of DIN 18015-2:2000-08 and RAL RG 678:2004-09 are taken as the basis for the same extent of equipment and for the same living space , the additional space required in the circuit distribution board when the recommended RCBOs are used is only slightly more than the space required in an installation with separate RCCBs and miniature circuit breakers.

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2.4.3 SIQUENCE universal current-sensitive RCCB type B and type B+ kHz

Type A residual current protective devices – for sinusoidal AC residual currents and pulsating DC residual currents – are not capable of detecting possible smooth DC residual currents. Due to pre-magnetization of the transformer, DC residual currents can even result in the inability of type A residual current protective devices to detect AC residual currents.

For these reasons, Siemens introduced the universal current-sensitive type B RCCB, which is also used for smooth DC residual currents, in 1994, the first manufacturer to do so. Since then, the required RCCB technology can be used in many applications in which smooth DC residual currents occur.

In addition to the residual current waveforms described above, AC residual currents of different frequencies can originate in the case of electronic components, for instance on the outgoing side of a frequency converter (also see section 3.3.2). Type A RCCBs are not designed for this purpose.
The type B RCCBs, which are intended for use in three-phase systems (not in DC voltage systems), are therefore defined in DIN VDE 0664-100 (for RCCBs) and DIN VDE 0664-200 (for RCBOs) in the expanded tripping conditions up to 2 kHz. This SIQUENCE Type B RCCB are also fulfilling the IEC 62423 or EN 62423. The tripping characteristics of the SIQUENCE universal current-sensitive type B RCCB with rated residual currents of 30 mA and 300 mA are shown in Figure 11.
The tripping value of the circuit breaker always lies within the limit values according to the product standard and, for 30 mA rated residual current, is well below the limit curve for dangerous cardiac fibrillation (according to IEC 60479-2).

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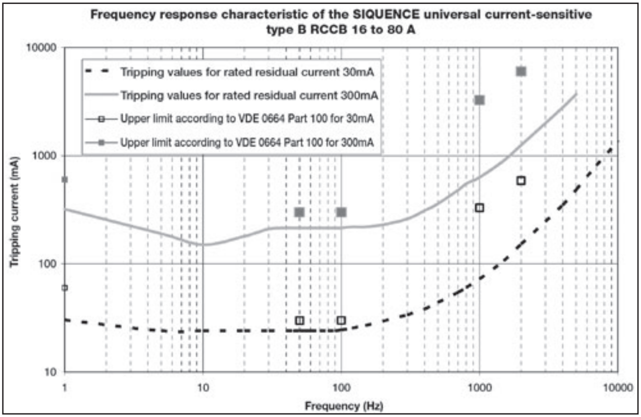

Figure 11: Frequency-dependent tripping current

In order to fulfill the tripping conditions for protection against indirect contact (fault protection) using the SIQUENCE universal current-sensitive RCCB, it's tripping characteristics at different frequencies and the frequency spectra which occur in the application at the fault location must be taken into account.

On the assumption of unfavorable conditions (high clock-pulse rate of a frequency converter; also see section 3.3.2), the maximum permissible grounding resistances listed below are recommended:

Rated residual current	Maximum permissible grounding resistance in the case of touch voltage	
	50 V	25 V
30 mA	120 Ω	60 Ω
300 mA	16 Ω	8 Ω
500 mA	10 Ω	5 Ω

Table 2: Recommended maximum grounding resistances for SIQUENCE universal current-sensitive type B RCCBs

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To protect against fires caused by ground-fault currents, the use of residual current protective devices with a rated residual current of 300 mA is required in certain applications (IEC 60364-482 or HD 60364.4.482). This is derived from the assumption that approximately 70 W is sufficient to cause a fire. The tripping values of the SIQUENCE universal current-sensitive type B RCCB increase with higher frequencies. However, since residual current contains high-frequency and low-frequency components (see section 3.3.2), an effective contribution to fire protection in the case of ground-fault currents can also be achieved with a tripping characteristic which rises with the frequency. The positive effect of the increasing tripping current is a higher degree of operational safety for the system as a whole, since leakage currents from capacitors can lead to a reduced level of unwanted tripping of the RCCB.

The dimensioning of the SIQUENCE universal current-sensitive type B RCCB's frequency response takes these secondary conditions into account, and represents a solid compromise between fire protection and operational safety. Since the influence of existing capacitive leakage currents on the tripping of the RCCB is clearly limited, the RCCB can be used in a significantly larger number of applications.

The use of type B+ residual current protection devices is recommended if the use of residual current protection devices with rated residual currents of max. 300 mA is required in accordance with DIN VDE 0100-482 “Fire protection against special risks or hazards” in connection with DIN VDE 0100-530. They meet all requirement of the well-known type B, but remain below the tripping value of 420 mA at up to 20 kHz in accordance with product standards DIN V VDE V 0664-110 (FI circuit breakers) and DIN V VDE V 0664-210 (FI/LS circuit breakers) as well as VdS Guideline 2501, thus offering an increased level of preventative fire protection.

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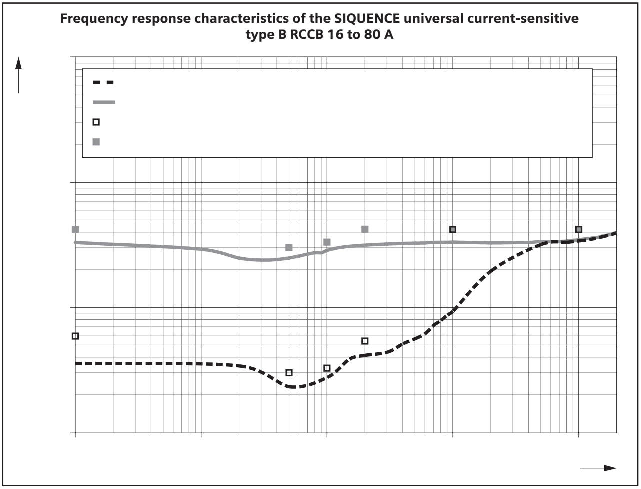

Figure 12: Type B+ frequency-dependent tripping current

The maximum permissible grounding resistance for type B+ residual current protection devices amounts to:
– 120 Ω for contact voltage 50 V
– 60 Ω for contact voltage 25 V

High-intensity leakage currents can occur briefly when capacitors are switched on which are connected to the protective ground PE (e.g. in the case of EMC filters in conjunction with frequency converters). In order to ensure trouble-free operation in such cases, the SIQUENCE universal current-sensitive type B RCCBs are extremely resistant and feature short-time delayed tripping (type **K**).

2.4.4 SIQUENCE universal current-sensitive RCBO type B and type B+ kHz

The principle of detection on which the SIQUENCE universal current-sensitive RCBO type B is based is identical to that on which the SIQUENCE universal current-sensitive RCCB type B is based, and functions with regard to the requirements for type A in accordance with VDE 0664-200 (applicable standard in Germany) and DIN V VDE V 0664-210 (type B+) independently of the supply voltage. This SIQUENCE Type B RCBO are also fulfilling the IEC 62423 or EN 62423.

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With regard to the type B response in case of residual currents and the protective functions, the same statements and specifications which apply to the SIQUENCE universal current-sensitive type B / type B+ RCCB are applicable.
RCBOs combine protection against electric shock, fire protection and line protection functions in one unit. Thanks to the integrated overcurrent protection feature, intrinsic thermal protection of the device is ensured automatically without further adaptation to upstream/downstream overload protection systems. In addition to those mentioned in Section 2.4.2, direct allocation of a SIQUENCE universal current-sensitive type B RCBO to a circuit offers the following special advantages over an RCCB and multiple miniature circuit breakers in the outgoing circuit:

- The maximum possible leakage current (0.3 * $I_{\Delta n}$) can be utilized in each branch
- As in the case of overcurrent, tripping due to residual current disconnects only the affected branch from the supply voltage
- High system availability, since the fault-free part of the system is still supplied with power.

2.4.5 RC units for installation on miniature circuit breakers

RC units are suitable for installation on miniature circuit breakers in accordance IEC 61009-1 or EN 61009-1, Appendix G. The customer can combine these RC units with an appropriate miniature circuit breaker to generate the same functionality as the factory-built RCBOs.
A large number of different combinations can be made up from the available RC unit and miniature circuit breaker product lines without having to stock a large number of products. This results in important advantages:

- High degree of application flexibility
- Customized combination of device features from RC unit (rated residual current, instantaneous or selective) and miniature circuit breaker (rated current, characteristic, short-circuit capacity)
- The device combination offers all advantages of an RCBO as regards electric shock, fire and line protection

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2.4.6 SIGRES RCCB (for severe environmental conditions)

When residual current protective devices are used under severe environmental conditions with increased emissions of corrosive gases, for instance in
– indoor swimming pools (chlorine gas; ozone),
– farming (ammonia),
– industry (sulfur dioxide),
they are subject to a significantly higher load.
These gases, in conjunction with humidity, have a corrosive effect on all metal components and therefore also on the metal surfaces of the holding magnet trip unit.
The SIGRES RCCBs are suitable for such applications and their patented active condensation protection feature gives them a significantly longer service life. Direct heating of the holding magnet trip unit produces a slightly higher temperature on the metal components with only minimum power required. Since condensation of the humid air enriched with corrosive gases is thereby avoided, corrosion cannot take place, resulting in a longer service life of the devices.
A voltage supply is required for heating. If the RCCB is also used for a longer period of time while in a disconnected state, the direction of the incoming supply (from below) must be observed. This ensures that heating is possible in this case as well.
The protective function of the RCCB continues to remain absolutely independent of the supply voltage according to the product standard.

2.4.7 Type K, super resistant

Leakage currents and residual currents arising from the operation of electrical equipment cannot be distinguished. The reaction to both is the same. If a temporary high leakage current occurs, it is neither necessary nor desirable to disconnect the load from the supply. If electronic equipment is used with capacitors connected against the protective conductor in order to eliminate faults, inadvertent tripping of the RCCB can occur when the equipment is switched on.

In order to avoid this tripping, the use of super resistant residual current protective devices is recommended. They trip with a time delay and are designated as type K devices.

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As far as the product standards IEC 61008-1 or EN 61008-1 (RCCBs) and IEC 61009-1 or EN 61009-1 (RCBOs) are concerned, there are only two types of device:
– Standard
– Selective
For these types of device, the limits for the disconnecting times are defined. In accordance with the standard, the super resistant residual current protective devices are instantaneous standard types.

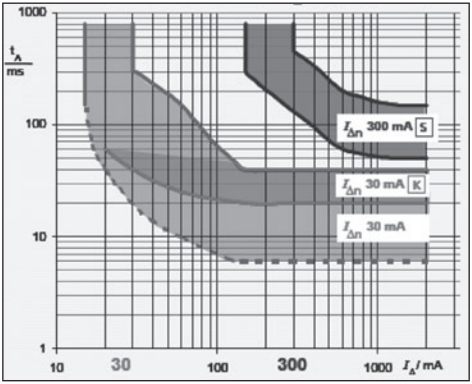

Figure 13: Disconnecting time t_A in relation to the tripping current I_Δ

Figure 13 shows the tripping range of the different types of residual current protective devices. It can be clearly seen that the tripping ranges of the standard version and the super resistant version are identical in terms of the maximum value. Only the minimum value is higher in the case of type **K** . The type **S** device behaves selectively in relation to these two types.

The super resistant residual current protective devices, type **K** exploit the maximum permissible tripping range of the standard. They have a minimum time delay of approx. 10 ms. In other words, short-time leakage currents and high surge currents (8/20 µs) are ignored for this length of time. Only when a residual current flows for longer than the delay time, disconnection from the supply is initiated. Protection against electric shock is provided by this residual current protective device, too. The devices can be used for all the protective measures (with disconnection from the supply) required in the installation conditions. The installation is not switched off unnecessarily and its availability is considerably increased.

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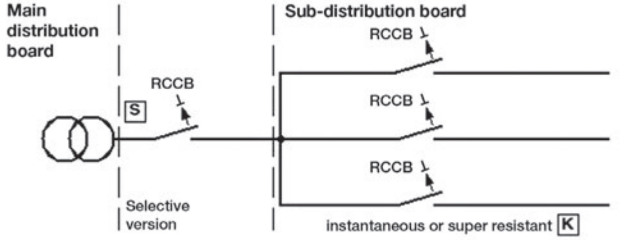
2.4.8 Type S, selective

In order to achieve selective tripping in the case of series-connected residual current protective devices in the event of a fault scenario, both the rated residual current $I_{\Delta n}$ and the tripping time of the devices must be staggered. The different permissible tripping times of the standard and selective residual current protective devices can be taken from Figure 14. The suitable staggering of the rated residual currents can also be seen in Figure 14.
Selective residual current protective devices of type S also have a very high surge withstand capability of 5 kA (8/20 µs current waveform). They are identified by the symbol S .



Upstream RCCB for selective disconnection S		Downstream RCCB or		
			instantaneous version	super resistant version K
$I_{\Delta n}$	break time with 5 x $I_{\Delta n}$	$I_{\Delta n}$	break time with 5 x $I_{\Delta n}$	break time with 5 x $I_{\Delta n}$
100 mA 300 mA 500 mA 1000 mA	50 - 150 ms	10 mA or 30 mA 10 mA, 30 mA or 100 mA 10 mA, 30 mA, 100 mA 300 mA	<= 40 ms	20-40 ms

I2_06168g

Figure 14: Layout of different residual current protective devices and their tripping times

2.4.9 Versions for 50 to 400 Hz

Because of the principle according to which they function, residual current protective devices in their standard version are designed for maximum efficiency in a 50/60 Hz system. The device specifications and tripping conditions also relate to this frequency. With increasing frequency, sensitivity normally decreases. In order to be able to implement effective residual current protection in systems up to 400 Hz (e.g. industrial systems), suitable devices must be used.

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Such RCCBs fulfill the tripping conditions up to the specified frequency and provide corresponding protection.

2.4.10 Versions for 500 V operational voltage

The standard versions of residual current protective devices, with their creepage and clearance, are designed for systems up to 240/415 V alternating voltage.
Suitable residual current protective devices are available for power supply systems up to 500 V.

2.4.11 RCCB with N-conductor on the left side

RCCBs, particularly in Germany, are normally placed at the left of the miniature circuit breakers but have the N-conductor on the right. This causes problems with regard to integrated busbar connection. RCCBs in conjunction with miniature circuit breakers therefore require a special busbar.
In order to make it possible use standard busbars whenever required, four-pole RCCBs with the N-conductor on the left are also available.
The habit of installing the RCCB at the left of the miniature circuit breakers and using standard busbar connections can thus be maintained.

2.5 Additional components for RCCBs

2.5.1 Remote controlled mechanism (RC)

Favored locations for remote controlled mechanisms are spacious or not continually manned work areas, such as water-treatment plants or radio stations as well as automated plants for energy and operations management.
The use of a remote controlled mechanism allows the user direct and immediate access to the installation even in remote or hard-to-access locations. Fast reconnection to the supply following a fault scenario, in particular, saves considerable time and costs.
The remote controlled mechanism is controlled by means of a mechanical function selection switch. In the “OFF” position, the remote controlled mechanism is disabled and can also be closed.

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“RC OFF” prevents remote switching and allows only manual actuation of the RCCB. This prevents unauthorized remote switching during service assignments, for instance. In the "RC ON" position, “Remote ON” and “Remote OFF” switching as well as local operation are possible. If a fault trip occurs, the connected handles on the RCCB and the remote controlled mechanism are set to the "OFF" position. The circuit breaker must only reclosed if the hazardous situation no longer exists. To reclose the breaker, the operator must also acknowledge disconnection of the supply with a RESET (OFF command) for the remote controlled mechanism.

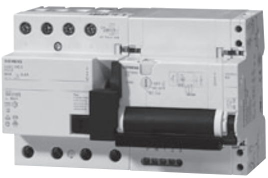

Figure 15: Remote controlled mechanism with RCCB

2.5.2 Auxiliary switches

Auxiliary switches can usually be retrofitted on the RCCB by the customer. They serve to indicate the circuit breaker’s switching state.
Three variants are possible (1 NO/1 NC; 2 NCs; 2 NOs).

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3 Notes on installation and use

3.1 General information

3.1.1 Selection of protective devices

When selecting a suitable protective device for the protective measure "automatic disconnection of the power supply" in accordance with IEC 60364-4-41 or EN 60364-4-41 for fault protection the conditions of disconnection depending on the supply system must be taken into account.
Table 3 summarizes the relevant characteristic variables for the conditions of disconnection from the supply.

Characteristics	Values in the TN system	Values in the TT system
Impedance of the fault loop Z_s (measured values)	several 10 mΩ to approx. 2 Ω	up to 100 Ω
Residual current $I_F = \frac{230V}{Z_S}$	Approx.115 A to several 1000 A	At least 2.3 A
Maximum permissible break time t_a according to Table 41.1. in IEC 60364-4-41 or EN 60364-4-41[1)]	**0.4 s**	**0.2 s**
Touch voltage U_T (empirical values)	80 V up to 115 V	160 V up to 230 V
Touch current $I_T = \frac{U_T}{1000\Omega}$ Impedance of the human body in case of hand-to-foot flow of current (guide value)	80 mA up to 115 mA	160 mA up to 230 mA
[1)] For final circuits with a rated current not greater than 32 A in a 230/400 V system (50 Hz)		

Table 3: Characteristic variables for the conditions of disconnection in TN and TT systems with rated voltages of 230/400 V AC

Table 3 shows the clear differences in respect of touch voltages and the resulting touch currents in TN and TT systems. These differences explain why the maximum permissible disconnection times in the TT system must be shorter than in the TN system in order to provide the same protection.
Suitable protective devices are to be selected on this basis. Table 4 provides an overview.

	TN system			TT system		
Trip currents I_a of overcurrent protective devices for ensuring the required disconnecting time t_a	$Ia \le \frac{230V}{Zs}$			$Ia \le \frac{230V}{Zs}$		
	Protective device	I_a	t_a 1)	The necessary trip currents I_a of overcurrent protection devices are generally not reached by the residual currents I_F.		
	MCB type B	≥ 5 I_n	< 0.1 s			
	MCB type C	≥ 10 I_n	< 0.1 s			
	Melting fuse gG	ca. > 14 I_n	< 0.4 s			
Tripping conditions I_a of residual current protective devices for ensuring the required disconnecting time t_a	$Ia \le \frac{230V}{Zs}$ In the TN system, the residual currents I_F are considerably higher than 5 $I_{\Delta n}$			$I\Delta n \le \frac{50V}{Ra}$ In the event of a fault, there is 230 V at the fault location. The following therefore applies to the trip current I_a: $Ia = \frac{230V}{50V} I\Delta n = 4{,}6 I\Delta n$		
	Type	I_a	t_a 1)	Type	I_a	t_a 1)
	RCCB general	> 5 $I_{\Delta n}$	≤ 0.04 s	RCCB general	> 2 $I_{\Delta n}$	≤ 0.15 s
	RCCB selective	> 5 $I_{\Delta n}$	≤ 0.15 s	RCCB selective	> 2 $I_{\Delta n}$	≤ 0.2 s

1) The values for t_a relate to the stipulations in the relevant product standards.

R_a - the sum of the resistances in Ω of the ground electrode and the protective conductor of the bodies;

$I_{\Delta n}$ - the rated residual current in A of the residual current protective device.

Table 4: Selection of protective devices in TN systems and in TT systems with rated voltages of 230/400 V AC

3.1.2 Use of residual current protective devices

Residual current protective devices can be combined with any other protective devices. Even if other forms of protection are already installed in an existing system, residual current protection can still be used for this system or parts of it.
Almost any type of protection can be converted to residual current protection with comparatively little effort.
According to the standard DIN VDE 0100-530, it is permissible that if a residual current protection device with a rated residual current of $I_{\Delta n} \le 30$ mA is used, it can simultaneously be used to provide fault protection in the form of automatic disconnection of the power supply and additional protection in the event of direct touching. However, because this additional protection by means of residual current protective devices with a rated residual current that does not exceed 30 mA is envisaged as additional protection for the event that precautions for basic protection and/or precautions for fault protection are not successful, it is nevertheless recommended that the protective functions be split up among different devices in order to fulfill both of these protection goals.

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In order to achieve maximum availability and operational safety, the circuits must be divided up appropriately among several residual current protective devices. These requirements are specified in different documents:

– According to IEC 60364-3 or HD 60384.3 S2 the circuits must be divided up in order to avoid hazards, limit the consequences of faults, facilitate inspection, testing and maintenance and take into account hazards which can be caused by a fault in only one circuit, e.g. lighting failure.

– DIN 18015-1:2007-09 "Electrical Installations in Residential Buildings – Part 1: Planning Principles" requires that connection points for items of current-using equipment be assigned to a circuit in such a way that automatic tripping of the protective device assigned to this circuit (e.g. overcurrent protection device, residual current protective device) in the event of a fault or necessary manual disconnection from the power supply only cause a small part of the customer's installation to be disconnected from the supply.

– TAB 2007 (Technical Connecting Conditions) states that when circuits are divided up, connection points for items of current-using equipment be assigned to a circuit in such a way that automatic tripping of the protective device assigned to this circuit in the event of a fault or necessary manual disconnection from the power supply only cause a part of the customer's installation to be disconnected from the supply.

This means: Except when selective residual current protective devices are used, the circuits are to be divided up in such a way that tripping of a residual current protective device does not lead to the failure of all circuits.

If a residual current protective device for other protection tasks (fault protection, fire protection) is connected upstream of an RCD for additional protection (rated residual current ≤ 30 mA), this second RCD should always have a selective tripping characteristic (e.g. type **S**).

As shown in table 4, selective and standard RCDs achieve the maximum permissible tripping times in both power supply systems.

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The following points must be noted when residual current protective devices are used in Germany for fault protection, fire protection, and (in accordance with DIN VDE 0100-530) additional protection:

- All poles of all active conductors – i.e. including the neutral conductor – must always be disconnected.
- Only voltage-independent residual current protective devices (type A) are allowed.
- Purely AC-sensitive residual current protective devices (type AC) are not allowed.

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3.2 Choosing the right residual current protective device

Figure 16 can help users to select a suitable residual current protective device.

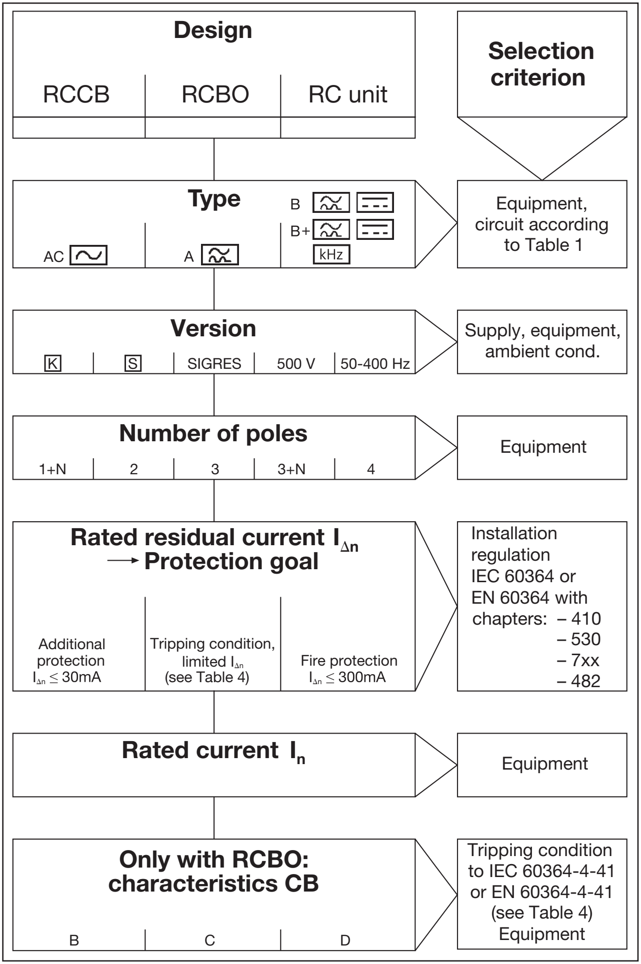

Figure 16: Aid to selection of a suitable residual current protective device

Details are explained below.

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3.2.1 Type A or type B / type B+?

The correct type of residual current protective device for each application can be selected with the help of Table 1 (in accordance with DIN EN 50178/VDE 0160 "Electronic equipment for use in power installations" and DIN VDE 0100-530 Section 531.3.1).
If the electronic equipment (e.g. a frequency converter) is operated directly on the three-phase system and input circuits 7 to 10 are switched (see Table 1), universal current-sensitive RCCBs type B must be used. Type B and type B+ are deemed equivalent for this selection.
It is sufficient to use type A residual current protective devices (sensitive to pulsating current) for all other applications.

3.2.2 What protection goal must be achieved?

Various protection goals must be achieved depending on the application and location of use:

- Additional protection with a rated residual current of $I_{\Delta n} \leq 30$ mA: These RCDs are intended to provide additional protection against electric shock in case of a failure of the other basic protective measures (protection against direct contact) and/or for protection against faults (protection against indirect contact) or in the event of carelessness by the user. Their protection is effective up to a maximum frequency of 100 Hz. All statements concerning the risk of cardiac fibrillation (up to 1 kHz) are at present only of limited validity at higher frequencies. No reliable evidence is available regarding the impact of other effects (thermal, electrolytic) on the human organism.

- Fault protection with a rated residual current of $I_{\Delta n} > 30$ mA: Protection against electric shock can be provided with these rated residual currents under fault conditions. The tripping conditions of the respective power system must be complied with. At frequencies higher than 100 Hz, protection in the event of indirect touching must be provided and account must be taken of the frequency response of the RCCB, the maximum permissible touch voltage (e.g. 50 V), the critical frequency components in the residual current and the maximum permissible grounding resistance determined from these components (see also Section 2.4.3).

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- Fire protection with a rated residual current of $I_{\Delta n} \leq 300$ mA:
  – at particular risk of fire (premises exposed to fire hazards),
  – primarily made of flammable construction materials,
  – containing irreplaceable goods of great value
  the use of residual current protection devices with rated residual currents of max. 300 mA is required in accordance with DIN VDE 0100-482 in connection with DIN VDE 0100-530. Exceptions are only permitted if mineralized lines and busbar systems are used. Type B+ residual current protection devices must be used in the above-mentioned systems to increase the preventative fire protection of electrical equipment with input current circuits no. 7 through no. 10 (see Table 1).

3.2.3 What electrical interference occurs and how is it handled?

3.2.3.1 Leakage currents

Leakage currents are currents that are leaked to ground although the insulation is not faulty. They can be either static or dynamic, and they trip the RCCB if the tripping value is exceeded.
These currents must therefore be taken into account when the rated residual current $I_{\Delta n}$ of an RCCB is selected and, if necessary, minimized, in order to ensure that the specified protection requirements are met.

- Static leakage currents
  Static leakage currents are continuously leaked to ground or the PE conductor during normal operation of the load, even though the insulation is not faulty. They tend to be mainly leaked from line and filter capacitors.
  Static leakage currents in an existing system can be measured with the 5SM1 930-0 leakage current measurement unit (see also Section 3.7).
  For problem-free use of residual current protective devices in practical applications, the stationary leakage current should be $\leq 0.3 * I_{\Delta n}$.

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- Dynamic leakage currents
  Dynamic leakage currents are transient currents to ground or the PE conductor. They occur in the range from a few µs to a few ms, especially when devices with filter circuits are switched. Their duration depends on the time constant that is derived from the circuit impedances, and above all on the switching device that is used to connect the filter to the power supply. Due to the asymmetric contacting of the individual switching contacts, high capacitances to PE can occur for short periods depending on the filter circuit design. These capacitances are reduced to low residual values to PE owing to the star connection of the capacitors after the device has been fully closed.
  Dynamic leakage currents can have a magnitude of a few amperes. In other words they can also trip instantaneous RCCBs with $I_{\Delta n}$ = 300 mA.
  The peak value of a dynamic leakage current can be determined by measuring with an oscilloscope in the PE conductor. The equipment must be arranged in an insulated setup, so that the complete leakage current is able to flow back along the measurement path.
  The use of short-time delayed residual current protective devices (type **K**) is recommended to prevent unwanted tripping in these kinds of application.

3.2.3.2 High load currents

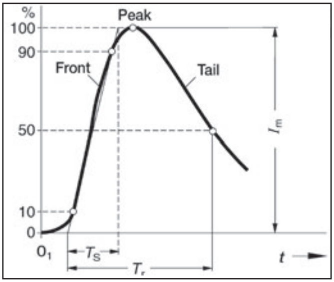
Even if no leakage currents are present, an RCCB can still be spuriously tripped as a result of high load currents (> 6x I_n). These high load current peaks can lead to different magnetizations in the magnetic strip core because the arrangement of the primary conductors is not absolutely symmetrical and the secondary winding on the circumference of the summation current transformer for residual current detection is not completely closed, so that a tripping signal is produced. Tripping can also result if the magnetic field around the current carrying conductor is directly irradiated onto the holding magnet tripping unit. High load current peaks are especially common in conjunction with direct starting motors, lamp loads, heater windings, capacitive loads (capacitances between L and N), and medical equipment such as CT machines or X-ray equipment.
According to the product standard, RCCBs are resistant to spurious tripping at up to six times the rated current.

3.2.3.3 Overvoltages and surge current load

During thunderstorms, atmospheric overvoltages in the form of traveling waves can penetrate the installation via the supply system and inadvertently trip residual current protective devices. To prevent these spurious tripping operations, our RCDs must pass a test with the standardized 8/20 μs surge current wave (see Figure 17). In the product standard (IEC 61008-1 and EN 61008-1), this test is only stipulated for selective RCDs (i = 3 kA).
All variants of our type A and B RCCBs offer a significantly higher surge current withstand capability. They consequently have a greatly reduced tendency to trip spuriously in practice.

The surge current withstand capability of the individual product series is as follows:
– Instantaneous ≥ 1 kA
– Super resistant (type **K**) ≥ 3 kA
– Selective (type **S**) ≥ 5 kA

Even in the standard devices, these values ensure good resistance to spurious tripping, and this form of protection with rated currents up to 30 mA can also be used for sensitive load circuits (e.g. refrigerators).



Characteristics of a current impulse acc. to DIN VDE 0432-2
T_s Front time in s
T_r Virtual time to half-value on tail in s
0_1 Virtual origin
I_m Peak value

Figure 17: Surge current characteristic 8/20 μs

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3.3 Special features regarding the use of SIQUENCE universal current-sensitive residual current protective devices (type B)

3.3.1 Applications

Typical applications that are vulnerable to smooth DC residual currents:
– Frequency converters with a three-phase connection
– Medical equipment such as X-ray equipment or CT machines
– Photovoltaic or UPS systems
– Elevator controls
– Pipe backup heaters
– Test setups in laboratories
– Construction sites in accordance with BGI 608 information leaflet (Electronic equipment on construction sites)
– Charging stations for battery operated forklift trucks
– Cranes of all kinds
– Mixing plants if relevant loads are connected
– Variable-speed machine tools, such as milling and grinding machines or lathes

3.3.2 Residual currents at different fault locations, with a frequency converter (FC) as an example

A frequency converter (FC) is considered below as a typical example of equipment where different residual current waveforms can occur depending on the fault location (see Figure 18).

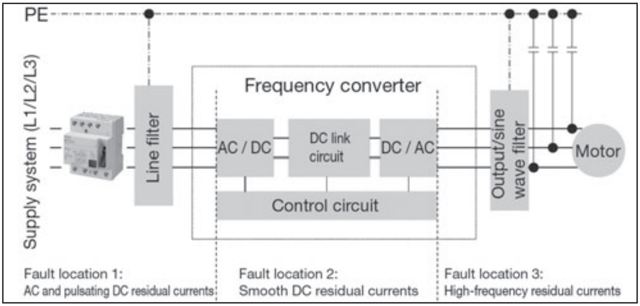

Figure 18: Circuit with a SIQUENCE universal current-sensitive RCCB and a frequency converter

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Fault locations in section 1 (upstream of the FC)

Line-frequency AC residual currents occur between the RCCB and the frequency converter (see Fig. 19). Protection against these purely sinusoidal 50 Hz residual currents is provided by all RCCBs (types AC, A and B). If the tripping value of the RCCB is reached in the range from 0.5 to 1 $I_{\Delta n}$, the endangered section is disconnected.

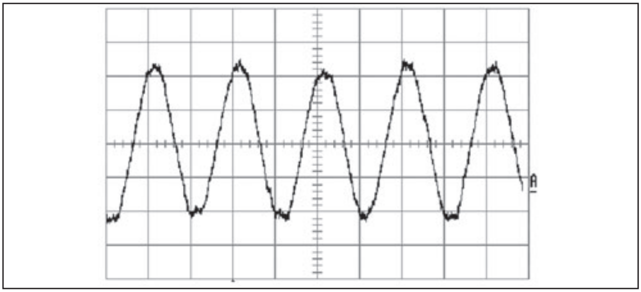

Figure 19: Residual current waveform at fault location 1

Fault locations in section 2 (in the FC)

Nearly smooth DC residual currents occur in the frequency converter (between the input rectifier and the output electronics, i.e. in the DC link circuit). If a UC-sensitive RCCB type B is used, the endangered section is reliably disconnected in the range from 0.5 to 2 $I_{\Delta n}$.

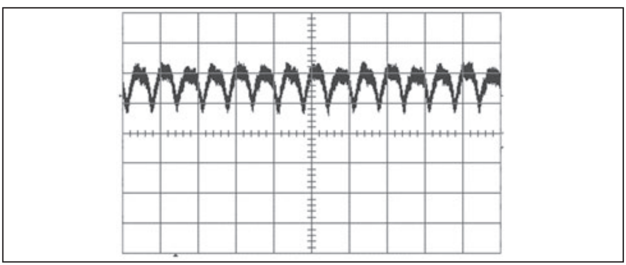

Figure 20: Residual current waveform at fault location 2

Type A residual current protective devices are unable to offer any protection here. There is no tripping because the DC residual current does not cause any time change in the transformer

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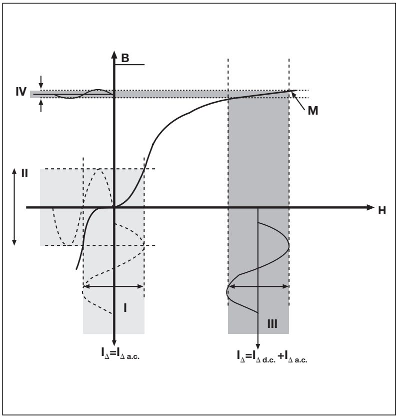
induction of the RCCB, which operates according to the induction principle. In addition, a smooth DC residual current (or leakage current) due to a creeping insulation fault leads to biasing of the transformer material of a type A residual current protective device. Figure 19 shows the difference between a transformer signal without and with DC residual current superimposition. Without DC residual current ($\boldsymbol{I}_{\Delta\ \mathrm{d.c.}}$), an AC residual current ($\boldsymbol{I}_{\Delta\ \mathrm{a.c.}}$) causes modulation on the magnetic force axis of the size I. In accordance with characteristic magnetization curve M of the transformer a voltage of size II is induced. A DC residual current ($\boldsymbol{I}_{\Delta\ \mathrm{d.c.}}$) flowing via the residual current protective device shifts the working point of the transformer on the H axis. An AC residual current ($\boldsymbol{I}_{\Delta\ \mathrm{a.c.}}$) with the same value as in the case without DC residual current causes modulation of the same magnitude on the magnetic force axis H of size III. Although the change III has the same value as I, a significantly smaller voltage of the size IV is induced in the transformer. If it is assumed that a signal of size II is necessary for tripping, it becomes clear that the considerably smaller signal IV is not sufficient for this. Only much higher AC residual currents would lead to attainment of the necessary signal level. This shows that a type A residual current protective device is no longer able to trip if a purely sinusoidal residual current, which could otherwise be tripped without any problems, occurs simultaneously. The protective function of the residual current protective device is therefore no longer guaranteed.



I Modulation with AC residual current $I_{\Delta\ \mathrm{a.c.}}$
II Tripping signal generated by $I_{\Delta\ \mathrm{a.c.}}$
III Superimposition of DC residual current $I_{\Delta\ \mathrm{d.c.}}$ *with AC residual current* $I_{\Delta\ \mathrm{a.c.}}$
IV Tripping signal in the case of superimposition of DC residual current $I_{\Delta\ \mathrm{d.c.}}$ *with AC residual current* $I_{\Delta\ \mathrm{a.c.}}$ I_{Δ} *total residual current*
B Induction
H Magnetic field strength
M Magnetization curve of the transformer

Figure 21: Pre-magnetization due to DC residual current

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Fault locations in section 3 (downstream of the FC)

AC residual currents which deviate from the line frequency and the sinusoidal waveform occur between the outgoing terminal of the frequency converter and the motor. These currents represent a frequency spectrum with different frequency components (see Fig. 22). Smooth DC residual currents can also occur, depending on the operating mode of the frequency converter (e.g. as a DC brake or a DC pre-heater)

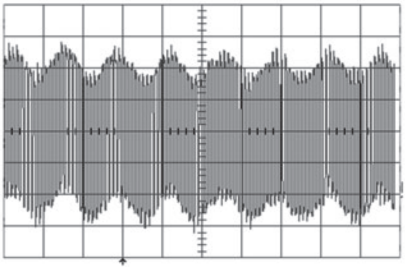

Figure 22: Residual current waveform at fault location 3

According to the product standard, type A RCCBs are only designed to detect residual currents with 50/60 Hz. The tripping value is therefore increased in an undefined way for higher frequency components of the residual current. The intended protective effect is usually lost as a result. Tripping conditions for frequencies up to 2 kHz are defined for type B RCCBs.

Frequency components in the residual current of a frequency converter

The frequency components in the residual current must be taken into account in addition to the tripping characteristics of the RCCB in order to assess the protective effect of this RCCB in conjunction with a frequency converter. The following critical frequency components occur at fault location 3:

- Clock frequency of the frequency converter (a few kHz)
- Motor frequency (normally 0 to 50 Hz, maximum frequency 1 kHz)
- 3rd harmonic of 50 Hz (150 Hz if the frequency converter has a three-phase connection)

Figure 23 shows a typical example of the frequency components that can flow across a fault impedance of 1 kΩ in the fault location 3 range (see Figure 22).

The clock frequency accounts for a smaller percentage of the total residual current as the motor frequency increases, while the motor frequency accounts for a correspondingly higher percentage.

This behavior is characteristic of many different frequency converter types.

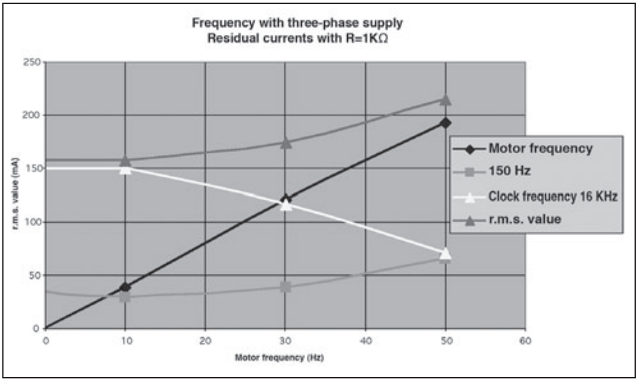

Figure 23: Frequency components in the residual current, with a frequency converter as an example

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3.3.3 Configuring

Type B / type B+ universal current-sensitive residual current protective devices must be used if smooth or nearly smooth DC residual currents can occur when electronic equipment is operated (input circuits 7 to 10 in Table 1).

In these cases, type A residual current devices (sensitive to pulsating current) must not be used to provide protection, as their function can be impaired by smooth DC residual currents to the extent that they are no longer able to trip even in case of those residual currents for which they are designed.

For this reason, it is essential to ensure that if type A and B residual current protective devices are arranged in the same system, a type B residual current protective device is always connected upstream of each type A residual current protective device (see configuring example in Figure 24).

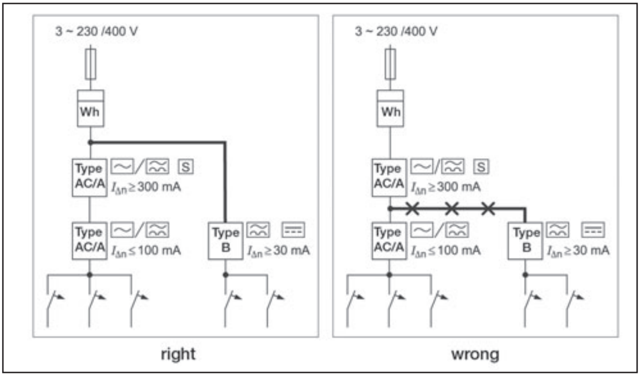

Figure 24: Configuring example with type A and B residual current protective devices

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3.3.4 Causes of high leakage currents and recommendations for reducing them

Causes of leakage currents	Effect
EMC (input) filter capacitances between line conductor and PE conductor	Highly dynamic and static leakage currents
Line capacitances	Mainly static leakage currents
Making/breaking asymmetries	High dynamic leakage currents possible
Summation of leakage currents due to connection of several loads (especially frequency converters) to an RCCB	High dynamic and static leakage currents
Clock frequency of frequency converters	Static leakage currents via cable capacitance
Grounding conditions	Static leakage currents
Harmonic component of the output voltage of the frequency converter	Static leakage currents via cable capacitance

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Corrective measure

- Use filters with low leakage currents.
- Clarification with converter manufacturer as to whether filters with lower degree of interference suppression (class B or C3/C4 instead of class A or C1) are possible or EMC input filters can be dispensed with if, for instance, output-side sine wave filters or du/dt filters or motor chokes can be used.

- Minimize cable lengths
  (the overall capacity and thus the leakage current flowing against the PE increase with the length of the cable corresponding to the capacitance per meter – leakage current of shielded cables from approx. 0.2 mA/m to 1 mA/m).
- Select lines with low conductor-ground capacity. Symmetrical cables achieve favorable values. Single conductor configuration yields higher leakage currents.
- The use of shielded cables can be dispensed with if the EMC requirements are also met with unshielded cables, for instance (i.e. with sine filters at the output).
- Connect existing cable shield according to information from the frequency converter's instructions.

- Avoid the use of manually operated switching devices for normal switching in order to reduce the duration of making and breaking asymmetries to a minimum.
- Use all-pole contactors or switching devices with a snap-action mechanism.
- Own power supply connection for the actuator
  (asymmetry in the grid causes additional leakage currents)
- Starting current limitation can reduce the dynamic leakage currents upon start-up.

- Use a common EMC filter for several loads
  (Keep the number of actuators after an FI circuit breaker as low as possible).
- Avoid simultaneously starting several frequency converters downstream of one RCD (or at least use starting current limitation).
- Distribute the circuit phases between several RCDs
  (leakage current is usually lower than the sum of individual filters).

Select as low a clock frequency as possible, in particular for type B+ residual current protection device (if usable for the application). Depending on the circumstances, an overall more favorable behavior can be achieved with higher clock frequencies with type B residual current protection devices which exhibit a tripping value which increases with the frequency, in spite of higher capacitive leakage currents. In any case, care must be taken to avoid resonance frequency ranges when setting EMC filters.

If possible, return all leakage currents to the frequency converter via the PE connection, in order to maximize the effect of the filtering measures and prevent the occurrence of undefined leakage currents.

Sine wave filters in the outgoing feeder of the frequency converter reliably filter out the switching frequency and its harmonics to produce almost sinusoidal output voltages and currents. EMC requirements can then usually also be satisfied with unshielded cables. This leads to a significant reduction in capacitive leakage currents downstream of the frequency converter (e.g. due to the cable capacitance per unit length). In some cases, it is even possible to dispense with the line filter on the input side and thus reduce the static and dynamic leakage currents still further. Output reactors, du/dt filters, or Nanoperm filters can be used as an alternative to sine wave filters, although they are less effective.

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3.4 Rated short-circuit capacity and rated conditional short-circuit current

Residual currents in the region of several hundred amperes can often occur, particularly in TN systems. This is the case if the insulation of a properly grounded device (e.g. a hot water storage heater) with a correspondingly low resistance is faulty. There is an additional possibility that arcing could simultaneously cause a ground fault, leading to a short-circuit.
In both instances, a current similar to a short-circuit flows via the residual current protective device whose contacts are in the process of opening. The contacts must be capable of withstanding this load. They must therefore be designed with a correspondingly high rated short-circuit capacity.

In accordance with the installation regulations (IEC 60364-4-41 or HD 60364-4-41), residual current protective devices can be installed in all system types (TT, NT, and IT). The residual currents similar to a short-circuit that occur in TN systems if the neutral conductor is used as a PE conductor mean that RCDs protected by a backup fuse must be designed for a corresponding rated short-circuit current. The rated short-circuit current of this combination is indicated on the RCDs together with the rated current of the upstream fuse.

In the case of Siemens residual current protective devices, rated short-circuit capacity and rated residual switching capacity are not differentiated and nor are rated conditional short-circuit current and rated conditional residual short-circuit current (see Section A.3 for definitions). The reason for this is that the values for the residual and short-circuit currents are often identical.

Siemens RCCBs with a suitable backup fuse usually have a rated conditional short-circuit current of 10 kA. The values indicated for the short-circuit backup fuse refer to the gG utilization category.

According to the valid device determination (DIN EN 61008-1/VDE 0664-10), the rated short-circuit capacity is predominately 800 A. As such, it clearly exceeds the minimum requirements of 500 A or 630 A (see Table 5) for devices of up to 63 A rated current. The specifications for the maximum permissible short-circuit backup fuse are based on a short-circuit resistance of 10 kA.

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Rated current of the residual current protective device Type AC Type A Type B Type B+		Rated short-circuit capacity Im acc. to IEC/EN 61008 (VDE 0664) at a grid distance of 35 mm	Maximum permissible short-circuit backup fuse NH, DIAZED, NEOZED Utilization category gG for residual current protective device 125 V ...	
			400 V AC	500 V AC
A	MW	A	A	A
16-40	2,0	500	63	–
63,80	2,5	800	100	–
100, 125	2,0	1250	125	–
25,40 (400Hz)	4,0	800	80	–
25-63	4,0	800	100	63
80	4,0	800	100	–
100	4,0	1000	100	–
125	4,0	1250	125	–

Table 5: Rated short-circuit capacity and maximum permissible short-circuit backup fuses

The use of miniature circuit breakers or power switches instead of the specified fuses will result in markedly lower rated values in parts due to the higher throughput values until the circuit shuts off. A direct specification for the permissible rated current of these circuit breakers cannot be given here due to the great differences in design and tripping characteristics. But the maximum permissible rated current of the allocated overcurrent protection device can be determined in consideration of the maximum permissible limit value of the residual current circuit breaker.
The rated current of the allocated overcurrent protection device can be determined based on the maximum permissible short-circuit back-up fusing according to Table 5 specified on the residual current circuit breakers. In the process, the following maximum values must be complied with for series 5SM3 residual current circuit breakers:

max. permissible short-circuit back-up fusing	maximum I^2t value	max. current peak value
63 A	25.000 A^2s	6,0 kA
80 A	40.000 A^2s	7,0 kA
100 A	70.000 A^2s	7,5 kA
125 A	94.000 A^2s	8,0 kA

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3.5 Selecting the rated current based on thermal load

The most important way to prevent thermal overloading of an RCCB is to carefully plan the load circuits downstream of this breaker. It is therefore imperative to ensure that

– the rated current of the upstream fuse does not exceed the rated current of the RCCB
or

– the sum of the rated currents of the overcurrent protective devices connected downstream of the RCCB does not exceed the rated current of this RCCB

If the purpose for which the circuits are to be used is known, it is permissible to estimate the expected operational current. A note in DIN VDE 0100-530 states that it is permissible to use the expected operational current as a rating selection criterion in order to prevent overloading of residual current protective devices without integrated overload protection as long as the instructions of the RCD manufacturer regarding the rated current and type of overcurrent protection device are used as basis form the estimation.

Rated load factors (demand factors) for the connected circuits can be used as a basis for determining the expected operational current. In the tables 6 and 7, guide values for considering the rated load factor are shown.

Load groups	Office buildings	Hospitals	Department stores
Lighting	0.85 ... 0.95	0.7 ... 0.9	0.85 ... 0.95
Air conditioning	1	0.9 ... 1	0.9 ... 1
Kitchens	0.5 ... 0.85	0.6 ... 0.8	0.6 ... 0.8
Elevators/escalators	0.7... 1	0.5 ... 1	0.7 ... 1
Socket outlets	0.1 ... 0.15	0.1 ... 0.2	0.2

Table 6: Rated load factors of different load groups

Number of main circuits	Load factor
2 and 3	0.9
4 and 5	0.8
6 and 7	0.7
10 and more	0.6

Table 7: Rated load factors according to the number of main circuits

The following points should be noted in order to avoid overloading of the RCCB:
– The rated current of the RCCB is the maximum permissible continuous operational current and must not be permanently exceeded.
– The backup fuse value indicated on the rating plate (63 A to 125 A) only provides short-circuit protection for the RCCB (see Section 3.4).

These thermal load considerations no longer apply if RCBOs are installed. Overloading is prevented by the integrated thermal release of the overcurrent protection feature.

3.6 Troubleshooting

If a residual current protective device trips, the first troubleshooting step should be to follow the procedure outlined in the diagram below (Figure 25).

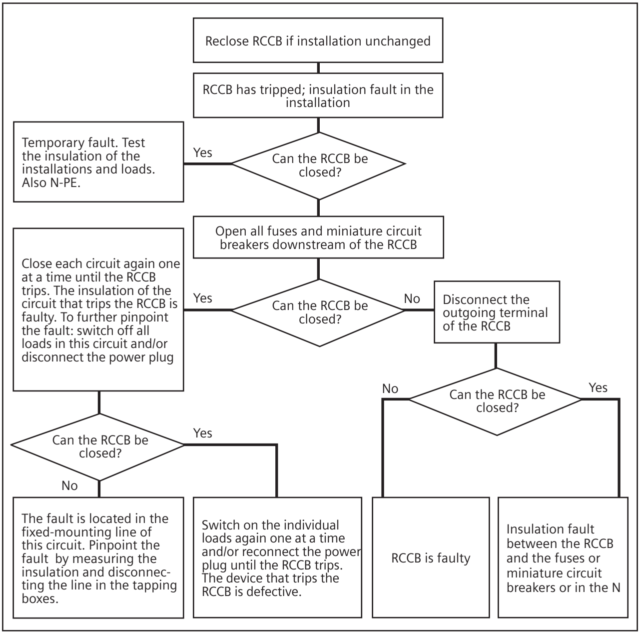

Figure 25: Troubleshooting flowchart

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3.7 Leakage current measurement

If leakage currents occur frequently in normal operation or if electrical loads with high leakage currents are used because the system has not been optimally configured, for instance if there are too many electrical loads, the tripping current of the upstream residual current protective device may be exceeded, depending on the operational status of the electrical installation. Spurious tripping results.

To prevent residual current protective devices from inadvertently tripping in practical duty, the leakage current that flows in the system during normal operation should always be less than 0.3 times the rated residual current.

A leakage current measurement unit (see Figure 26) can be connected into the system in series with the residual current protective device to facilitate detection, and if necessary monitoring, of the status of the installation. This unit measures the leakage current flowing during normal system operation.

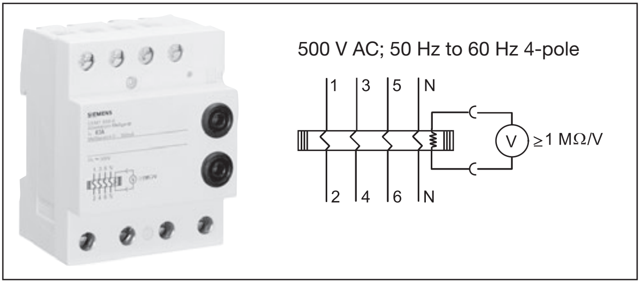

Figure 26: 5SM19300 leakage current measurement unit

The leakage current measurement unit functions according to the same principle as the residual current protective device. Instead of the device tripping, however, the leakage current is converted via the test sockets on the front to a voltage that can be read off on a high-impedance voltmeter. The calibration curve supplied with the unit provides a rough indication of the leakage current.

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3.8 Four-pole RCCBs in a three-pole system

The four-pole (3+N) variant of the RCCBs can also be operated in three-pole systems. In this case, the three-pole connection must be at terminals 1, 3, 5 and 2, 4, 6.

The device function is not impaired as a result. Functioning of the test circuit is only ensured if a jumper is fitted between terminals 3 and N (this is also described in the operating instructions).

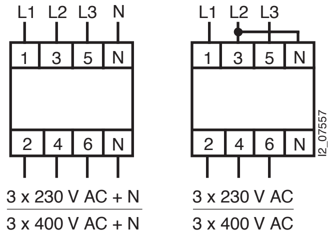

Figure 27: 4-pole RCCB in a 3-pole system

4 Differential current monitors (RCM)

In addition to personal protection by means of residual current protection devices (RCD), permanent differential current monitoring is becoming increasingly important in increasing system and operational safety and power supply monitoring.

Differential current monitoring devices, also known as residual current monitors (RCM), monitor residual currents in electrical systems and report when they exceed a determined value. RCMs are not approved for implementing the “automatic power supply shutoff” protective measure according to the product standard for residual current monitors DIN EN 62020 (VDE 0663) and/or IEC 62020. However, an RCM can be used in conjunction with protective devices.

Continuous residual current monitoring can already detect and signal faults before the protective device responds. Sudden system shutdown can frequently be avoided this way. For that reason, residual current monitors are primarily used in systems in which a signal, but not a shutdown, should be carried out in the event of a fault. In addition, the residual current monitoring counts as a preventative maintenance measure in electrical systems.

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The residual current monitors function the same way as fault current protection devices do. The summation current transformer covers all conductors needed to carry current, i.e. the neutral conductor as well, if necessary. In a fault free system, the magnetizing effects of the current-carrying conductors are cancelled out for the transformer, and the sum of all currents is equivalent to zero (Kirchhoff's 1st law of circuits). A residual magnetic field will only remain in the transformer core if a residual current is flowing which generates voltage. The voltage will be evaluated by the RCM electronics and the switched contact can be used to control such elements as an acoustic/optical signal, a superordinate control unit or a circuit breaker. RCMs are not equipped with a direct shut-off function.

RCMs are widespread in a design with integral current transformers as well as external summation current transformers. External summation current transformers are available with different inside diameters. This even makes it possible to monitor installations with rated currents of several hundred amperes. Furthermore, residual current monitors can be distinguished by adjustable values for response residual current, response time and, if applicable, the display of the current residual current value.

The ability to adjust the response residual current and time behavior constitutes a significant advantage of the RCMs. This enables system-specific adjustment and makes it possible to take leakage currents which are permanently present into account. These leakage currents are caused by capacities in the cables and lines or in electrical equipment, for instance.

RCMs as additional fire protection

In accordance with DIN VDE 0100-530, RCMs coupled with a switching device with separator function can be used as an alternative to fire protection if residual current protective devices (RCDs) cannot be used for fire protection, because the operating current of the circuit to be protected is greater than the greatest rated current of the residual current protective devices (RCDs). A perquisite for this is that the response residual current does not exceed 300 mA and that the monitored grid is shut off in the event of a failure in the residual current monitor’s (RCM) supply voltage.

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5 Outlook

There is a growing demand for residual current protective devices in electrical installations owing to the high level of protection they afford.

At the same time, the widespread use of residual current protective devices to protect a large variety of different loads means that even more complex functional requirements need to be met. The use of type B universal current-sensitive RCDs as well as super resistant devices or variants for severe environmental conditions exemplify how requirements have increased. This trend is predicted to continue in future.

Combinations of RCBOs are also increasing in popularity – either as a compact unit or as an RC unit in conjunction with miniature circuit breakers that can be installed where required.

These RCBO combination units are installed in all circuits of modern electrical installations, combining maximum operating safety with electric shock and line protection.

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Appendix

A.1 Key terms and definitions

(according to IEC 60050-826)

- *Line conductor (symbols L1, L2, L3)*
  Conductors that connect current sources to current-using equipment but that do not originate at the center point or start point.
- *Neutral conductor (symbol N)*
  Conductor that is connected to the center point or start point and that is suitable for transmitting electricity.
- *Protective conductor (symbol PE)*
  Conductor required for certain forms of protection against hazardous electric shock currents in order to establish an electrical connection with one of the following parts:
  - Body of the electrical equipment
  - External conductive parts
  - Main ground terminal
  - Ground electrode
  - Ground point of the current source or artificial star point
- *PEN conductor*
  Grounded conductor that simultaneously functions as the PE conductor and the neutral conductor.
- *Rated voltage (of an installation)*
  Voltage that characterizes an installation or part of an installation.
- *Touch voltage*
  Voltage that may be present between simultaneously touchable parts in the event of an insulation fault.
- *Live part*
  Conductor or conductive part that is intended to be live during normal operation, including the neutral conductor but (according to agreement) not the PEN conductor.

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- *Exposed conductive part (of the electrical equipment)*
  Touchable, conductive part of the electrical equipment that is not normally live but that may be live in the event of a fault.
- *Electric shock*
  Pathophysiological effect caused by an electric current flowing through the body of a person or animal.
- *Additional protection*
  Supplementary measure to reduce the risks that may arise to persons and livestock if the basic and/or fault protection is rendered ineffective.
- *Basic protection*
  Protection against electric shock in a non-faulty system.
  The basic protection usually corresponds to the protection against direct contact described in IEC 60364-4-41 or HD 60364-4-41.
- *Fault protection*
  Protection against electric shock if a single fault occurs (e.g. faulty basic insulation).
  The fault protection usually corresponds to the protection against indirect contact described in IEC 60364-4-41 or HD 60364-4-41.
- *Direct contact*
  Contact between live parts and persons or livestock (pets).
- *Indirect contact*
  Contact between a body of electrical equipment that is live as a result of a fault and persons or livestock (pets).
- *Shock current*
  Current flowing through the body of a person or animal with characteristics that are likely to trigger a pathophysiological (harmful) effect.

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- *Leakage current (in an installation)*

  Current flowing in a non-faulty circuit to ground or to an external conductive part.
- *Residual current*
  Sum of the instantaneous values of all currents flowing through all active conductors in a circuit at a defined point in the electrical system.

  In connection with residual current protective devices, the differential current is referred to as "residual current" in accordance with the standards in IEC 61008-1 or EN 61008-1 series.
- *Operational current*
  Current that should flow in the circuit during normal operation.
- *Ground (earth)*
  Conductive mass of ground whose electric potential is set to zero at all points according to agreement.
- *Ground electrode*
  Conductive part or parts that make good contact with ground and form an electrical connection with it.
- *Total grounding resistance*
  Resistance between the main ground terminal/busbar and ground.

A.2 Types of system grounding and protective devices

The various power systems are defined in IEC 60364-3 or HD 60384.3 S2. The permissible protective devices for these systems are specified in IEC 60364-4-41 or HD 60364-4-41.

The power systems are identified by means of codes where the individual letters have the following meanings:
1st letter = Relationship of power system to ground

T Point grounded directly

I Either all active parts insulated from ground or a single point connected to ground via an impedance

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2nd letter = Relationship of the exposed-conductive-parts of the installation to ground

T direct electrical connection of exposed-conductive-parts to ground, independently of the grounding of any point of the power system

N direct electrical connection of exposed-conductive-parts to grounded point of the power system.

Subsequent letters = Arrangement of the neutral and PE conductors in a TN system

S Neutral and PE conductor functions implemented with separate conductors

C Neutral and PE conductor functions combined in a single conductor (PEN conductor)

A.2.1 TN system

All bodies in the system must be connected by PE conductors to the grounded point of the supply system, which must be grounded on or in the vicinity of the associated transformer or generator. The various types of TN system are shown in Figures A1, A2, and A3.

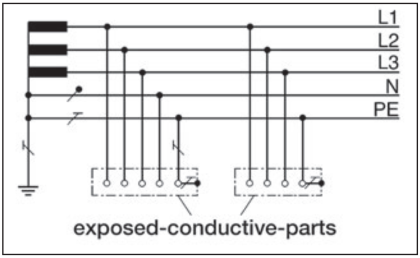

Figure A1: TN-S system

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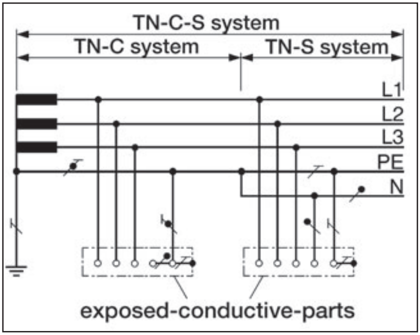

Figure A2: TN-C-S system

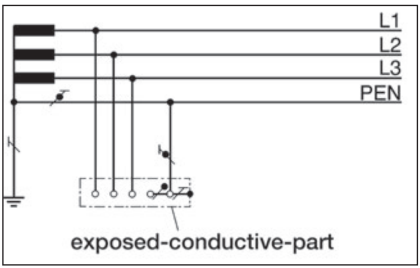

Figure A3: TN-C system

Permissible protective measures in TN systems:
– Overcurrent protective devices
– Residual current protective devices
  (but not in TN-C systems)

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A.2.2 TT systems

All bodies protected by the same protective device must be connected to a common ground electrode by means of PE conductors (see Figure A4).

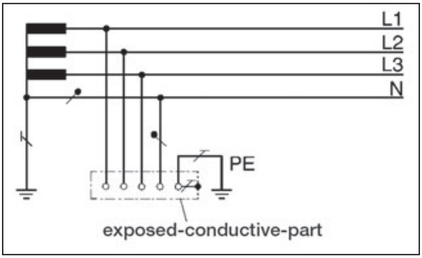

Figure A4: TT system

Permissible protective measures:
– Residual current protective devices
– Overcurrent protective devices

If residual current protective devices are used, different maximum permissible grounding resistances are specified for type AC and type A to enable the above conditions to be fulfilled, depending on the rated residual current (see Table A1).

Rated residual current $I_{\Delta n}$	Max. permissible grounding resistance at a max. permissible touch voltage of	
	50 V	25 V
10 mA	5000 Ω	2500 Ω
30 mA	1660 Ω	830 Ω
100 mA	500 Ω	250 Ω
300 mA	170 Ω	85 Ω
500 mA	100 Ω	50 Ω
1 A	50 Ω	25 Ω

Table A1: Max. permissible grounding resistance depending on $I_{\Delta n}$

If the equipment used has different frequency components in the possible residual current, the information contained in Section 2.4.3 must be noted for type B SIQUENCE universal current-sensitive RCDs.

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A.2.3IT systems

Live parts in IT systems (see Figure A5) must either be insulated from ground or designed with a sufficiently high impedance. The bodies must be grounded individually, or in groups, or provided with a common ground.

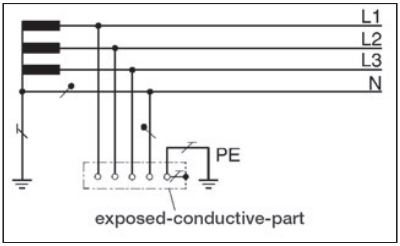

Figure A5: IT system

Permissible protective measures:
– Insulation monitoring devices
– Overcurrent protective devices
– Residual current protective devices

Tripping is not required for the first fault. However, measures must be taken to preclude all risk of pathophysiological effects on persons when the second fault occurs.

It is essential that an insulation monitoring device is fitted to enable the first fault to be indicated by an acoustic or visual signal and eliminated as quickly as possible.

Certain conditions must be satisfied after the first fault, depending on how the loads are grounded (individually, in groups, or with a common ground). If these conditions cannot be met with overcurrent protective devices, either separate residual current protective devices must be provided for each item of current-using equipment or additional equipotential bonding must be provided.

No mutual interference results if insulation monitoring devices and residual current protective devices are used in the same system.

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A.2.4 Summary

Residual current protective devices can be used in all three different types of system grounding of an AC or three-phase system (TN, TT, or IT, see Figure A6). The protection afforded by residual current protective devices is superior to that offered by other approved protective devices, because in addition to protection in case of indirect contact when RCDs with $I_{\Delta n} \leq 30$ mA are used, they also provide protection in the event of direct contact, and with their $I_{\Delta n} \leq 300$ mA play an important role in preventive protection against electrically ignited fires caused by ground fault currents.

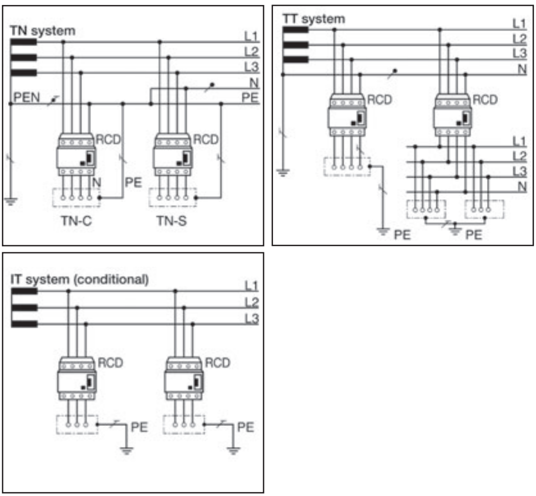

Figure A6: Residual current protective devices in the all different types of system grounding

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A.3 Key terms and definitions for specifying the switching capacity

– Rated making and breaking capacity I_m of an RCCB (IEC 61008-1 or EN 61008-1):
Prospective r.m.s. value of the short-circuit current which an RCCB can make, carry, and break under defined circumstances.

– Rated short-circuit capacity I_{cn} of an RCBO (IEC 61009-1 or EN 61009-1):
The rated short-circuit capacity of an RCBO is the ultimate short-circuit switching capacity value determined by the manufacturer.

– Rated residual switching capacity $I_{\Delta m}$ (IEC 61008-1 or EN 61008-1 and IEC 61009-1 or EN 61009-1):
Prospective r.m.s. value of the residual current which a residual current protective device can make, carry, and break under defined circumstances.

– Rated conditional short-circuit current Inc (IEC 61008-1 or EN 61008-1):
Prospective current which an RCCB protected by a short-circuit backup fuse can withstand without undergoing functional impairments.

– Rated conditional residual short-circuit current $I_{\Delta c}$ (IEC 61008-1 or EN 61008-1):
Prospective residual current which an RCCB protected by a short-circuit backup fuse can withstand without undergoing functional impairments.

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A.4 Installation standards for electrical installations with residual current protective devices

Standards IEC or HD	Application	Required $I_{\Delta n}$ [mA]	Recommended Siemens residual current protective device		
			5SM.. (Type A)	5SM3 SIQUENCE (Type B)	5SM...-KK12 SIGRES
60364-4-41	Protection against electric shock	30 ... 500	+	+	+
	Socket outlets up to 20 A, outdoor installations	10 ... 30	+		
60364-4-482	Fire protection against special risks or hazards	30 and 300	+	+	
60364-5-551	Low-voltage power generating installations	10 ... 30	+		
60364-7-701	Rooms with bathtubs or showers, outlets in zone 3	10 ... 30	+		
60364-7-702	Swimming pools and other pools	10 ... 30	+		+
60364-7-703	Rooms and cabins with sauna heating	10 ... 30	+		+
60364-7-704	Construction sites, socket outlet circuits up to 32 A and for handheld equipment, plug-and-socket devices up to I_n > 32 A	≤ 30 mA ≤ 500 mA	+ +	+ +	+ +
60364-7-705	Agricultural and general horticultural premises, socket outlet circuits	≤ 300 10 ... 30	+ +		+ +
60364-7-706	Conductive areas with limited freedom of movement	10 ... 30	+		
60364-7-708	Electrical equipment on camping sites, each socket outlet individually	10 ... 30	+		+
DIN VDE 0100-710	Medical premises in a TN-S system, depending on application group 1 or 2 and equipment	10 ... 30 or ≤ 300	+ +	+ +	
60364-7-712	Solar PV power supply systems (without a simple means of disconnection)	≤ 300		+	

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Standards	Application	Required $I_{\Delta n}$ [mA]	Recommended Siemens residual current protective device		
			5SM.. (Typ A)	5SM3 SIQUENCE (Typ B)	5SM...-KK12 SIGRES
DIN VDE 0100-723	Classrooms with experiment stands	10 ... 30		+	
DIN VDE 0100-739	Additional protection for direct touching in homes	10 ... 30	+		
EN 50178	Equipment of heavy-current installations with electronic components	General requirements for the correct selection of RCDs	+	+	
HD 60638 S1	Road traffic lights Class T1 Class U1	 ≤ 300 ≤ 30	 + +		 + +
	Food and chemical industry	recommended ≤ 30 mA	+		+

Note:
For reasons of basic fire protection, we recommend a maximum rated residual current of 300 mA for residual current protection devices.

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