RCD Principles

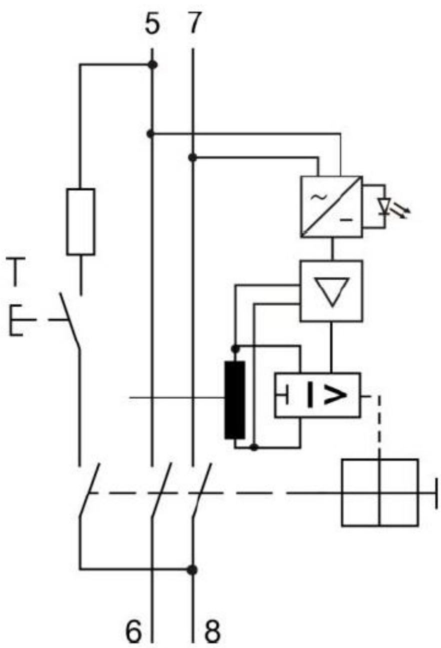
Residual Current Protection

&

Selection for UK Installations

Oct 2017

(Includes proposed 18th Edition RCD requirements)



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Content

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Reference to the 18th Edition of BS7671 is purely for example only and not for use in the design of any installation. Users must be in possession of their own copy and are responsible for its correct application. Other references documents used: HD60364-5-53: 2015, TR62350, IEC62477-1

Technical Questions

Please direct any questions, ambiguity, inaccuracy and or suggestion for improvements or additions to this publication to:

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 Adapted for the UK Market from the original German version 10/2015

1. Fundamental principles of residual current protection

1.1 Principle

A residual current operated protective device (**RCD**) continuously monitors the sum of the instantaneous values of all currents, flowing through the Live and Neutral (current carrying) conductors connected to an electrical load, supplied from an AC energy source.

RCD	Generic term covering devices incorporating residual current protection.
RCCB	Residual Current Circuit Breaker - without overload or short circuit protection
RCBO	Residual Current Circuit Breaker + overload and short circuit protection (MCB)
CBR	Residual Current Circuit Breaker + overload and short circuit protection (MCCB)

RCDs use the principles of Kirchhoff's first law: That is, the algebraic sum of the currents flowing to and from a node in a circuit should be equal to zero. In the event of an insulation fault to earth, a fault current (Residual Current) flows back to the source of the current via the earth and not via the current carrying conductors. This induces a current flow in the RCD trip circuit, i.e. the sum of the currents flowing through the RCD no longer equal zero. If the effective value of the residual current I_{Δ} exceeds 50% of the designed operating level of the RCD (Rated residual current $I_{\Delta n}$), the RCD will trip and disconnect the load from the supply. Additional information on the basic operating principles of RCDs can be found in Appendix 1.

"Passive" RCDs work independently of the supply voltage, and are used for the majority of applications in the UK. Passive RCDs will remain energized during a power failure, thus ensuring that when the power is restored, freezers and lighting etc will be powered up immediately. "Active" RCDs trip on the loss of the supply voltage and are only used for specific applications such as garden tools, power tools etc where in the event of a lose of supply the RCD will trip.

1.2 Protective Measure: Automatic Disconnection of Supply as per BS 7671 Regulation 411

Note: Refer to the 18th Edition Chapter 41 for detailed changes and new requirements.

Under single fault conditions the metal casing (exposed conductive part) of electrical equipment may become live. A person touching a live casing who is also in contact with earth, or other earthed equipment or services such as gas or water pipes (extraneous conductive parts), will be exposed to the risk of electrocution if the electrical supply is not disconnected quickly enough. Therefore BS7671 specifies maximum disconnection times (411.3.2.2), in combination with maximum earth fault loop impedance values Z_s (411.5.3) and the RCD characteristics (<30mA), to reduce the risk of a fatal electric shock under single fault conditions; see Figure 1 page 4.

Note: 18th Edition proposed changes to clause 411.3.2.2 , 411.3.3 and 411.3.4 (RCD protection)

Basic Protection, Fault Protection and Additional Protection provided by an RCD

30mA RCDs (see 415.1) provide additional protection in conjunction with basic protection (see 416) and fault protection (see 413) i.e. RCDs are in addition to, not instead of, see Figure 2 page 5.

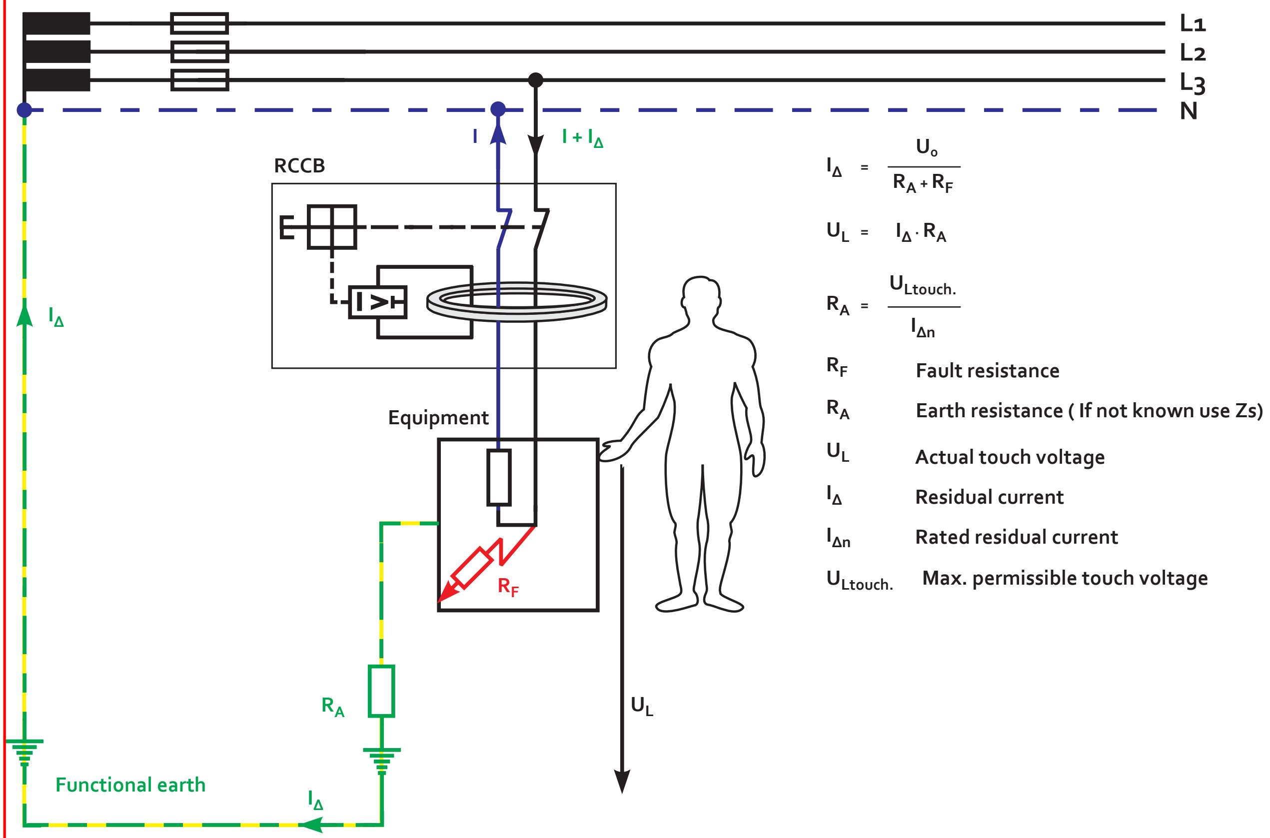


Figure 1: Residual current protection under single fault conditions in a TT system

An RCD used for fault protection must meet the condition RA × IΔn ≤ 50 V (see 411.5.3) and the disconnection times given in Table 41.1 applied to final circuits see changes to clause 411.3.2.2. To meet this requirement the circuit Z_S value must be low enough and stable enough to maintain the tripping time: See Table 41.5 Note 2 and Regulation 542.2.4

Table 1. Maximum earth fault loop impedance (Z_s) for non-delayed RCCBs to BS EN 61008-1

Rated residual current $I_{\Delta n}$	$U_L \leq 50$ V (-5°C)	$U_L \leq 50$ V (-25 °C)
0.01 A	5000 Ω	4000 Ω
0.03 A	1660 Ω	1330 Ω
0.10 A*	500 Ω	400 Ω
0.30 A*	166 Ω	130 Ω
0.50 A*	100 Ω	80 Ω

Notes:
Operating current IΔn of the RCD at -25°C can be 25% greater than at -5°C.

Where RA is not known it may be replaced by Z_S.

*When using Selective RCDs, the Zs values may be halved to achieve fire protection.

Notes : Automatic disconnection in case of a fault; see BS7671 Regulation 411.3.2 / Table 41.1

Changes to 411.3.2

(i) Final circuits with a rated current <63A with 1 or more sockets
(ii) Final circuits with a rated current <32A supplying only fixed equipment

Changes to 411.3.3

(i) Socket outlets with a rated current <32A
(ii) Mobile equipment with a rated current <32A for use outdoors

The Regulations now require RCD protection for all socket outlets (No exceptions).

New 411.3.4

All final lighting circuits (fixed) within domestic installations shall be provided with additional protection via an RCD not exceeding 30mA.

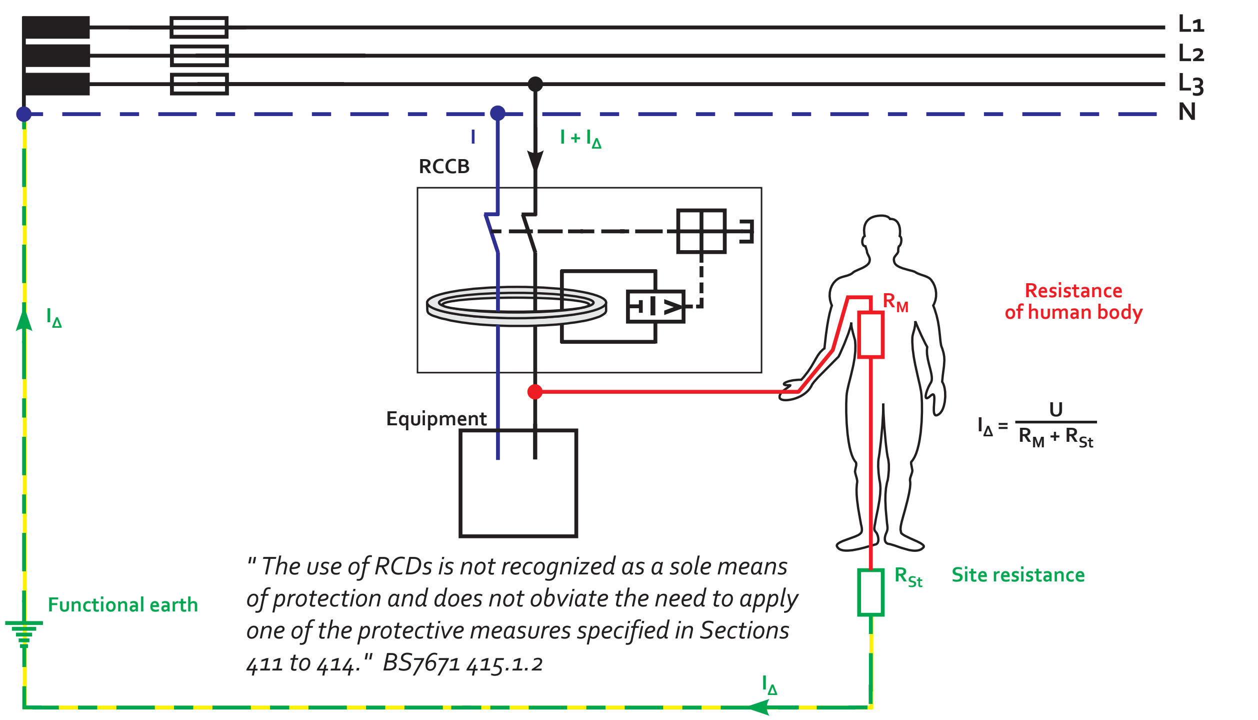


Figure 2: Residual current protection under normal conditions

1.3 Additional protection (RCDs): BS7671 Regulation 415

RCDs with IΔn <30mA and an operating time <40mS at 5IΔn, are recognized as a means of additional protection in the event of a person coming into contact with a current carrying conductor, due to carelessness (see Figure 2). Special note should be taken of the additional requirements for supplementary protective equipotential bonding. The resistance between simultaneously accessible exposed-conductive-parts and extraneous-conductive-parts must meet the following condition for AC circuits: R < 50 V / IΔn

Examples of applications requiring additional protection using RCDs:

(i)	Socket-outlets < 32A:	Reg.	411.3.3
(ii)	Mobile equipment outdoor use < 32A	Reg.	411.3.3
(iii)	Fixed Lighting in domestic premises	Reg.	411.3.4
(iv)	Concealed cables	Reg. 522.6.202 & 203	

(v) Special installations / locations as detailed in BS7671 section 7: See below

- » Locations containing Bath or Shower: See Reg. 701.411.3.3
- » Swimming Pools and other Basins (Zone 2): See Reg. 702.410.3.4.3
- » Rooms / Cabins containing Sauna Heaters: See Reg. 703.411.3.3
- » Construction and Demolition Sites: See Reg. 704.410.3.10
- » Agricultural / Horticultural Premises: See Reg. 705.411.1
- » Conducting Locations with Restricted Movement: See Reg. 706.410.3.10
- » Caravan / Camping Parks: See Reg. 708.415.1
- » Exhibition Stands and Shows: See Reg. 711.411.3.3
- » Outdoor Lighting: See Reg. 714.411.3.3
- » Marinas, Medical, Solar, Mobile Units, EV Charging : Additional conditions and risks apply / specific experience required in the design and construction of installations associated with these applications. Refer to the revised Regulations for details.

Current flows through the human body to earth when contact is made with a voltage-carrying component, i.e. the body is subjected to the effects of the current (electric shock) until the supply is disconnected. RCDs limit the duration of the electric shock, not the level of current; see Figure 1 &2. Therefore RCDs cannot be used in place of a basic protective measure, they provide an additional protection measure when a basic protection measure has failed or been breached; see BS7671 Regulation 410.

1.4 Fire protection

RCDs with IΔn ≤ 300 mA reduce the risk of earth fault currents igniting combustible materials in locations where particular fire hazards exist; see Regulation 532.1. A build-up of surface contamination from carbon based products such as cooking oil, detergent, soot, material fibers found in households and commercial kitchens, can increase the risk of fire due to earth leakage / tracking on contaminated surfaces. RCDs with IΔn > 300 mA can be used where the electrical power output at the point of the fault (surface tracking), is below the ignition temperature of the surrounding surfaces and or any surface contaminates.

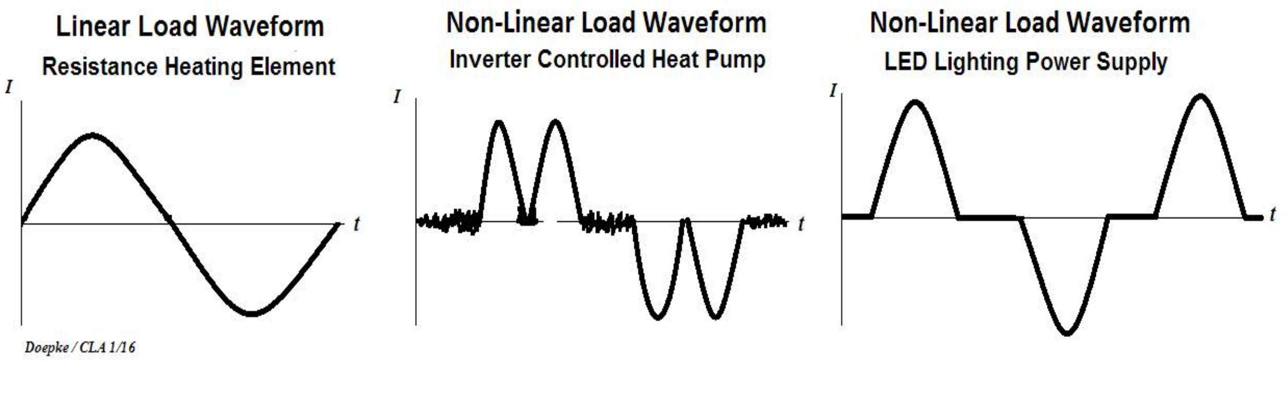
1.5 Devices for Electric Shock Protection (Automatic Disconnection of Supply)

Regulation 531 defines the requirements for RCDs for fault protection, compared to a device suitable only for fault monitoring (RCM); see note in BS7671 Regulation 411.1 : RCMs require immediate attention by trained electrical staff.

1.6 Supply frequency

To meet the tripping characteristics and operating tolerances defined in the standards, RCDs must be calibrated for specific supply frequencies and voltages. For standard devices supplied in Europe this value is 50 Hz /230V for 2 pole devices and 50Hz/400V for 4 pole devices. For other voltages and frequencies, refer to the manufacturer for the availability of specially manufactured products. Doepke manufacture a wide range of non-standard RCCBs see contact details inside front cover.

Figure 3: Examples of Linear and Non-Linear loads



2. Types of RCD and areas of application: BS7671 Regulation 531.3.3

2.1 Characteristics of the load determine the Type of RCD required for protection

The nature of the load connected to the electrical supply has an effect on the characteristics of the supply wave form; see fig 3 page 6.

i. Linear loads (Resistive) do not alter the supply wave form, the residual current matches the original supply wave form.

ii. Non-Linear loads (Impedance changes with applied voltage) alter the shape of the supply wave form, the leakage current and the residual current wave form.

AC voltage equipment that contains non-linear passive or active electronic components, produces non-linear load currents and residual currents. The characteristics of the residual current will be a function of the currents generated by the load, at the point in the circuit where the fault is located, i.e. residual currents may contain, 50Hz AC, pulsed DC, smooth DC and high frequency AC components.

BS7671 Regulation 531.3.3 defines the Type of RCD required, based on the characteristics of the residual current. This is summarised in the table below. BS7671 Figure A531.1 details the Type of RCD required based on the load/circuit characteristics, the location of the fault and the most likely residual current ; see pages 8 & 9.

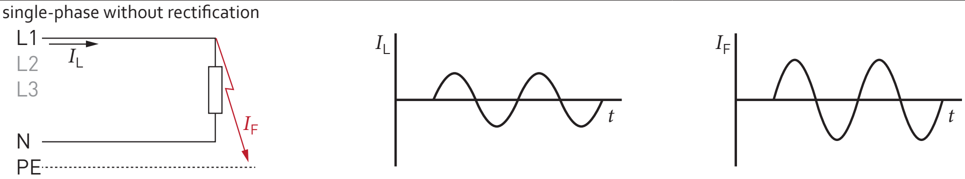
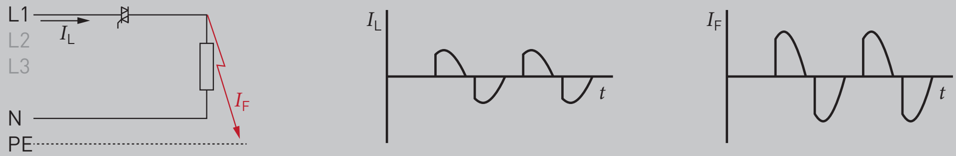
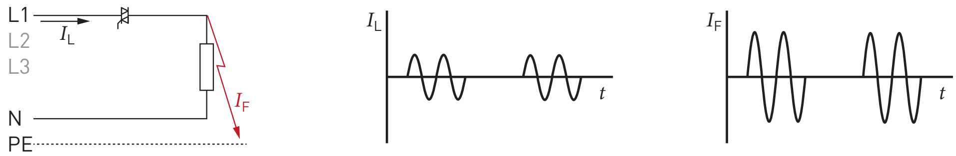
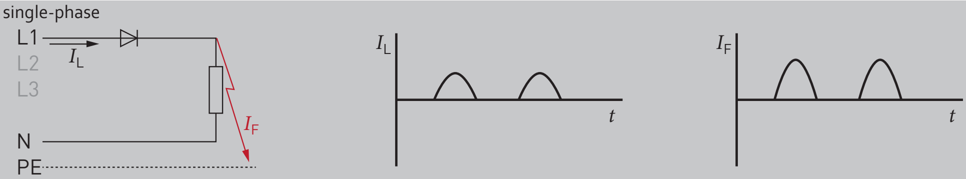
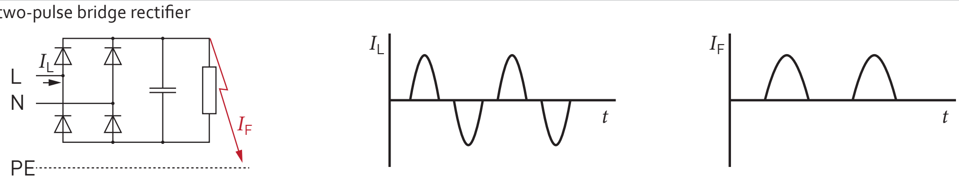
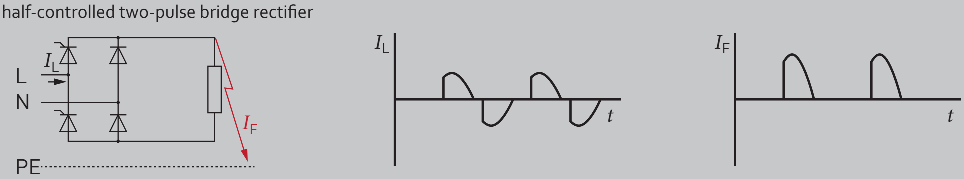
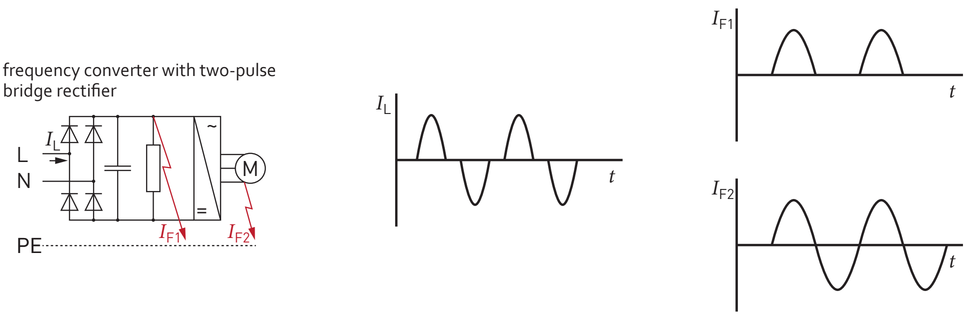
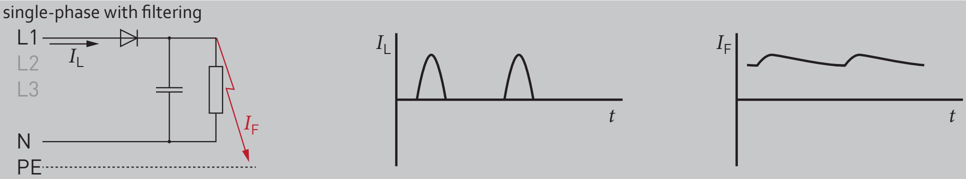
Points to note with regard to the detection of smooth DC residual currents:

(1) Type B: Trips on smooth DC at levels related to the AC IΔn value.

(2) Type A, AKV, F do not detect smooth DC. Therefore they must not be used in circuits where the indicated value could be exceeded, as this will result in a loss of protection; see Appendix. 1. for further details

(3) Type EV: Trips on smooth DC residual current if the level exceeds 6mA. Type EV RCDs are designed specifically to meet the requirements of BS7671 Regulation. 722.531.2.101.
Each charge point must incorporate one of the following protective measures against DC fault currents; provided in EV technology or Type B RCD or Type A with associated technology to detect smooth DC residual current and disconnection if the current exceeds 6mA.

	Residual / Leakage current components				Transient Resistant
RCCB Type	AC 50Hz	AC 50Hz Pulse	Smooth DC	AC>50HZ<kHz	3kA/20µS Current Wave
AC	✓	X	X	X	X
A	✓	✓	< 6mA (1)	X	X
AKV	✓	✓	< 6mA (1)	X	✓
F	✓	✓	< 10mA (1)	✓	✓
B	✓	✓	✓ (1)	✓	✓
EV	✓	✓	< 6mA (2)	✓	✓

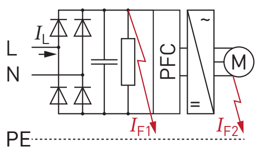
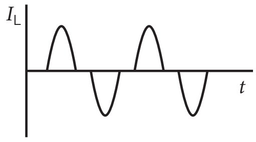
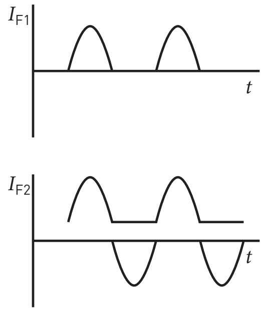
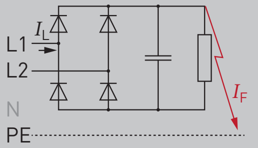
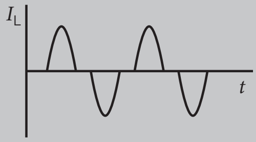
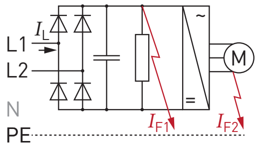
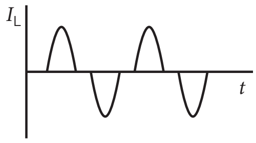
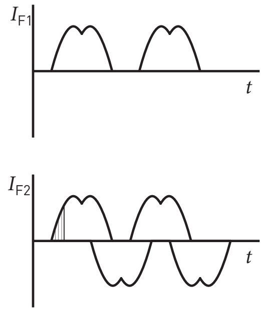
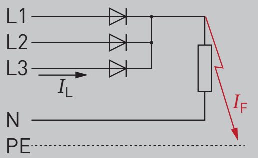
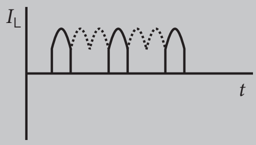
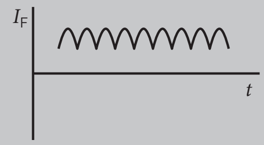
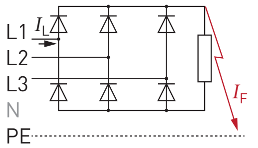
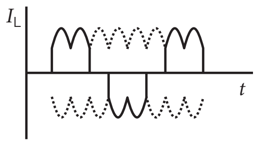
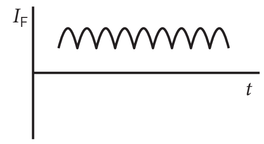
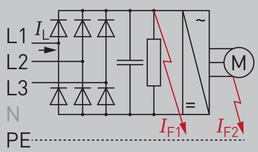
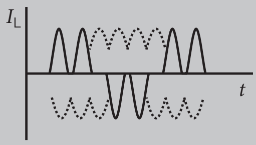
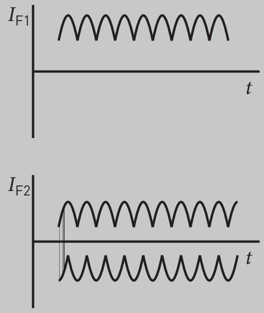
No.	Basic circuit with fault point	Load current profile	Residual current profile	Tripping characteristics AC	A	F	B	B+
1	single-phase without rectification 			✓	✓	✓	✓	✓
2	leading edge control 			✓	✓	✓	✓	✓
3	burst control 			X	✓	✓	✓	✓
4	single-phase 			X	✓	✓	✓	✓
5	two-pulse bridge rectifier 			X	✓	✓	✓	✓
6	half-controlled two-pulse bridge rectifier 			X	✓	✓	✓	✓
7	frequency converter with two-pulse bridge rectifier 			X	X	✓	✓	✓
8	single-phase with filtering 			X	X	X	✓	✓

Note: The resistance in the basic circuits with frequency converter (no. 7, 9, 11, 14) may be a brake resistor, for example.

Ref: BS7671 Fig. A53.1 Possible fault currents in systems with semiconductors.

Basic circuits for electronic equipment with non linear characteristics:
Time/current curve for load and residual currents, using the correct type of RCD and sensitivity achieves the required tripping time in line with applicable RCD Standards.

X : Indicates that this Type of RCD must not be used with the associated load.

No.	Basic circuit with fault point	Load current profile	Residual current profile	AC	A	F	B	B+
				Tripping characteristics				
9	frequency converter with two-pulse bridge rectifier and PFC level 			X	X	X	✓	✓
10	two-pulse bridge rectifier between external conductors 			X	X	X	✓	✓
11	frequency converter with two-pulse bridge rectifier between external conductors 			X	X	X	✓	✓
12	AC star circuit 			X	X	X	✓	✓
13	six-pulse bridge rectifier 			X	X	X	✓	✓
14	frequency converter with six-pulse bridge rectifier 			X	X	X	✓	✓

Note: The resistance in the basic circuits with frequency converter (no. 7, 9, 11, 14) may be a brake resistor, for example.

Manufacturers of equipment containing power electronic converter systems (PECS)*, must define clearly the safety requirements for RCD compatibility when their equipment is connected to an RCD protected circuit. If this information is not provided, Type B RCDs would have to be used by default.
The provision of clear installation instructions to enable safe installation, is a basic legal requirement of the UK Product Safety Regulations:

*Safety Reference Standard for PECS IEC62477-1 Annex H.

General guidance on the selection and use of RCDs is given in BS7671 Regulation 132.8 *"The protective devices shall operate at values of current, voltage and time which are suitably related to the characteristics of the circuits and to the possibilities of danger."* and Regulation 331.1 *"An assessment shall be made of any characteristics of equipment likely to have harmful effects upon other electrical equipment or other services or likely to impair the supply..".* The Regulations require that where RCDs are installed in any application and or location, they must be selected taking for the connected load, to ensure they will operate safely i.e. the Type of RCD is compatible with the load characteristics.

2.1.1 Application areas for type AC, A and F RCDs

Type AC RCDs for use on 50Hz supplies are designed to respond to sinusoidal residual currents with an average value of zero over 1 cycle, i.e. no DC component and THD <10%. The increasing use of equipment with non-linear load characteristics now requires the use of at least Type A RCDs to maintain a safe level of protection, e.g. PCs, Audio equipment, washing machines, some EV chargers and lighting controllers, contain circuits similar to those shown on page 8 & 9.

RCDs subject to residual currents with characteristics outside of the RCDs design limits (see table on page 7), will not provide the protection required. It is dangerous to use Type AC RCDs, where they may be subjected to pulsating DC and or smooth DC residual currents, rendering them ineffective for detecting AC residual currents.

Type A RCDs are designed to operate on 50Hz sinusoidal waveforms and pulsed DC with ≤ 6mA smooth DC present in the supply. Type A devices do not detect smooth DC current and therefore must not be used in applications where this value could exceed 6mA. For the RCD to function correctly, Type A residual current must pulsate so that it's instantaneous value is zero or almost zero (≤ 6 mA), at least for the duration of half a period of the mains frequency; see circuits 1 to 5 on page 8. Type A RCDs cannot be used with equipment containing 1/2wave rectification + filtering as this produces a DC residual current - see circuit 8 on page 8.

Some single-phase frequency-controlled equipment produces residual currents with mixed frequency components > 50Hz <1kHz, e.g. washing machines , power tools. Type A RCDs do not reliably detect mixed frequency residual currents, in this case Type F RCDs should be used; see table on page 7. The examples of equipment given above, normally contain EMC filters that produce transients during switch on and off. Type F RCDs have a greater resistance to nuisance tripping for fast transients < 3kA ,(standard RCD transient resistant < 0.25kA).

The residual current under fault conditions will be defined by the internal design and components included in the equipment and the location of the earth fault. Consequently only the original manufacturer of the inverter/equipment, can define accurately the characteristics of the residual current associated with faults on their equipment and the Type of RCD required. Using the incorrect Type of RCD with any electrical equipment with non-linear load characteristics is extremely dangerous, as it could lead to loss of the RCD protection within the installation.

Some common examples are given below, however, for safety reasons you must refer to the Equipment Manufacturers installation instructions relating to the correct Type of RCD that must be used with their equipment.

EQUIPMENT	Inverters [1] Heat Pumps HVAC etc.	Inverters Heat Pumps HVAC etc.	Lighting [1] Control Systems	Solar/Wind [1] Generation	Electric Vehicles [2] (EVCP) Mode 2 & 3 [3]
RCCB	Single Phase	Three Phase	Single Phase	Single or Three Phase	Single or Three Phase
Type A	✓	X	✓	✓	✓
Type AKV	✓	X	✓	X	✓
Type F	✓	X	✓	X	X
Type B	✓	✓	✓	✓	✓
Type EV [4]	X	X	X	X	✓
Selection Notes Doepke/CLA 7/16	1. **Selection** based on equipment technology & installation. (see manufacturers instructions) 2. **Selection** based on the Make & Model of the vehicle to be charged. (see manufacturers instructions) 3. **Mode 4** requires Type B RCCBs in all applications. 4. **EV applications only;** Trips if smooth DC fault current > 6mA.				

2.1.2 Application area for type B and B+ RCDs

Type B RCDs are used in applications where the equipment generates, in addition to residual currents mentioned, smooth DC residual current > 6mA; see circuits 8 to 14 on page 8 & 9.

To meet the requirements of UK Product Safety Regulations, manufactures of equipment that can generate smooth DC residual currents, have to specify the use of Type B RCDs with their equipment. Installers and Users have to follow the equipment manufacturers installation recommendations, relating to the use of Type B RCDs, to meet the requirements of UK Safety Regulations and Installation Regulations.

The use of Type B RCDs, applies to virtually all earthed two or three-phase power electronic equipment, if it is operated without galvanic isolation, e.g. inverters used in speed control, UPS , welding, PV, EV. Equipment of this type usually generates an output voltage in the form of bipolar pulse-width modulated rectangular pulses, with switching frequencies in the range from 1 kHz < 20 kHz for IGBT based inverters. In speed control applications, the resulting load current is sinusoidal with the desired set motor frequency, due to the inductance of the connected motors, but earth faults will generally be of a resistive nature. Consequently the output voltage of a frequency converter generates pulse-width modulated rectangular residual currents at the same frequency as the inverter switching frequency.

Operational leakage currents generated by "Power Drive System" (PDS), present a challenging subject for inverter manufacturers when specifying RCD characteristics for use with their inverters; see BSEN62477-1 for guidance. These leakage currents flow to earth continuously and can result in nuisance tripping of RCD protection devices. To avoid unwanted tripping, the sum of all leakage currents across the frequency response of the RCD should not exceed 30% of the rated residual current; see Regulation 531.3.2 (ii) and notes 1 and 2.

In these types of applications an RCD must also respond to residual currents generated at the switching frequency and the associated harmonics (at least 3rd and 5th harmonic), in order to achieve complete protection. The response thresholds of the associated RCD, must not exceed the maximum permissible values for the protection level required by the Regulations, namely fault protection, fire protection or additional protection, across the entire frequency range of the leakage currents generated by the load.

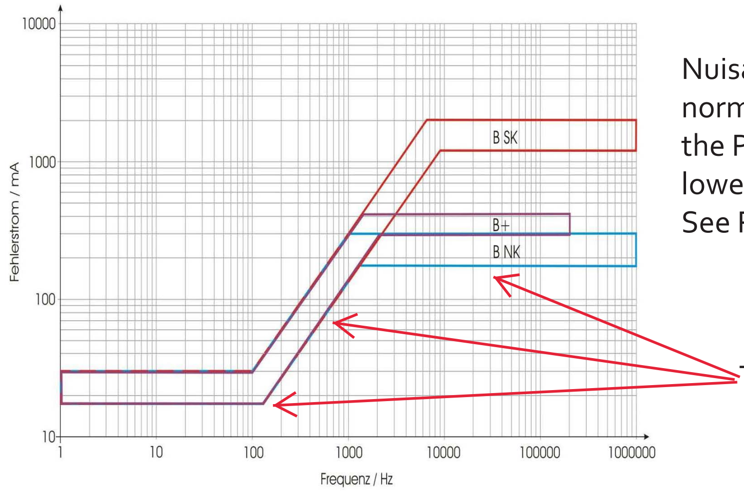
Unfortunately, insufficient attention has been given to this point in existing device standards. BSEN standards are based on international standards IEC 60755 and IEC 62423. These standards only cover residual current detection < 1 kHz. The German standard VDE 0664-100 E goes a little further, but still only provides information for residual current detection up to 2 kHz. At these higher frequencies, the standards allow for a corresponding increase in residual current detection level; 10 or 20 times the rated residual current are still permitted.

To maintain fire protection, for example to Regulation 532, the rated residual current must not exceed 300 mA - refer to 532.1. An Inverter based PDS may generate appreciable residual currents at frequencies < 100 kHz. Therefore the corresponding RCD must be capable of detecting leakage and residual currents, if they are likely to exceed the limits given in the Regulations for fire protection. The technology used in Doepke Type BNK and BSK RCCBs detect leakage currents with frequencies from 0 Hz< 100 kHz *.

***Note: Type B+** RCCBs are only suitable for detecting leakage currents < 20kHz.

The German standard VDE 0664-400 "RCCB Type B residual currents for advanced preventative protection against fire – RCCB Type B+", represents a compromise in terms of the above mentioned requirements for fire protection. This VDE standard allows for an increased tripping threshold < 420 mA < 20 kHz, to allow for the operational technology limits for some RCD designs. Doepke BNK <300 mA can achieve the more stringent UK fire protection lever of 300 mA < 100kHz. See Regulation 532.2

Doepke manufacture Type B RCCBs with 3 basic characteristics : B-NK, B+ and B-SK giving a range of tripping thresholds, for various levels of protection. The frequency response of the residual operating current for the various Type B characteristics is presented graphically. This enables the PDS designer to check the key leakage current characteristics of the PDS against the proposed RCD characteristic; see example for 30mA B-NK, B+ and B-SK below.



Nuisance tripping occurs when the normal leakage currents generated by the PDS at any frequency, intersect the lower limit of the RCD trip characteristic. See Regulation 531.3.2 (ii)

For detailed tripping characteristics see: http://www.doepke.co.uk/rcd/images/typebgraphs.pdf

The DRCA 1 residual current analysis system available from Doepke, can be used to carry out a precise and reliable assessment of inverter design leakage currents at specific frequencies, and their effects on the proposed RCD residual current characteristic. This enables the machine manufacturer to provide reliable data on the exact Type of RCD characteristic that can be used safely with their equipment, e.g. Medical Scanners ; see Section 710.411.3.2.1.

2.1.3 Designs with increased surge current resistance - Type A-KV, F and B

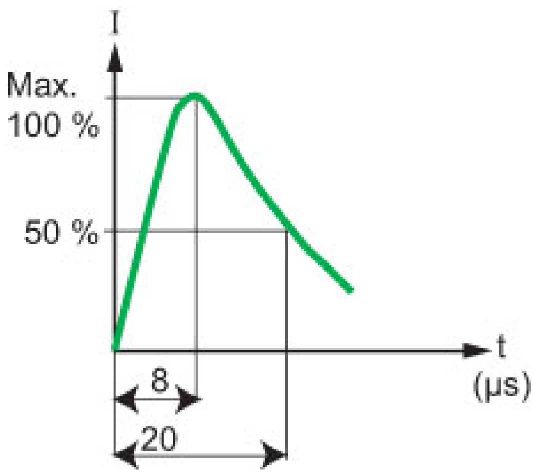
Transient over-voltages caused by switching processes or thunderstorms can generate leakage current surges, resulting in nuisance tripping of instantaneous RCDs. Installations incorporating surge protection devices (SPD) must use transient resistant RCDs ; see Regulation 534.2.6.

Note: This feature is incorporated in Doepke Type A-KV, F, Type B and Selective RCCBs.

*Surge Current Resistance (8/20 µs Wave) Type

A-KV	>300A
Type F	>3000A
Type B	>3000A
Type S	> 5000A

The response time for normal sinusoidal residual currents is still within that required by the standards and regulations; see Figure 4. P14.



8 / 20 Waveform for RCD surge current immunity to Regulation 534.2.6

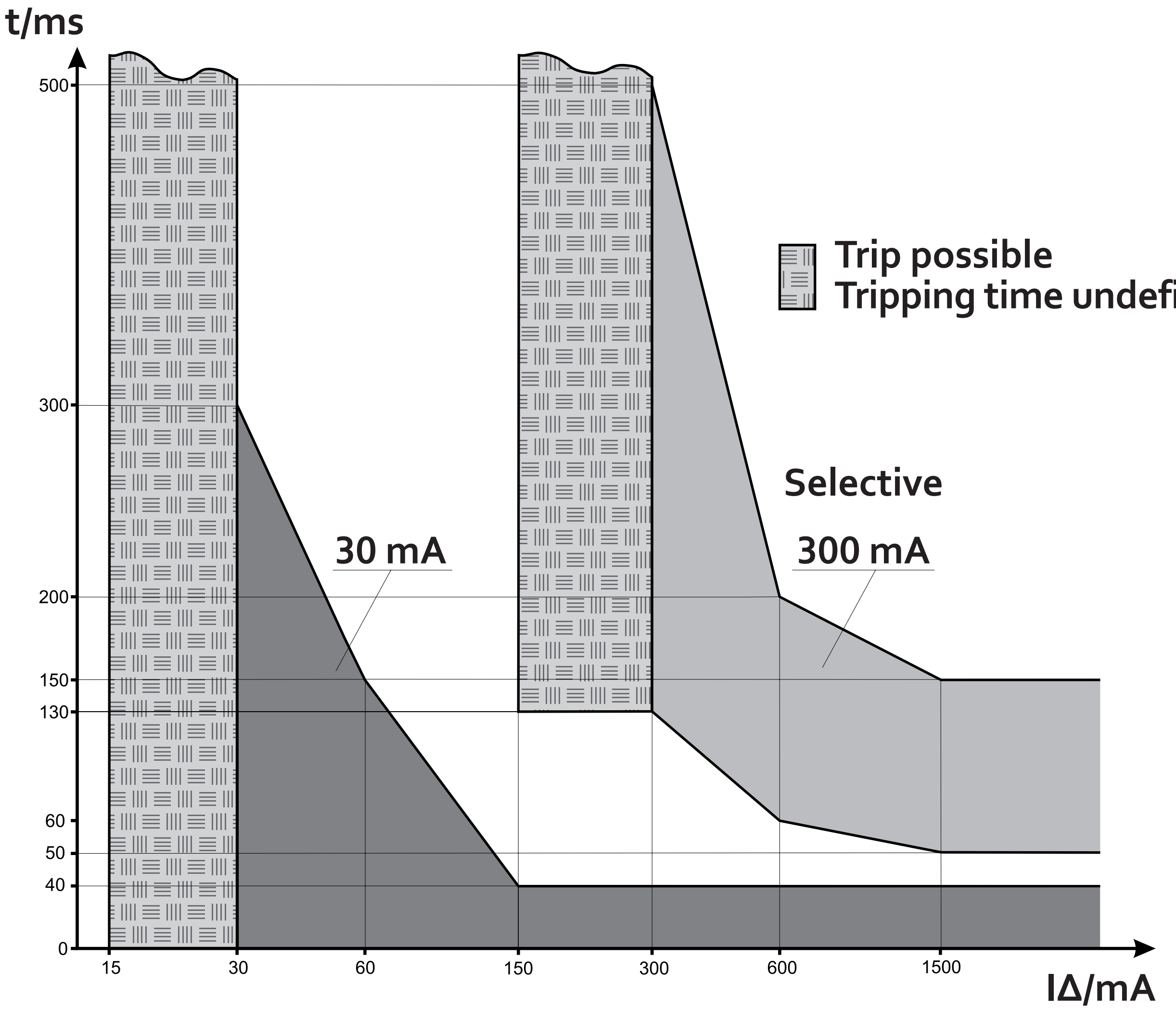


Figure 4: Example of time / current characteristic for DFS2 and DFS4 RCCBs to EN61008-1
RCD performance criteria detailed in BS7671 Appendix 3 Table 3A are based on EN61008-1 & 9-1

		Upstream RCCB 1 ($I_{\Delta n1}$)				
		DFS 2/4 S	**DFL 8 time range I**	**DFL 8 time range II**	**DFL 8 time range III**	**DFL 8 time range IV**
Downstream RCCB 2 ($I_{\Delta n2}$)	**DFS 2/4**	$I_{\Delta n} \geq 3 \cdot I_{\Delta n2}$			$I_{\Delta n1} \geq I_{\Delta n2}$	$I_{\Delta n1} \geq I_{\Delta n2}$
	DFL 8			$I_{\Delta n1} > I_{\Delta n2}$	$I_{\Delta n1} > I_{\Delta n2}$	$I_{\Delta n1} > I_{\Delta n2}$
	DFL 8 time range I			$I_{\Delta n1} \geq I_{\Delta n2}$	$I_{\Delta n1} \geq I_{\Delta n2}$	$I_{\Delta n1} \geq I_{\Delta n2}$
	DFL 8 time range II				$I_{\Delta n1} \geq I_{\Delta n2}$	$I_{\Delta n1} \geq I_{\Delta n2}$
	DFL 8 time range III					$I_{\Delta n1} \geq I_{\Delta n2}$

Table 3: Discrimination : RCCBs from the DFS 2/4 and DFL 8 series.

2.1.4 Selectivity

Selective or Time delayed RCDs designed to EN61008-1 have a fixed time delay, so they take longer to respond to the residual current before tripping. Consequently selective RCDs should only be manufactured in 100mA and above. They are generally used in applications where RCDs need to be connected in series.

In the event of a fault, the down stream RCD protecting the branch circuit where the earth fault has occurred, must trip before the upstream RCD; see Reg 314 & 531.2.9.

Figure 4 details the relationship between the tripping characteristics of an instantaneous 30mA RCD and a selective 300mA RCD. In figure 5 if an instantaneous 300mA RCD were to be used in place of RCD 1, a residual current IΔ > 0.3 A occurring in the down stream circuit (section b) protected by RCD 3, may result in both RCDs tripping and the loss of power to all circuits. Using a selective RCD in position 1, ensures power is maintained to circuits protected by RCD 2.

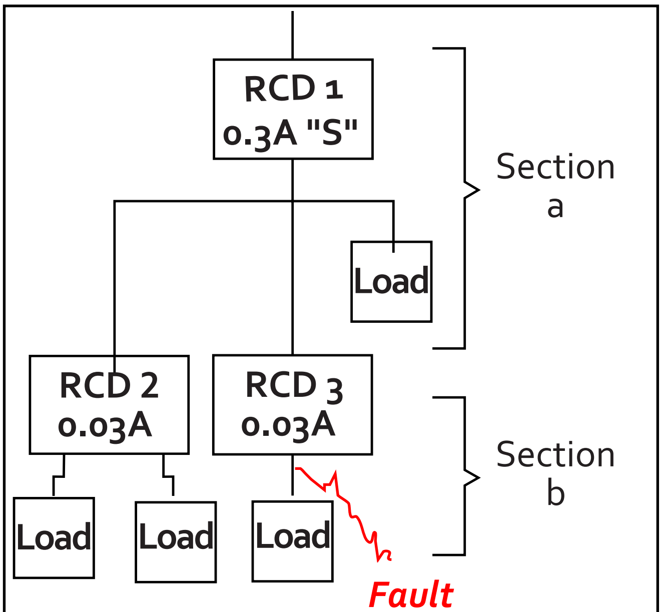


Figure 5

Safety Note:
4Ï ÃÏÎÆÏÒÍ ÔÏ %. ÓÁÆÅÔÙ ÓÔÁÎÄÁÒÄÓ Selective / Time delay characteristics are not suitable for electric shock protection.

Applications requiring 30mA protection must use RCDs with an instantaneous tripping characteristic conforming to EN61008-1 or 61009-1 / BS7671 Appendix 1.

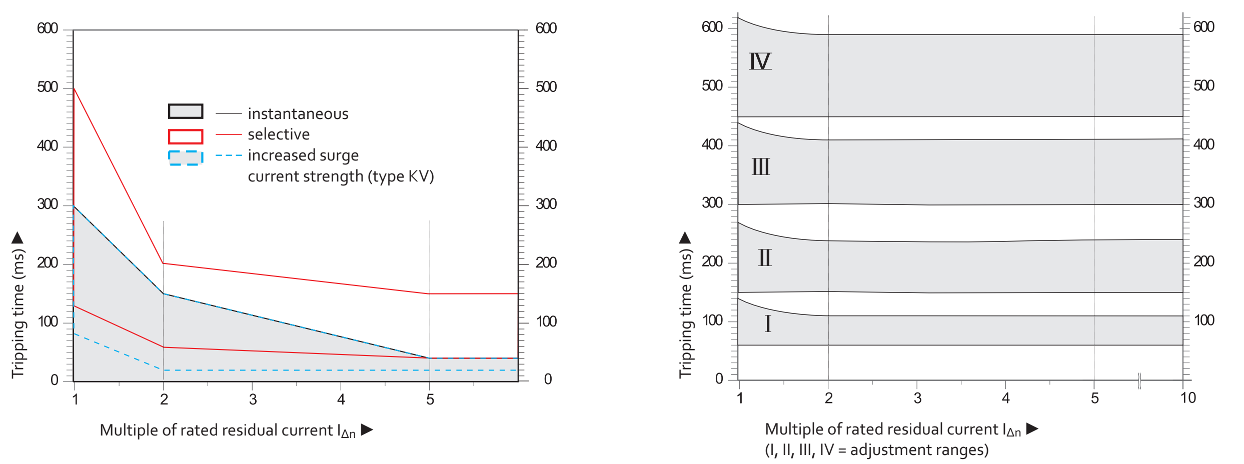


Figure 6: Overall disconnection times for instantaneous and selective RCCBs type DFS 2 / 4 (left) and CBRs from the DFL 8 series (right)

The response time of both selective and normal RCCBs depends on the level and profile of the residual current. Figure 4 uses the example of a normal RCCB with $I_{\Delta n}$ = 30 mA and a selective RCCB with $I_{\Delta n}$ = 300 mA to illustrate the response time. An overview of the possible combinations with selective response behavior is shown in Table 3 for RCCBs from the DFS 2/4 and DFL 8. The fields for the permissible combinations specify the condition for classifying the rated residual currents.
To ensure selectivity, the conditions specified in the table must be observed for the rated residual currents $I\Delta n2$ for the upstream RCCBs and $I\Delta n2$ for the downstream RCCBs.

For selective RCCBs, the earth resistance R_A must be a maximum of half of the value given in Table 1. P4. This ensures that a residual current with twice the value of the rated residual current can flow in the event of a fault, without the permissible touch voltage U_{Ltouch} being exceeded, so that even the selective RCCB trips within a time of < 300 ms; see Figure 6. P15.

Doepke selective RCCBs have a surge current resistance of > 5 kA.

2.2 Disconnection times

Figure 6 shows the disconnection times for RCCBs and CBRs depending on several multiples of the rated residual current. The disconnection times for each residual current value for RCCBs of all rated residual currents can be derived from here.

2.3 Passive RCDs

Conventional "Passive" RCDs use the leakage / residual current for the energy required to trip. Passive RCDs still function if the mains voltage* drops or the neutral conductor is interrupted. Even longer periods of over-voltage following mains disruptions cannot affect the tripping function of a passive residual current circuit-breaker.

In the UK passive RCDs must be used in installations that are not under the supervision of skilled or instructed persons (this is the majority of installations covered by the Regulations); see Regulation 531.2.6.
*Note:
This should not be confused with the voltage required to operate the test function on the RCD. The supply voltage must be compatible with the RCD test circuit operating voltage. A recent change in the standards requires a much tighter tolerance on the test circuit current delivered when you operate the test button. To meet this requirement manufacturers have to provide RCCBs for specific voltages i.e. standard 230V RCCBs cannot be used on 110V supplies. Order 110V RCDs for use on 110V supplies.

Doepke DFS 2 and DFS 4 RCCBs are manufactured to the Standard EN61008-1 meeting the requirement for mains-voltage independence (Passive RCDs) tripping on Type AC and Type A residual current faults. This also applies to Doepke DFL8 circuit -breakers (CBRs) manufactured to EN60947-2 Appendix B for in-built residual current tripping, and FIB and FIC RCBOs manufactured to EN61009-1.

DFS 4 Type B RCCBs and DFL 8 Type B CBRs are also considered mains voltage independent under standard EN 61008-1 and VDE 0664-10, because they still respond to Type A residual currents even if the mains voltage drops, i.e. if two external conductors and the neutral conductor are interrupted.

Type B RCCBs and CBRs require a low auxiliary voltage of 50 V, which they pick up from the mains voltage, for tripping on smooth DC residual current and residual currents with frequencies that deviate from the mains frequency. As a result disconnection is always ensured, even if Type B residual currents occur down to the permissible touch voltage of 50 V, specified in international installation standards.

2.4 Ambient temperature range

The normal ambient temperature range for RCDs is -5°C to +35°C in virtually all international standards, with short-term temperatures up to 40°C for max. 1 h in a 24 h period.
If these RCDs are to be operated at temperatures below -5°C, all international standards stipulate a permissible tripping current that is higher by 25%. Therefore in applications below -5°C to -25°C, the earth resistance figures have to be reduced to 80% of the values given for -5°C, for the permissible touch voltage: Refer to Table 1 Page 4.

2.5 Co-ordination with short-circuit and over-current protection devices

RCCBs must be used in conjunction with separate short-circuit and overcurrent protection devices. The manufacturer must specify the maximum prospective short-circuit current in connection with the maximum permissible back-up fuse (as per VDE 0636 utilization category gL).

The symbol 63 10000, for example, on the rating plate of the RCCB indicate that the device can withstand a prospective short-circuit current of 10 kA in combination with a 63 A back-up fuse.
Fuse ratings for short-circuit protection may be different to those required to provide overcurrent protection. To verify the maximum size fuse size for overcurrent protection, refer to the RCCB manufacturer's installation data provided with their product. For example, if the manufacturer specifies a back-up fuse of 100 A for an RCCB with a rated current of 63 A, the 100A fuse will only provide short-circuit protection. In a conventional consumer unit, overload protection is provided by down stream MCBs. The installation designer must take account of maximum diversity, to ensure that the upstream RCCBs cannot subjected to a continuous overload current above their rated current.

3. Installation notes

3.1 Assembly

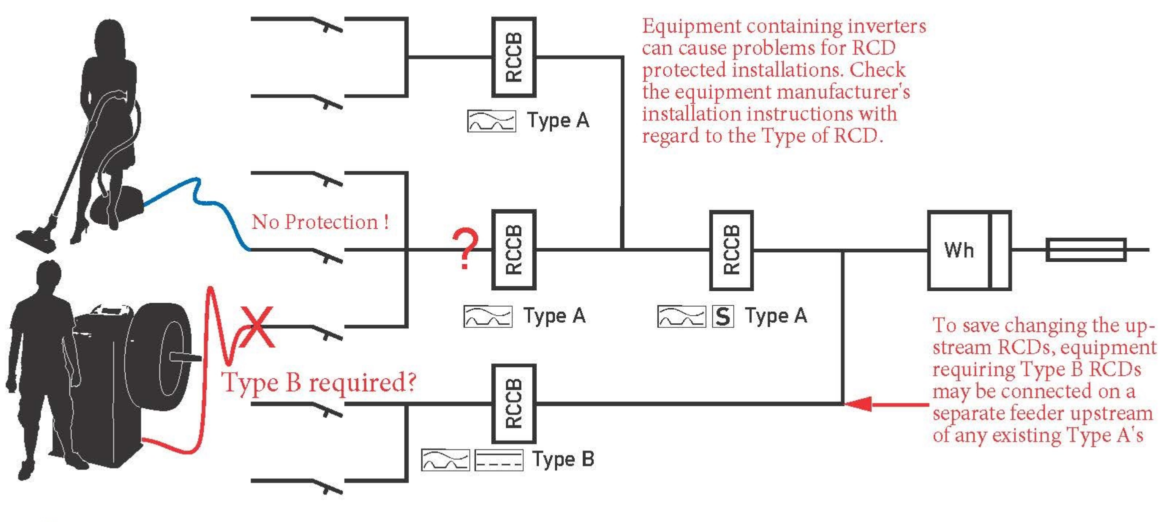
Doepke RCCBs can be used in any position. The supply side and load side are not defined, with the exception of type B RCCBs and CBRs and type EV. Four-pole devices can also be used for three-pole operation. All devices are designed for din rail mounting, have an IP20 protection class and must be installed in a suitable enclosure, i.e the enclosure IP rating must be suitable for the particular application, e.g. BS7671 requires a minimum of IP2X. **3.2** for indoor use.

3.2 Division of RCD Protected Circuits/Protective Conductor Currents

RCDs are designed to trip when the residual current IΔ > 50%. Therefore to reduce nuisance tripping, the leakage current of the loads connected to an individual RCD should be < 30% IΔ, i.e. for a circuit protected by a 30mA RCD, total leakage current of the loads must be <10mA. When designing installations, the protective earthing requirements for individual items of equipment (Regulation 543.7), can be used as an indicator of possible problem areas:

- Equipment supplied with a standard 13A plug must have leakage currents <3.5mA.
- Equipment with a leakage current >3.5 < 10mA must use 60309-2 connectors, or be permanently connected to the supply. You may be restricted to one item of equipment, if the circuit requires 30mA protection; see Regulation 531.2.4
- Single items of equipment with leakage currents >10mA may not be suitable for connection to a circuit protected by the correct type of 30mA RCD.
- Inverter based equipment may have low leakage current measured at 50Hz, but much higher leakage currents at harmonic frequencies based on the equipment design.
- Check the equipment manufacturers recommendations for RCD protection.

The risk assessment for the equipment carried out prior to installation, should identify if the leakage current is likely to be an issue for the position and location of the equipment. RCDs installed on feeder circuits must be compatible with any RCDs installed upstream of the feeder; see Regulation 531.2.4. and example below.



3.3 Connection and testing

Refer to the installation sheet provided with each RCCB. The supply voltage must correspond to the RCCB test circuit voltage: Live to N on 2 pole devices, Phase to Phase on 4 pole devices. Refer to the latest edition of BS7671 for UK installation and test requirements for RCCBs. Testing RCCBs regularly will improve the life of the device. The recommended time between testing for normal domestic environments is 3 months; see Regulation BS7671 514.12.2. Test Label detailed below.

> This installation, or part of it, is protected by a device which automatically switches off the power supply if an earth fault develops. **Test quarterly** by pressing the button marked **'T'** or **'Test'.** The device should switch off the supply and should be then switched on to restore the supply. If the device does not switch off the supply when the button is pressed seek expert advice.

In non-domestic environments, RCCBs must be tested regularly to maintain adequate levels of safety; see EWR's 1989 Regulation 4(2) 68. The frequency of inspection and testing must be based on the judgment of the duty holder. Portable equipment may be damaged during operation, transport and storage. Therefore the standards stipulate that the RCCB should be checked for correct operation using the test button, before each use.

3.4 Reset function

Doepke RCCBs have a blue operating lever on the front. When the RCCB trips, the lever moves to the centre position. To switch on, the lever must be moved to the off position (0) before the RCCB can be reset.

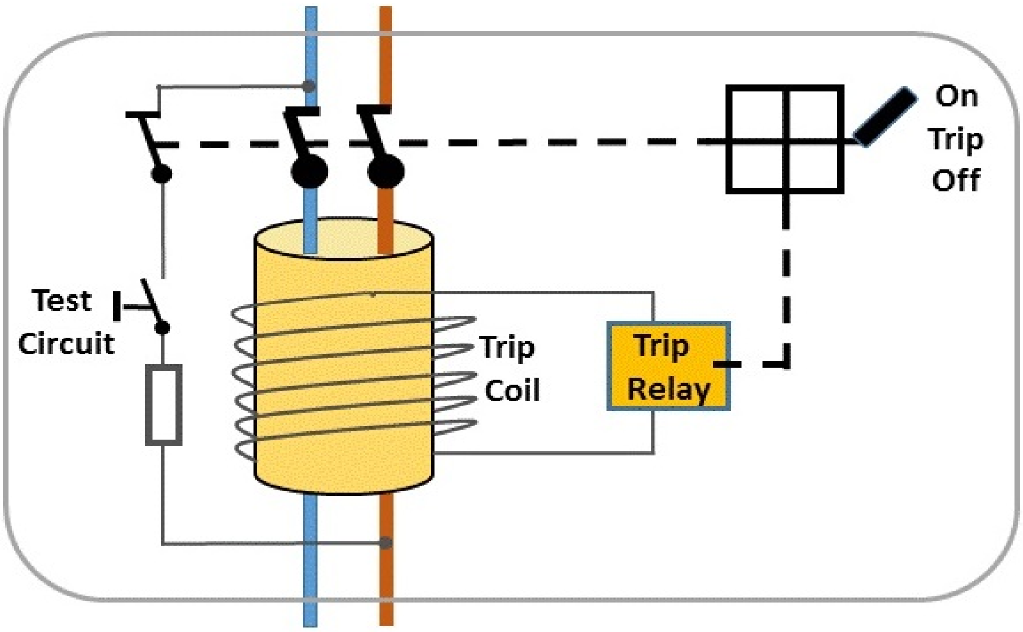
4. Quality features

- The switching mechanism's metal components are made of high grade stainless steel.
- All devices meet the requirements of the RoHS guideline, i.e. all plastics used are bromide and halogen-free and metal components do not contain any lead or cadmium.
- All materials used can be recycled.
- Individual RCCBs are subjected to 100% testing and marked with a unique serial number.
- All electrical data is checked multiple times in extensive final tests and permanently archived for each individual RCCB.

Appendix 1 Basic operating principles of RCDs

1.1 Basic RCD Circuit

The live and neutral conductors pass through the center of a current transformer, the output of the current transformer (trip coil) is connected to the trip relay. During normal operation, the current flowing in the live conductor from the source to the load, will be equal to the current flowing in the neutral conductor from the load back to the source. If these currents are equal and opposite they cancel each other out, i.e. the sum of the currents induced in the trip coil will equal zero. If the currents are not equal in the live and neutral conductors, e.g. insulation fault, a current equal to the difference (residual current) will be induced in the trip coil. If this residual current reaches a predetermined value, the trip relay will open the RCD contacts.



Basic RCD Circuit

1.2 RCD Test Circuit

RCDs are provided with a test function: The test button connects a resistor between the live terminal on the load side, to the neutral on the supply side of the RCD. Pushing the test button creates an imbalance across the trip coil, resulting in a current flow in the trip coil and operation of the trip relay and opening of the RCD contacts.

1.3 Electric Shock

It can be seen from the above that RCDs do not prevent electric shocks, but they will reduce the time that the electricity flows through the body, when a person is connected directly or indirectly to a current carrying conductor and earth.

Note: A person connected across current carrying conductors and protected from earth, will not be protected by an RCD.

1.4 RCD Blinding

Type AC and Type A RCDs rely on the principles of magnetic induction, i.e. there must be a change in the direction of current flow, to produce an emf in the trip coil. Consequently they will only detect AC current. DC and high frequency AC current passing through the CT core results in saturation of the magnetic material, and consequently the RCD will not be able to detect residual currents. This is refereed to as RCD Blinding; see below.

1.5 Example Type A Hysteresis Curve

In the diagram, o to B3 represents the +ve half of the RCD CT core magnetic characteristic. The green area represents optimum operational area and yellow represents the area of increasing magnetic saturation. A 50Hz residual current $I_R$ac, (I) equal to the tripping value sensitivity, produces a magnetic field o to B1 for the +ve ½ cycle.

The resultant change in the magnetic field, as IRac passes through zero for –ve ½ cycle induces a proportional voltage (II) in the trip circuit winding and would result in the RCD tripping.

A residual current with +ve biased DC component $I_R$dc > 6mA passing through the CT, will shift the operating point of the magnetic material on the H axis to the right. Now if a residual current $I_R$ac with the same value as (I) flows, the combined current $I_R$dc+ $I_R$ac (III) produces a magnetic field B2 to B3. Although the amplitude of (III) is similar to (I), the resultant voltage (IV) induced in the trip circuit winding is lower and not sufficient to trip the RCD, due to the effect of the smooth DC content, i.e. the RCD will not detect residual currents flowing in the circuit.