Enhance reliability with the right drives protection.

Build it in.

Peter-Lukas Genowitz
1st Edition

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Introduction

Machine builders are under continuous pressure to offer more sophisticated, energy-efficient machines with better throughput. One increasingly popular response is to use variable-speed frequency-controlled drives. Although effective, this approach can cause nuisance tripping problems or even complete loss of the protection function unless complemented with suitable Residual Current Device (RCD) types. A harmonized drives and RCDs solution is essential to facilitate machines that combine the most energy-efficient motor control with the highest possible protection for equipment and users.

The success of this solution depends on a detailed understanding of the drive and RCD components and their interaction. The right choice of RCDs is dictated by the location of the residual currents generated by the drives, as well as their magnitude, waveform and frequency components.

This white paper helps manufacturers to design safe, efficient operation into their machines by looking at all likely residual current scenarios and discussing suitable RCD solutions for each. It also shows how digital RCDs can further improve machine performance and uptime through providing better visibility of impending faults, more control accuracy and further reductions in nuisance tripping susceptibility.

The paper starts by reviewing the basics of frequency converters, together with the locations, types and components of the fault currents they generate. Bearing these factors in mind, it then looks at RCD types designed especially to give the highest protection levels for operators and equipment from system-caused earth leakage currents at high frequencies. It shows how to choose the most suitable RCDs for different fault current scenarios. Finally, the paper outlines the advantages of digital RCDs, and offers some advice on how to reduce high leakage currents. It is the third white paper in a series by Peter-Lukas Genowitz, Product Manager RCD at Eaton, that explores the topic of residual current.

Basics of electrical drive systems

Drive systems' utility is greatly increased if their speed can be varied continuously. Achieving constant variable speed adjustment with high positioning accuracy depends on modulation methods. However modulation circuits cause unavoidable leakage currents which persist throughout normal operation, not just during error conditions.

Smooth DC leakage currents and AC leakage currents in a frequency range up to some MHz occur and can reach 100 mA or more – particularly if there is an imbalance of power phases or a large number of drives is connected.

Basic structure and function of frequency converters

Frequency converters operate as shown in Fig. 1 by rectifying the mains voltage supply using a B2 rectifier bridge for single-phase or a B6 rectifier bridge for three-phase supplies. The DC voltage is smoothed before being converted by an inverter into an output voltage which can be varied in level and frequency.

Frequency converter leakage currents (2-3) are essentially caused by interference suppression on the device, additional RF filters (1), output filters (4), the shielded motor cable (5) and the motor (6).

In general, as leakage current increases, radiated capacitive interference and high-frequency conducted interference voltages are reduced. This means that designers sometimes allow leakage currents to increase as they work to reduce radio frequency interference levels.

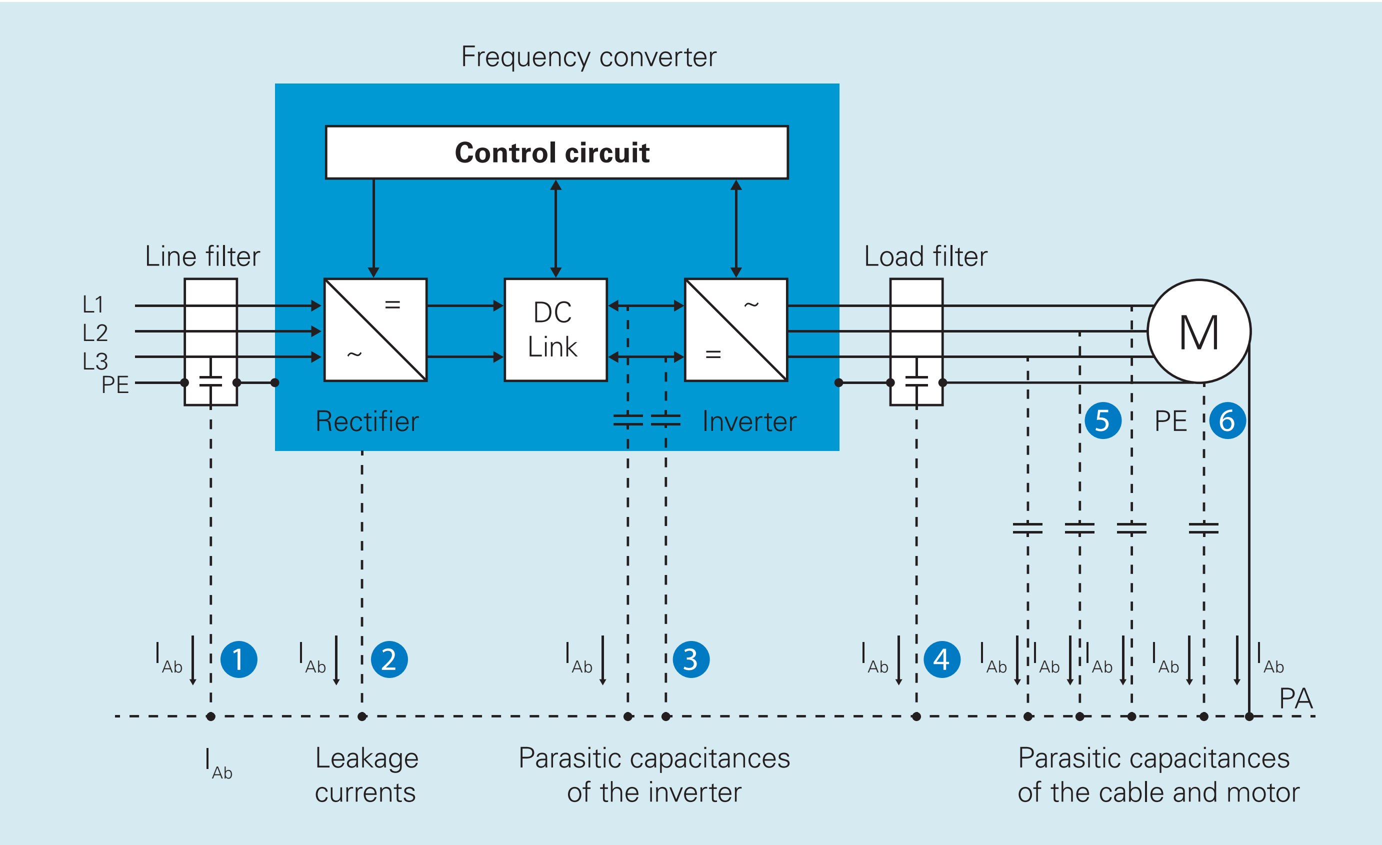


Fig.1: Frequency converter operation and leakage current generation

Source: „Leitfaden für Fehlerstrom-Schutzeinrichtungen und elektrische Antriebe" Page 2, ZVEI (Zentralverband der Elektro Industrie)

Fault currents and their locations

Fault currents are distinguished by the point at which the ground fault occurs, and depend on the frequency inverter circuit, as shown in Tables 1 and 2 below.

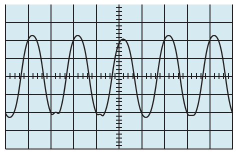
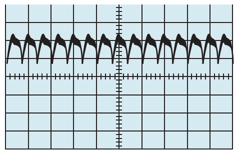
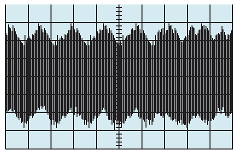
Fault location upstream of the drive system creates power frequency AC fault currents between the RCD and drive, of the form shown.	
Fault within the drive base modulew A fault that occurs in the DC link within the frequency converter – between the input rectifier and output electronics – creates nearly smooth DC fault currents as shown.	
Fault on the output side of the frequency converter AC fault currents deviating from the line frequency and the sinusoidal waveform can occur on the output side of the frequency converter – which is also the feed to the motor. The waveform is a spectrum of frequencies with different components of varying proportions. Depending on the operation mode of the frequency converter, fault conditions here can also lead to smooth DC fault currents as shown.	

Table 1: Fault condition locations and fault currents

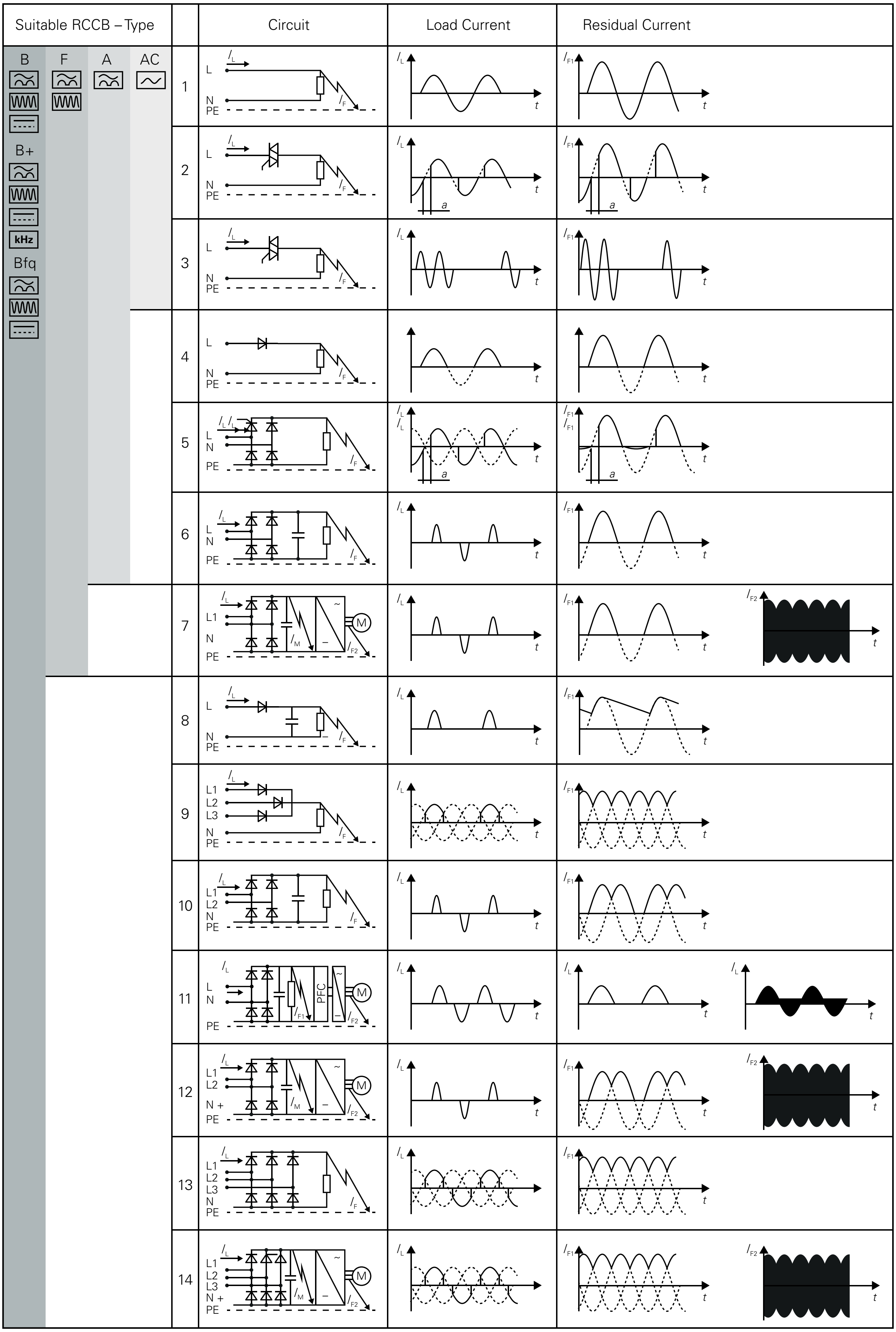
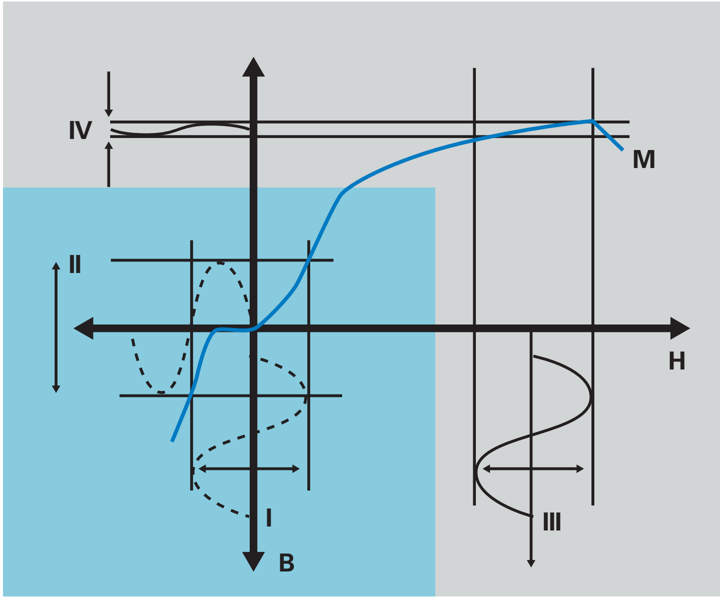


Table 2: Possible residual current wave forms and suitable residual current protection devices

Source: EN 61008-5-1 standard

Dangers of smooth DC fault currents

Smooth DC residual currents lead to transformer pre-magnetization in a Type AC or A RCD. This reduces the transformer's ability to detect changes and if a sinusoidal AC fault then occurs, a safe disconnection is no longer guaranteed. However, Type B RCDs cover this failure situation and guarantee the necessary protection. The difference between a transformer signal with and without the influence of a smooth DC current interaction can be seen in Fig.2.



(I) **Change with AC fault current IΔa.c.**
(II) **Trip signal generated by IΔa.c**

(III) **DC fault current IΔd.c. superposed on AC fault current IΔa.c.**
(IV) **(IV) Trip signal when DC fault current is superimposed on AC fault current IΔd.c. = IΔ for total fault current**

B **Induction**
H **Field strength**
M **Transformer magnetization**

Fig. 2: The difference between a transformer signal with and without the influence of a smooth DC current interaction

* Source: ZVEI - Zentralverband Elektrotechnik und Elektronikindustrie e. V.;

Frequency components in the residual current of a frequency converter

A plan of protection from errors on the frequency converter output should allow not only for the RCD's tripping characteristic but also the frequency components in the residual current.

Frequency converters generate the following critical frequency components:

- Switching frequency of the frequency converter (typically up to 20 kHz)
- Motor frequency (typically 0 to 50 Hz, maximum up to 1 kHz)
- 3rd Harmonic of 50Hz (150 Hz in three-phase applications)

Fig.3 shows an example of the main frequency components at a fault resistance of 1 kΩ. Only the portion of the individual components change. The example shows that as motor frequency increases, the switching frequency part of the fault current decreases. Type B, Bfq and B + RCDs detect these according to their tripping characteristic with different weighting.

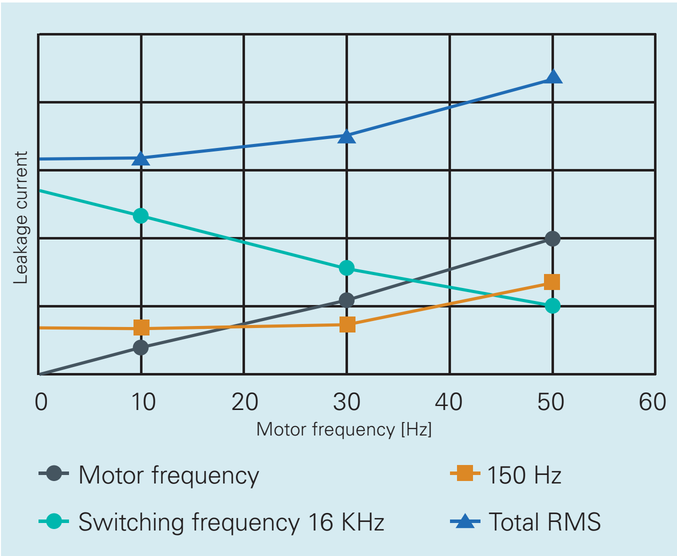


Fig.3: Frequency converter residual current frequency components

Source: ZVEI - Zentralverband Elektrotechnik und Elektronikindustrie e. V.;

RCDs that can be used with variable speed drives

Fig.4 shows which RCDs can be used upstream of a drive. It is not possible to calculate how many drives can be used downstream of an RCD without causing nuisance tripping, as the quality of the installation has a significant impact on the level of leakage current. However, as a 'Rule of Thumb', up to three drives can be installed downstream of an RCD within a correctly installed system.

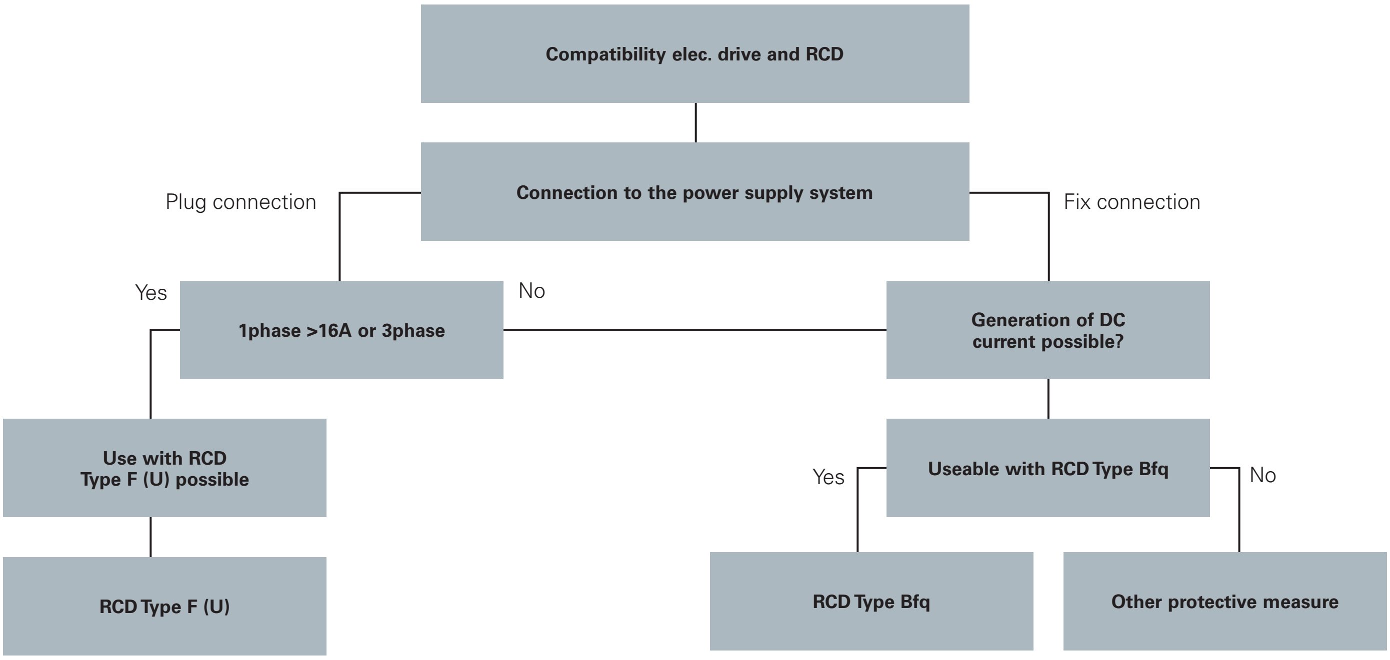


Fig.4: Choosing RCDs for variable speed drives

Type F

Type F RCDs have been specifically designed for single-phase inverter applications, to assure adequate protection in the event of an earth fault associated with inverter-generated harmonic content, while also increasing resistance to nuisance tripping.

These RCDs offer the same range of protection and functionality as Type A RCDs; accordingly they detect sinusoidal AC currents as well as pulsating DC currents.

In addition they detect multi-frequency residual currents up to 1 kHz according to IEC/EN 62423. The Type F RCDs have a surge current withstand capacity of 3 kA and tolerate superimposed smooth DC residual currents of up to 10 mA without affecting their protection functionality.

With the additional functionality, Type F RCDs offer a higher safety level and system stability compared to RCDs Type A for applications with 1phase frequency converters.

Types B, Bfq and B+

Type B residual protective devices can detect sinusoidal AC and pulsating DC as well as smooth DC fault currents, making them suitable for all kinds of applications and occurring waveforms according to IEC/EN 62423. RCDs of this type are designed for use in 50/60 Hz three-phase systems. Additionally, trigger conditions for fault currents with different frequencies up to 1 kHz are defined for Type B residual current devices.

Type Bfq RCDs comply with Type B requirements (IEC/EN 62423) while being designed for use in circuits that include frequency converters for speed-controlled drives. They have specially-adapted tripping curves defined up to 50 kHz, and are designed to avoid nuisance tripping. The curves exhibit a decreased sensitivity to leakage currents of higher frequencies.

Type B+ RCDs comply with the requirements of VDE 0664-400 and have a frequency tripping response defined up to 20 kHz. Their maximum tripping current at higher frequencies is limited to 420 mA. This provides superior protection from fire risk caused by ground fault currents in applications with electronic drives.

Note that if a complex current waveform is drawn through an RCD, the RCD will trip if even one single frequency reaches the tripping curve. This effect can lead to RMS values higher than the rated RCD tripping current - which is the value for 50 Hz tripping.

Type B, Bfq and B+ RCDs (up to 63 A) are equipped as standard with digital RCD features. (See Digital RCDs white paper for more details).

In general type F, B, Bfq and B+ RCDs also help to increase the system availability because they have a high resistance to nuisance tripping (surge current withstand capacity of ≤3 kA and a time delayed tripping).

Digital RCDs and their advantages in frequency converter applications

There are two key advantages to using digital RCDs in frequency converter applications. First, digital RCDs give local visualisation of the leakage current via their LEDs. This ultimately helps the user to see if the leakage current is on the limit.

Secondly, they offer increased accuracy, which facilitates an RCD tripping level nearer to 100% of I n. As a result, early tripping in case of leakage currents can be avoided. For more information see the Digital RCDs white paper.

RCD add-on blocks for moulded case circuit breakers (MCCBs)

For higher load currents and breaking capacities RCD add-on blocks Type A are also available for combining with MCCB devices including Eaton's NZM1 and NZM2, with a current capacity of up to 250 A. Type B add-on blocks are available for NZM2 MCCBs up to 250A.

Select the right RCD for your drives applications

Applications with:
- Appliances and motors with 1 phase frequency converters (supply: phase/neutral)

↓

- Washing machines,
- Dishwashers
- Heat pumps
- Motor applications
- Ventilation, cooling and air condition systems
- Welding equipment

↓

RCD Type F
(acc. IEC 62423)
Standard type. mutti-frequency residual currents up to 1 kHz

Applications with:
- Appliances and motors with 1 phase frequency converters with PFC (Power Factor Compensation) or
- 1 phase frequency converters supplied between phase/phase or
- 3 phase frequency converters
- DC systems (photovoltaic systems, ups units…)

↓

- PV Systems
- Battery banks
- UPS Units
- EV charging
- Medical devices

↓

RCD Type B
(acc. IEC 62423)
Standard type, sensitive to all residual currents according up to 1 kHz

↓

Industrial applications which contains high-power frequency converter controls as:
- 3 phase motor applications
- Speed regulated machine tools

↓

RCD Type Bfq
(acc. IEC 62423)
Non-sensitive against system caused earth leakage currents at high frequencies up to 50 kHz

↓

Fire risk applications as:
- Petrol station
- Agriculture
- Paint shop
- Warehouses
- Biogas plants
- VDE 0664-400

↓

RCD Type B+
According VDE 0664-400 for superior fire protection (max. tripping current of 420mA for frequencies up to 20 kHz)

Fig.4: Choosing RCDs for variable speed drives

RCD selection for Eaton drives

1Phase:	**3Phase:**
• DC1-1…	• DC1-3…
• DE1-1…	• DE1-3…
• DA1-1…	• DA1-3…
> **Type F:**	> **Type Bfq:**

Max. 3 frequency converters RCD

Causes of high leakage currents and recommendations for reducing them

High leakage currents have various causes and methods for reduction. In the event of unwanted tripping, there are a number of suggestions for troubleshooting:

Radio interference suppression:
Limited to what is normatively prescribed

Switching frequency:
If possible adjust so that the lowest total system leakage is achieved

Manufacturers' tips:
With which filter and which switching frequency can the best solutions be achieved?

Motor cables:
Keep cables and wires as short as possible and use low-capacitance designs

Connections:
Use symmetric connection of single-phase converters to three phases. Split circuits with high leakage currents. Ensure proper installation with full implementation of ground connections.

Filter:
Use filters with low leakage currents. Use sine wave filters, du/dt filters or motor chokes on the drive output.

Active leakage current filter:
This add-on module minimizes leakage currents that cause RCD tripping and improves the EMC performance of existing line filters.

The module detects the common-mode currents on the load-side via a current sensing transformer. An amplifier generates an inverse of the leakage currents and feeds this to the power line through a capacitor network. This almost completely cancels the leakage currents.

Besides minimizing earth leakage currents, active filter modules can also improve the EMC performance of power drive systems in the range up to around 500 kHz.

Active filter modules can be retrofitted into existing converter-based installations to improve their EMC and the RCD compatibility of the power drive system.

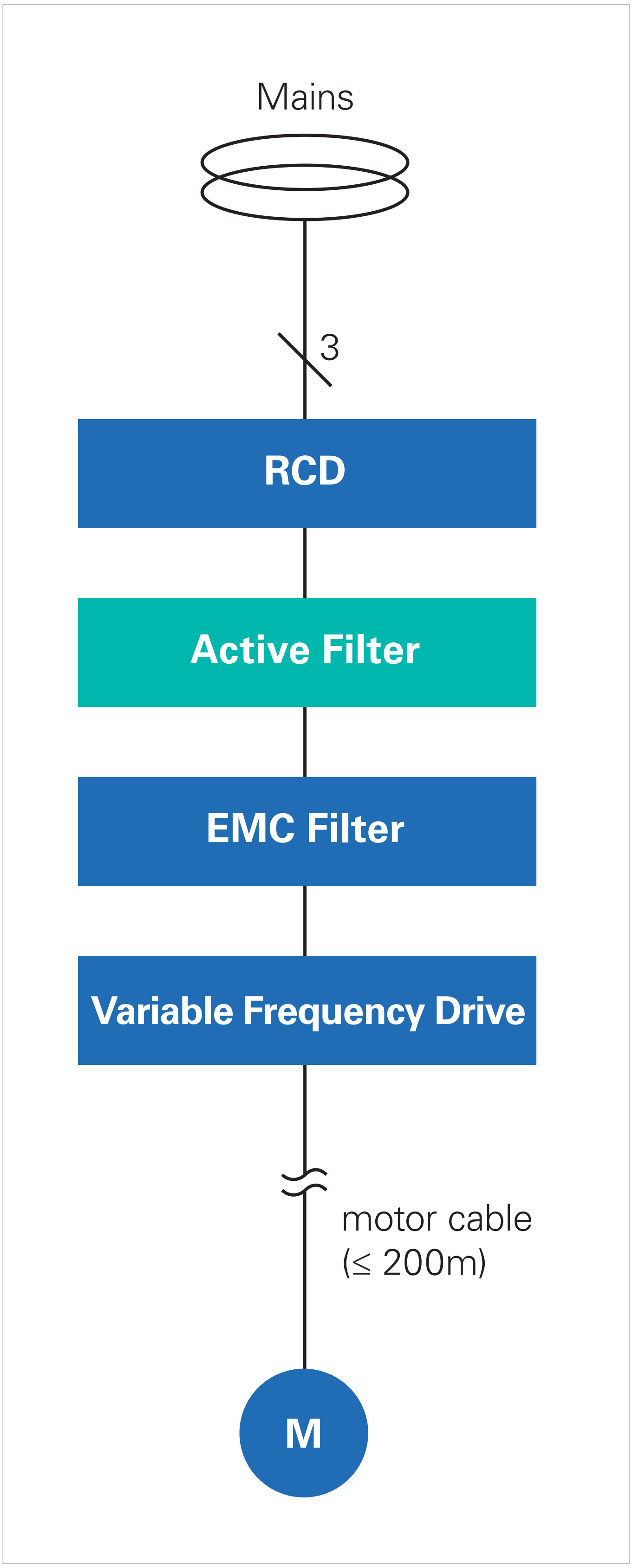


Fig 5: Functional principle active filter module

Efficient planning and engineering with the Power XL Selection Aid

As product life cycles have become increasingly compressed, pressure on engineers and organizations to continually drive efficiency and improve productivity has intensified. To remain competitive and deal with these challenges, companies must continuously optimize their processes, reducing time and cost in the design, development, operation and optimization phases of their machine automation systems.

One effective way to do this is to take advantage of software tools and support available from system and component suppliers. As a full-line provider, offering total solutions from the mains supply to the motor such as short-circuit and overload protection, as well as motor chokes, sin filters and all necessary system components for energy efficient motor control and protection, Eaton makes it as easy as possible for machine builders to select the appropriate equipment for their application.

PowerXL™ Selection Aid provides a simple online planning solution, helping engineers quickly select the drive required for the application as well as the associated switchgear, protective elements, chokes and filters complete with the corresponding article number.

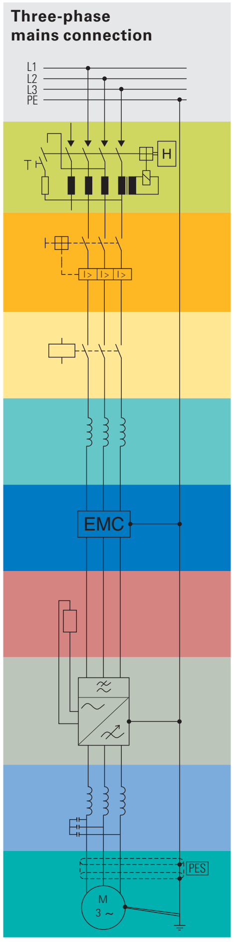
The PowerXL Selection Aid also helps engineers to choose the right RCD Type. Based on the selected drive the aid will recommend the correct Type and size (RCD or MCCB with RCD add on Block). Engineers only need to define the required protective goal and depending on that a 30mA RCD will be used for additional protection or a 300mA RCD for fault protection.

Further information on the tool can be found here:
www.eaton.eu/rcd_drives.

Fig 6. shows the various devices that should be selected for different drive applications, for three and single-phase mains connections.

Solutions

Mains voltage	3AC 400 V 50/60 HZ	
Residual current protection		
RCD (optional)	FRCDM Type BFQ 40A	
Short circuit and overload protection		
Fuse or	32 (35)*0)	A
MCB or	FAZ-B32/3	
Motor Protective CB (optional)	PKM0-32	
Contactor (optional)	DILM7-10 (230V/50Hz)	
Mains choke (optional)	DX-LN3-025	
EMC filter (optional)	DX-EMC34-025-FS3	
Brake resistor (optional)	DX-BR047-5K1	
VFD type	DC1-34024FB-A20N	
FS	3	
Input current	24.7	A
Output current	24	A
Motor choke (optional) or	DX-LM3-035	
Sine filter (optional)	DX-SIN3-023	
Motor power	11	kW



Solutions

Mains voltage	1AC 230 V 50/60 HZ	
Residual current protection		
RCD (optional)	FRCMM Type F 40A	
Short circuit and overload protection		
Fuse or	25	A
MCB	FAZ-B25/1N	
Contactor (optional)	DILM7-10 (230V/50Hz)	
Mains choke (optional)	DX-LN1-024	
EMC filter (optional)	DX-EMC12-014-FS2	
Brake resistor (optional)	DX-BR035-1K1	
VFD type	DA1-12011FB-A20C	
FS	2	
Input current	19.5	A
Output current	10.5	A
Motor choke (optional) or	DX-LM3-011	
Sine filter (optional)	DX-SIN3-016	
Motor power	22	kW

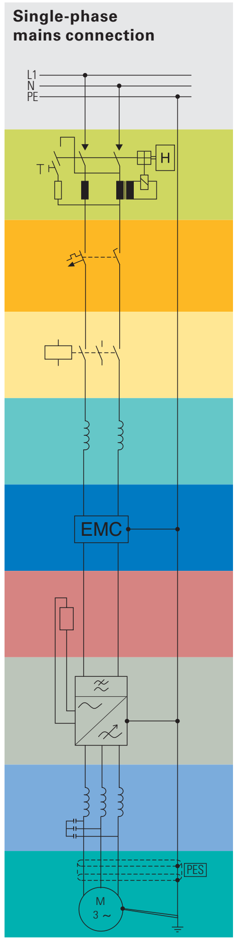


Fig 6. Various devices that should be selected for different drive applications, for single and three-phase mains connections.

Conclusion

This white paper has shown how machine builders can achieve a harmonized RCD and drives solution that guarantees the highest level of protection together with energy efficient motor control. Digital RCDs and their offering of enhanced process visibility and further uptime improvements are also introduced.

For machine builders, this harmonized solution gives an extra competitive edge to their equipment designs, offering reduced downtime and lower operating costs to their end-user manufacturing customers – yet adds no risk to their traditional designs.

Eaton is a power management company with 2015 sales of $20.9 billion. Eaton provides energyefficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power more efficiently, safely and sustainably. Eaton has approximately 97,000 employees and sells products to customers in more than 175 countries.

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