

Leakage currents in fault-current protected environments

To provide for improved protection of operating personnel, residual current operated circuit breakers are seeing increased use in electrical installations. These, however, often trip unnecessarily due to leakage currents caused by electrical systems. The results are machine downtime and costs that can otherwise be prevented with design consideration to high leakage currents and targeted countermeasures. Because frequency inverters and power-line filters are significant causes of ground currents, they deserve special attention.

In addition to fuses and circuit breakers, today there is increasing use of residual current operated circuit breakers (also called RCDs, residual current devices) in electrical systems. Fuses protect electrical systems primarily against short circuits and fires, whereas RCDs provide for reliable protection of operating personnel. They register fault currents flowing to ground, for example caused by defective insulation, and cut them off before anyone can be harmed. The problem is that a RCD cannot distinguish between residual currents that arise in normal operation and those that occur due to dangerous fault currents. Frequency inverters in particular, which are needed for energy efficient operation of motors, cause large residual currents.



Frequency inverter and motors (source: Control Techniques AG Switzerland)

In addition, the capacitance of the cables and power-line filters that are necessary to maintain electromagnetic compatibility (EMC) create additional ground currents. The sum of all leakage currents can thus trigger a RCD and shut down all loads on the same cable harness. This results in machine downtime, causes loss of production and thus considerable expenses. However, there are measures for dealing with high leakage currents to ensure efficient yet safe operation.

Leakage current vs. fault current

The term leakage current refers to current that flows to ground in a properly operating circuit or to an external conductive component. In other words, the current does not return

through the neutral conductor. The same holds true for a fault current, which arises due to defective insulation between live conductors and flows back to ground. Even if a person directly touches a live conductor, the fault current flows to ground. An upstream RCD detects this fault current and immediately disconnects the circuit.

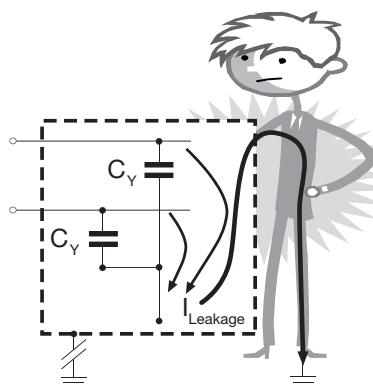


Fig. 1: Leakage currents are dangerous for human beings when the ground conductor is disconnected (source: SCHURTER AG)

Such fault currents have a high resistive component as opposed to leakage currents, which predominantly have a capacitive reactance. The RCD, however, cannot distinguish between the different types of ground currents. Thus, it can already trip when the sum of all leakage currents exceeds the trip value. This is also possible in normal operation even if there is no fault.

The amount of leakage current depends on the design of a drive system, on the grid voltage, the inverter's pulse-width modulation frequency, the length of cables and the interference filters being used. Furthermore, grid impedance and the system's grounding concept also play an important role.

Leakage currents from frequency inverters

In both 1-phase and 3-phase inverters, the grid voltage is first rectified through a bridge

circuit and smoothed. From this, the inverter generates an output voltage that can vary in amplitude and frequency corresponding to the desired motor speed.

Leakage currents in frequency inverters arise through internal interference-suppression measures and all parasitic capacitances in the inverter and motor cables. The largest leakage currents, though, are caused by the method of operation of the inverter. It controls motor speed continuously using pulse-width modulation (PWM), which generates leakage currents far above the grid frequency of 50 Hz. For instance, the switching frequency of an inverter might be 4 kHz, and the associated harmonics can have very large amplitudes at higher frequencies. These frequencies then travel over the motor cables to the motor, and so the motor cables with their grounded shields act like a capacitor to ground. Current is then diverted to earth through this capacitance. It is thus recommended to separate filtered and unfiltered cables, otherwise high-frequency interference signals can be carried over the filtered cable (see Fig. 2).

Transient leakage currents

In addition, transient leakage currents can arise when the system is turned on or off. Depending on the phase angle, turning the system on, can result in steeply rising voltage spikes as a result of the fast voltage increase. The same thing happens, as well, when the unit is turned off due to inductivity in the circuit. These fast voltage spikes generate a transient leakage current to ground through the filter capacitors. It can arise that the RCD shuts down operation when the system is first turned on.

One way to prevent this is to use a RCD with delayed response characteristics. So as to not seriously hinder the RCD's ability to provide safety, these response characteristics are set to narrow limits. Type B RCDs as a rule already have a delay in the response. If such a RCD is not built in, it is relatively simple to start the machine in steps. In this way, for machines with multiple units, it is possible to start up the various frequency inverters one after the other.

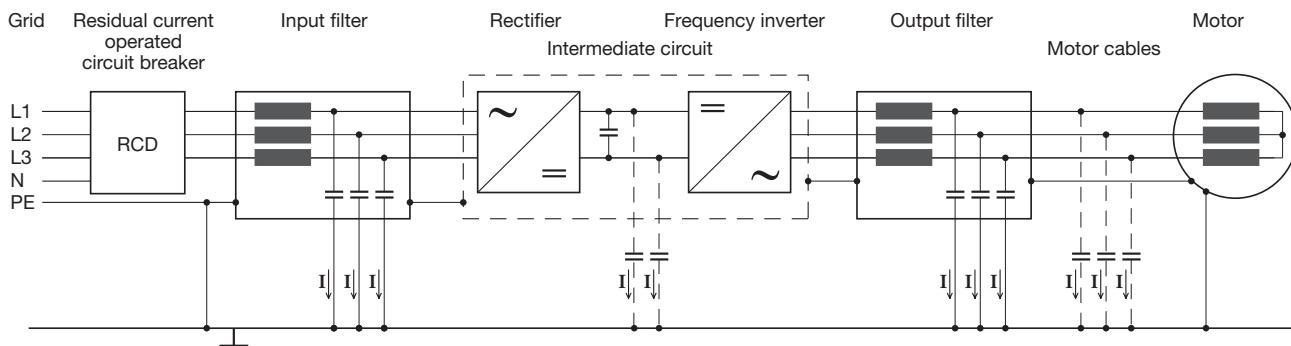


Fig. 2: Typical leakage currents in a motor drive with a frequency inverter (source: SCHURTER AG)

Properties of RCDs

The job of a RCD is to immediately interrupt the circuit in the event of a fault. For this, there are a variety of designs. Such devices with a trip value of 300 mA are frequently used for protection against fires, and those with 30 mA for human contact. If the trip values are reached because of defective insulation or someone touching a line, the RCD trips immediately.

DIN VDE 0100-410 has been in effect since June 2007, and it mandates a fault-current protective device for all power-socket circuits up to 20 A with a rated fault current of up to a maximum of 30 mA. This is also applicable to circuits up to 32 A in outdoor areas intended for connecting portable equipment. The probability that a machine or device that is not permanently connected into the power grid is also tied into an electrical installation protected with a RCD is thus relatively large. As a manufacturer, it is thus important to check machines for leakage currents.

Besides the various trip values, it is also worth noting the various characteristics of the RCD. Depending on the model, the RCDs trip only upon sinusoidal fault currents. Others are sensitive to all types of current and also measure these currents in the frequency range from 0 to several kilohertz (see Table 1).

Fig. 3 shows the tripping characteristic curve of a Type B+ RCD that is sensitive to all currents. This breaker handles all fault currents up to 20 kHz. The trip value of 30 mA is specified in the range of a grid frequency of 50 Hz because the possibility of a fault current is largest there. The permissible trip value increases with frequency. Thus high-frequency leakage currents from the frequency inverter are already accounted for.

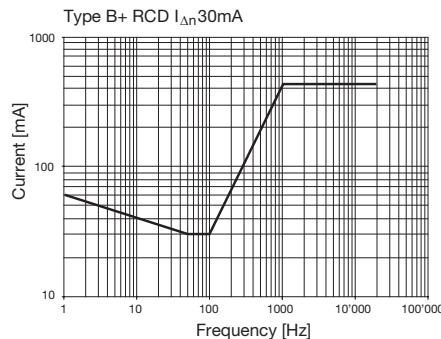


Fig. 3: Tripping characteristic curve of a RCD sensitive to all currents (source: SCHURTER AG)

If it is not possible to bring the leakage currents in a system below the RCD's response threshold, the option exists to replace that device with a differential RCM (residual current measuring device). Here the system's highest constant leakage current (e.g. 60 mA) and the fault-interrupter trigger value (30 mA) are added together (90 mA) and used as the setpoint. The RCM allows normal leakage current in the system but immediately interrupts any excess level above the limit of the sum.

Measuring leakage currents

It is recommended to measure the leakage current for every newly installed machine. The simplest method for doing so is to measure the current on the ground conductor with a clip-on ammeter (Fig. 4). However, most clip-on ammeters display only 50-Hz current, and thus a better way to measure the value is with a leakage-current analysis system. Figure 5 shows that the leakage current in higher frequency ranges (example: 14 mA @ 6 kHz) can be larger than



Fig. 4: Measuring current on a ground conductor (source: SCHURTER AG)

at 50 Hz (6 mA @ 50 Hz). Based on such measurement results, it is possible at an early stage to assess the cause of the leakage current and take remedial measures.

When measuring leakage current, it is important to measure the current during various operating conditions. In particular, a change in motor speed can have a major influence on the resulting leakage current. For instance, leakage currents can become significantly larger if the inverter's switching frequency is a multiple of the EMC filter's resonant frequency. This puts the filter into oscillation and can generate high leakage currents.

Leakage currents in filters

In EMC filters, capacitors from all conductors are wired to ground. Current is continually flowing through each of these Y-capacitors, and the amount depends on the size of the capacitor, grid voltage and the frequency. In an ideal 3-phase power network with sinusoidal voltages, the sum of all these currents is zero. In practice, however, there is a continuous leakage current to ground due to strong distortion in the grid voltage. This is also present even if the machine is not running, in other words even if voltage is applied only to the filter. Most filter manufacturers specify the maximum expected leakage current so that it is easier to select the most suitable filter. Keep in mind, though, that these are theoretical values, which can deviate due to unsymmetrical loading or a higher frequency (> 50 Hz). Thus, it is advisable to measure current to ground with filters installed and in operation (see Fig. 6).

RCD type	Symbol	Fault current	Characteristics
AC		sensitive to AC	sinusoidal AC
A		sensitive to pulsed current	sinusoidal AC pulsed DC
B		sensitive to all currents	all currents up to 2 kHz
B+	kHz	sensitive to all currents	all currents up to 20 kHz

Table 1: Characteristics of the RCDs (source: SCHURTER AG)

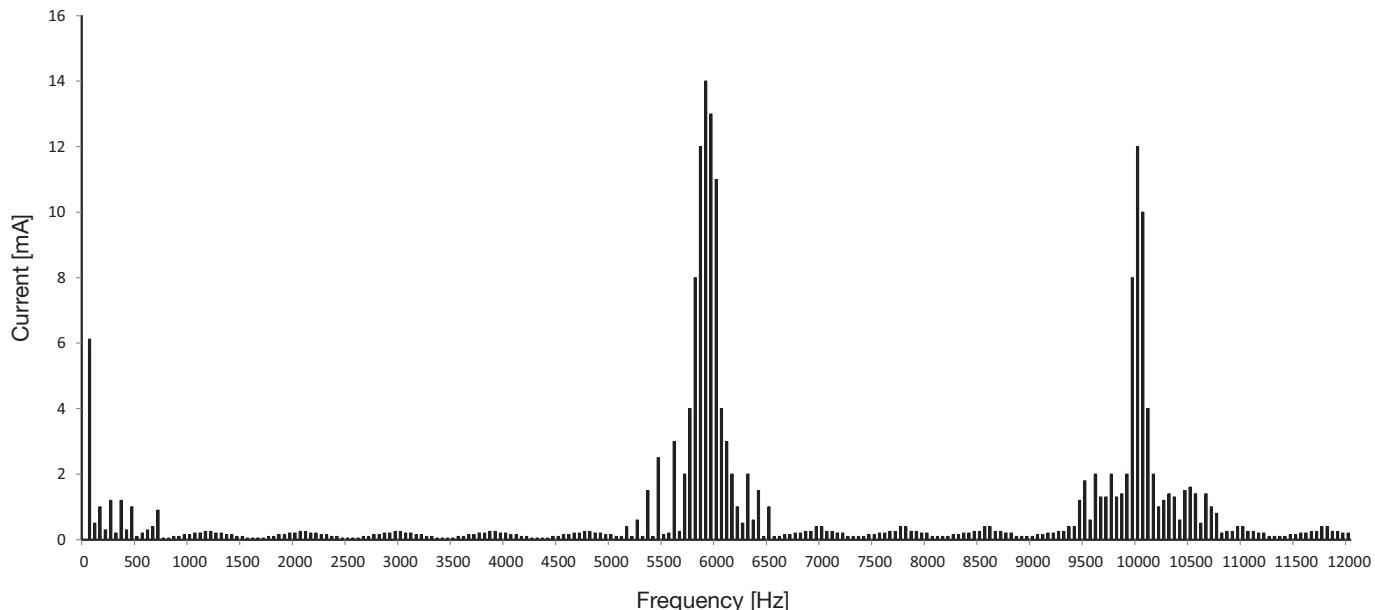


Fig. 5: Leakage current by frequency range (source: SCHURTER AG)

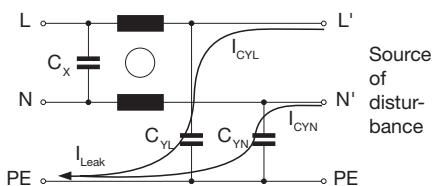


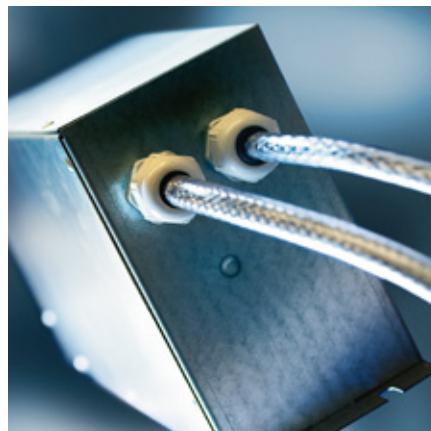
Fig. 6: Leakage currents in filters (source: SCHURTER AG)

Many frequency inverters are delivered with integrated filters or what are known as footprint filters. These are generally simple, inexpensive filters with small chokes and large capacitors between the phase conductors and ground that cause large leakage currents. The filtering effect of the large Y-capacitors can generally be replaced only with larger inductances. For example, a 1-stage filter with large Y-capacitors must be replaced with a 2-stage filter with two chokes, which makes it larger and more expensive.

Often there is also an EMC statement of conformity for such filters. This, however, is valid only for an ideal installation and short motor cables. Longer motor cables, for instance those extending longer than 10 m, require a new EMC measurement. Long motor cables also generate a larger capacitance to ground, which in turn can result in larger leakage currents. These additional asymmetrical currents can lead to the magnetic saturation of the filter chokes. As a result, the filter loses a large part of its effectiveness and the system then exceeds the permitted EMC limits.

Reducing leakage currents in filters

A remedy can be provided with shorter cables or an output filter. This filter, also called a sinewave filter, should be inserted directly at the inverter's output. It effectively attenuates leakage currents above 1 kHz by reducing the slew rate of the motor voltage.



Sinewave output filter FMAC SINE from SCHURTER

If multiple inverters are used in a system, it can be worthwhile to use a central filter at the grid input instead of a filter for each individual inverter. This not only saves money and space but also reduces the leakage current. Many manufacturers also offer special low leakage current filters for their inverters or summation filters for use at the grid input.

An especially simple and effective option for reducing leakage current is to use a 4-conductor filter with a neutral conductor instead of a 3-conductor filter. Most filters with a neutral conductor have smaller leakage currents because many capacitors are connected between the phase conductors and the neutral conductor. With this arrangement, the leakage current is more effectively returned through the neutral conductor. Because the neutral conductor is measured by the RCD in the same way as the phase conductors, the device does not trip because the sum of the currents is equal.

If a filter does not have sufficient attenuation, it can be combined with an additional power-line choke. This reduces the current's ripple factor along with harmonics and thus provides for smaller leakage currents.

Conclusion

In summary, the following measures are suited to counteract high leakage currents in systems with frequency inverters. They can also be easily used in combination:

- Separate circuits in RCD protected/non-protected areas
- Separate filtered and unfiltered cables
- Starting up the frequency inverter in steps
- Placing the frequency inverter close to the motor (short motor cables)
- Overvoltage protection to protect against voltage spikes
- ARCD with delayed response characteristics
- A differential RCM (residual current measuring device)
- Power grid chokes
- A central filter at the grid input instead of multiple individual filters
- Use 4-conductor filters with a neutral conductor instead of 3-conductor filters
- An output filter (sinewave filter)
- Low leakage-currents filters

SCHURTER offers a wide range of power-line filters and output filters, many of them also in low leakage-current versions. SCHURTER's professional EMC measurement service will examine applications and determine filter requirements, and also measure the system's leakage current. If none of our standard products are suitable, a customer-specific solution can be developed in a very short time.

Company

SCHURTER continues to be a progressive innovator and manufacturer of electronic and electrical components worldwide. Our products ensure safe and clean supply of power, while making equipment easy to use. We offer a broad range of standard products including circuit protection, connectors, EMC products, switches and input systems, as well as electronic manufacturing services. Moreover, SCHURTER is ready to work with our customers to meet their application specific requirements, not covered in our standard range. You can rely on SCHURTER's global network of companies and partners to guarantee a high level of local service and product delivery.

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