⬥TDK

EMC filters

Technical information

Date: August 2022

1 Why electromagnetic compatibility?

We can no longer imagine our everyday lives without electrical devices. This applies to all areas of our lives, in the household as well as in industrial applications. We expect electrical devices and systems to function properly; which is based on the principle of electromagnetic compatibility (EMC). Electromagnetic compatibility means that a device does not influence other devices in the environment through undesired emissions and at the same time is not influenced by emissions from other devices. The resistance of a device against electromagnetic interference is also called susceptibility.

The image below represents the EMC principle between two devices. Each electronic device functions simultaneously as an interference source by emitting disturbance signals and as disturbed equipment during receipt. The electromagnetic energies emitted by an interference source may be conducted or radiated. At low frequencies, it can be assumed that the interference spreads only along conductive structures, at high frequencies in the MHz range increasingly by means of electrical and magnetic fields as well as electromagnetic radiation.
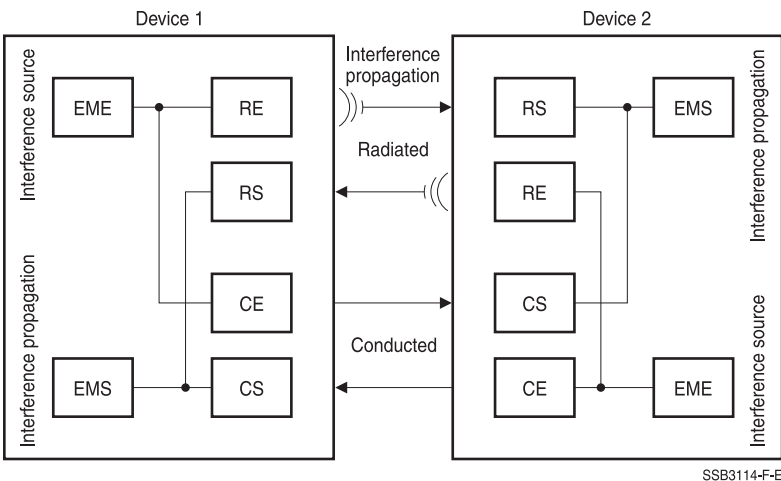

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Figure 1   Principle of electromagnetic compatibility

EME: electromagnetic emission
EMS: electromagnetic susceptibility
CE: conducted emission
CS: conducted susceptibility
RE: radiated emission
RS: radiated susceptibility

Technical information

The European directive 2014/30/EU on electromagnetic compatibility defines electromagnetic compatibility as *"the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment"*.

In order to meet this target, the following components described in this data book are used to limit conducted electromagnetic interference:

- EMC filters
- Output filters
- Chokes for power electronics

In doing so, the target is to maintain the limit values determined in standards for emission and susceptibility for the respective device or system.

2   Legal requirements

In order to ensure electromagnetic compatibility, there are diverse standards which need to be observed when placing devices in the market. The first Europe-wide EMC directive was published in 1996 (89/336/EC) by the European legislator. The EMC directive 2014/30/EU which came into force on 20 April 2016 currently applies. This is implemented in national law, for instance, in Germany by the "Law on electromagnetic compatibility of equipment (EMC Act)".

This directive specifies how electrically operated devices are to be designed with regard to electromagnetic compatibility. The limit values to be maintained in order to ensure EMC are separately defined in the generic standards, product standards and product family standards.

Examples for generic standards are EN 61000-6-3 for emissions for residential, commercial and light-industrial environments as well as EN 61000-6-4 for emissions for industrial environments. The limit values for conducted interference, among other things, are determined in both of the named standards.

EN 61800-3 can be named as an example of an important product standard: Variable frequency electrical drives – Part 3: EMC requirements including special test procedures. EN 55011 is named as an example here for product family standards: Industrial, scientific and medical equipment. Radio-frequency disturbance characteristics. Limits and methods of measurement.
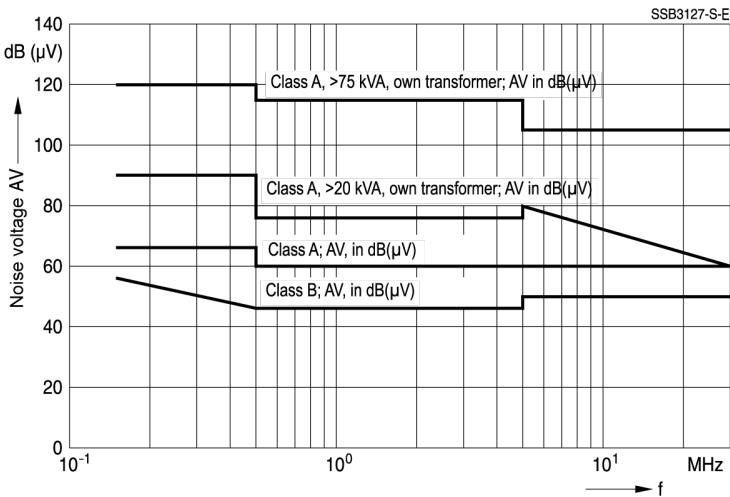
Figure 2   Limit values of interference voltages according to EN 55011 for Group 1 devices
(only AV detectors)

The limit value examples for the average interference voltage from the EN 55011 standard indicate that various classes, groups and nominal power ranges are differentiated for the devices and equipment.

- Classes:
  – According to the intended use of the devices and equipment
  – Class A: Use not in residential area and supply networks, by which residential buildings are supplied (e.g. own medium voltage transformer)
  – Class B: Operation in residential area and supply networks, which also supply residential buildings

- Groups:
  – Subdivision into areas of application
  – Group 1: all devices which do not belong to Group 2
  – Group 2: All ISM RF devices[1], which intentionally generate or use RF energy in the frequency range of 9 kHz … 400 GHz.

- Rated power:
  – The rated input power of the equipment or device is relevant.
  – Rated power $\leq$ 20 kVA (20 kVA corresponds to approx. 3-phase supply with 400 V and 29 A)
  – Rated power range > 20 kVA and $\leq$ 75 kVA
  – Rated power range > 75 kVA (75 kVA corresponds to approx. 3-phase supply 400 V and 109 A)

1) High-frequency devices in industrial, scientific and medical equipment, which use approved frequencies.
ISM: Industrial, Scientific and Medical

The named classifications do however deviate in the EN 61800-3 "Variable frequency drives ..." product standard:

■ Intended use:
  – First environment: in essential residential, business and commercial areas, small businesses, which are directly connected to the public low voltage network.
  – Second environment: in mainly industrial areas with their own medium voltage transformer
■ Category:
  – C1: first environment; V_R < 1000 V (similar to Class B, Group 1 according to EN 55011)
  – C2: first environment: V_R < 1000 V; setup and commissioning by specialist
  – C3: second environment; V_R < 1000 V
    (A distinction is made between limit values $\leq$ 100 A and > 100 A)
  – C4: second environment; $V_R \geq$ 1000 V; $I_R \geq$ 400 A; use in complex systems

The precise definitions and limit values can be found in the corresponding standards.

When placing devices on the market, the manufacturer must use a declaration of conformity to verify that the devices meet the requirements in the applicable EMC directives. EMC measurements are usually needed for this purpose. See also the "Services and EMC laboratory" Chapter.

3 Propagation of interference

In order to be able to select suitable EMC components, the way in which conducted interferences are propagated needs to be known.

A floating interference source primarily emits only differential-mode interference which is propagated along the connected lines, see Figure 3. The interference current will flow towards the disturbed equipment on one line and back to the source on the other line, just as the line current does.

Differential-mode interferences occur mainly at low frequencies (up to several hundred kHz).
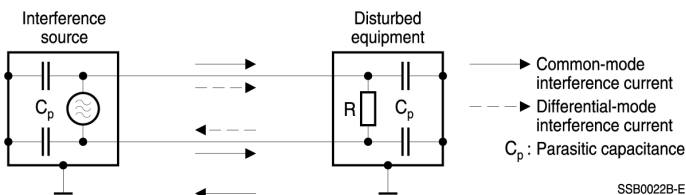

Figure 3   Common-mode and differential-mode interference

However, parasitic capacitances in interference sources and disturbed equipment or intended ground connections also produce an interference current in the ground circuit. This common-mode interference current flows towards the disturbed equipment along both the connecting lines and returns to the interference source through ground.

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and *Cautions and warnings*
5   8/22

Since the parasitic capacitances will tend to form a short-circuit with increasing frequencies and the undesired coupling effects on the connecting cables and the equipment itself will increase correspondingly, common-mode interferences become dominant above several MHz.

In addition to these two parts above, the term "unsymmetrical interference" or normal mode is used to describe the interference voltage between one line and a reference potential at a defined impedance, and consists of symmetrical and asymmetrical parts.

4   Interference characteristics

In order to be able to choose the correct EMC measures, we need to know the characteristics of the interference, how it is propagated and the coupling mechanisms involved. In principle, any interference can also be classified according to its propagation mode (Figure 4). At low frequencies, it can be assumed that the interference propagate only along conductive structures, at high frequencies virtually only by means of electromagnetic radiation. In the immediate near-field region, the term coupling (capacitive or inductive) is generally used to describe this mechanism.

Analogously, conducted interference at frequencies of up to several hundred kHz is mainly differential mode (symmetrical), whereas it is common-mode (asymmetrical) at higher frequencies. This is because the coupling factor and the effects of parasitic capacitance and inductance between the conductors increase with frequency.

X capacitors and series inductors are suitable as differential-mode corrective measures. X capacitors are capacitors, which are switched between phase and neutral conductor or between two phases. Common-mode interferences can be reduced by current-compensated chokes and Y capacitors. However, this requires a well-designed EMC-compliant grounding and wiring system.

Y capacitors are capacitors, which are switched between phase or neutral conductor and ground. An overview of potential corrective measures can be found in the table entitled "Overview of interference and corrective measures" on page 40.

The principle of named components is explained in detail in the "What is an EMC filter?" section.

The categorisation of types of interference and measures and their relation to the frequency ranges is reflected in the frequency limits for interference voltage and interference field strength measurements. The interference voltage is typically measured in the range of 150 kHz to 30 MHz; a future extension of the range is likely, starting at 9 kHz or even 2 kHz. Field strength measurements usually start from 30 MHz.
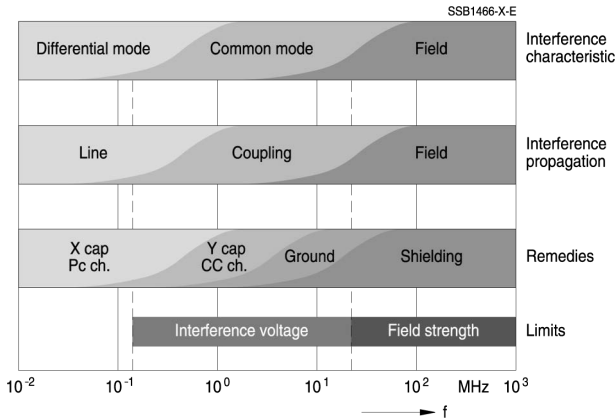

Figure 4   Propagation of interference

Pc-ch. = Iron powder core chokes, but also all single chokes
X cap   = X capacitors
CC-ch. = Current-compensated chokes
Y cap   = Y capacitors

Overview of interference and corrective measures:

Type of interference		Frequency range	Potential corrective measures
Conducted	Differential mode interference	Typ. < 1 MHz	X capacitors (C_x) Differential mode chokes
	Common mode interference	Typ. > 1 MHz	Y capacitors (C_y) current-compensated chokes
Radiated	Interference field strength	Typ. > 30 MHz	Shielding Good large-area grounding

5   Filters and chokes for power electronics

Variable frequency drives are predominantly used in industrial installations and building technology. Thanks to the flexible speed control, the overall efficiency of the system is improved, for example, regarding wear and energy consumption. To control the speed of the drives, frequency converters are used which generate a variable frequency output voltage. Besides the fundamental mode, interferences are generated by the clock frequency and voltage pulses, which overload the basic signal and may interfere with the network.

As such, in many cases the use of EMC components is needed to suppress interference. The block diagram in Figure 5 illustrates using EMC components in connection with a frequency converter.
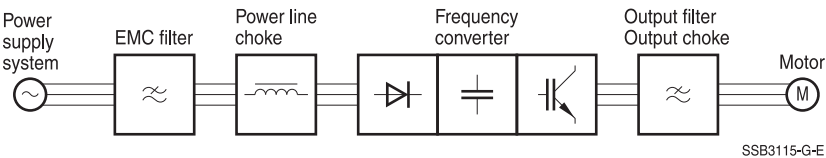

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Figure 5   Filters and chokes for power electronics

EMC components are also used outside of the industrial area for electrical devices and systems. For instance, many domestic appliances, consumer electronics and medical devices require full interference suppression in order to maintain standard limit values.

In addition to electronically controlled drives, electronic power controls and switch-mode power supplies, microprocessor systems are also often used in control units or in displays. Clock frequencies in the megahertz range often couple into the network connection of the device and are therefore relevant for standard evaluation of the interference voltage.

The interaction between various electrical devices and systems is often underestimated. Higher power drives are often positioned close to complex and sensitive measuring equipment. If electromagnetic compatibility is disregarded, this may lead to incorrect measurement results even if expensive measuring equipment is used. Even if the drive and measuring equipment meet standard requirements, an influence may be caused.

EMC may even cause problems for bus systems in complex electronic power controls. If the noise in electronics has been inadequately suppressed, this can cause an increased bit error rate.

These are just a few examples pointing out the importance of using EMC filters and chokes. The following can be summarised: Investments in EMC pay off from an overall analysis. In areas where high system availability and reliability are required, electromagnetic compatibility and therefore the use of EMC components is an absolute must.

5.1 What is an EMC filter?

The term EMC filter is used in the same way for various components. In these documents, EMC filters are an electrical circuit comprising inductors, capacitors and resistors, which limit electrical interferences in power networks. Output filters are excluded from this term and are discussed in the next chapter.

EMC filters predominantly act in the area of conducted interference. Radiated interference is however also influenced with corresponding circuits. The filter type is virtually always a low-pass filter, which feeds through the usable frequency (typically DC to 60 Hz) generally unaffected, interference frequencies are however weakened.

In the same way as the interference suppression measures presented in the "Interference characteristics" chapter (see page 39), the key components of an EMC filter are typically:

- X capacitors (C_x)
- Differential mode chokes
- Y capacitors (C_y)
- Current-compensated chokes
- Discharge resistors

Depending on the type of network or application, EMC filters are implemented with a different number of lines. 2-line filters are used for DC or single-phase applications. 3-line filters (no neutral conductor) or 4-line filters (with neutral conductor) are used for three-phase alternating current applications.

The structure of a 2-line filter is shown below in an equivalent circuit diagram
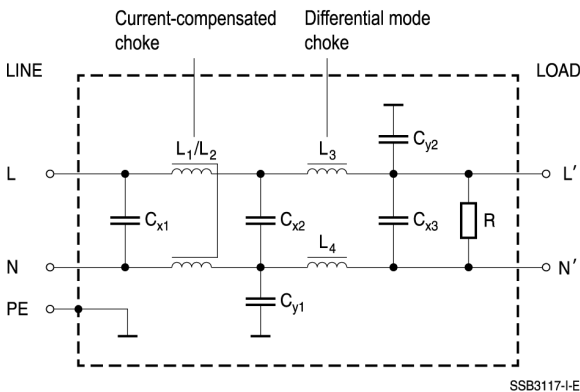

Figure 6   Equivalent circuit diagram for 2-line filters

The image below shows an example of the internal structure of a 2-line filter with the previously named components. Filters are usually (partially) potted after the assembly. The potting material is used to improve the heat dissipation and stability of the filters.

Current-compensated choke

Line side

Discharge resistors
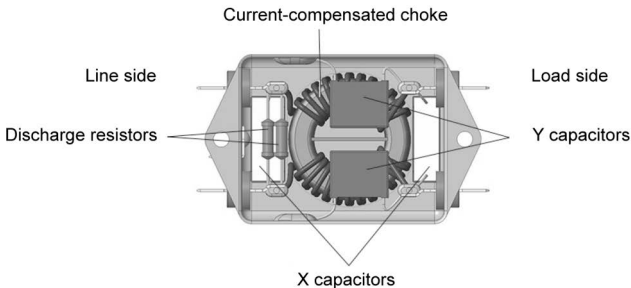
Load side

Y capacitors

X capacitors

Figure 7   Internal structure of an EMC filter

The inductors ensure together with the capacitors the filter effect. The capacitors used in EMC filters are almost exclusively interference suppression capacitors or capacitors with a special test.

When classifying interference suppression capacitors, a distinction is made between Class X for connection between the phases or between the phase and neutral conductor (2-line filter) and Class Y for connection between the live conductor (phase or neutral conductor) and the reference ground. As such, X capacitors attenuate more symmetrical interferences in the lower frequency range, while Y capacitors attenuate more asymmetrical interferences in the higher frequency range.

For three-phase applications the connection of the capacitors is mostly implemented from phase to a virtual star point. An additional capacitance can be connected from the virtual star point to the reference ground. Since the voltage from the virtual star point to the ground is very low in a symmetrically grounded three-phase network, the leakage current is also correspondingly low through the capacitor switched to the reference ground.

The functioning of the current-compensated choke is based on its winding direction. With an opposite winding direction, the magnetic fluxes of the differential mode operating current are compensated. The inductance is therefore theoretically equal to zero for the differential mode current (operating current). A low inductance is practically generated by the leakage fields, the so-called leakage inductance. In contrast, the current-compensated choke forms a high inductance for common-mode disturbances (disturbance signal). This principle is shown in Figure 8.

In order to improve the filter effect, a filter can be set up with multiple stages. A higher attenuation effect and a steeper rise in the attenuation curve are achieved.
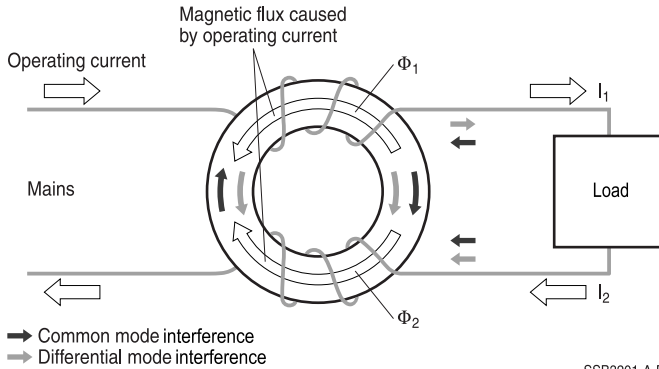

Figure 8   Principle of a current-compensated choke

A reduction in conducted interferences can generally be achieved with two types of filters: reflecting or absorbing filters.

The majority of filters used are based on the principle of interference energy reflection. This takes place through the above described cross capacitors (C_y), which act at higher frequencies as a short circuit and differential mode chokes, which have a high impedance at high frequencies. The filter effect is achieved through as big as possible mismatch of the filter to the source of interference and the disturbed equipment.

At absorbing filters, the interference energy in the filter is converted to heat and drawn from the system in this way. This type of filters is however of minor importance in practice.

5.2 What is an output filter?

TDK groups the following EMC components together under the term output filter:

- dv/dt filters/chokes: dv/dt filters or chokes are designed as LC low-pass filters, whose cutoff frequency is higher than the switching frequency. As such, the voltage rise rate between the phases is limited. dv/dt filters comprise a differential mode choke and capacitors, at the dv/dt choke the cable capacitance provides the filter capacitance.

- Sine-wave output filters: In a sine-wave filter, the main components are also a differential mode choke and capacitors. The components are dimensioned in such a way that the cutoff frequency of the low-pass is between the output and switching frequency. The smoothing effect between the phases is therefore considerably greater than with the dv/dt filter.

- Sine-wave EMC output filters: A sine-wave EMC filter comprises a sine-wave filter with current-compensated choke on the motor side and capacitors to the reference ground. The interferences between the phases and reference ground are therefore reduced. As such, the use of unshielded motor cables is possible in many applications, which can result in considerable cost savings.
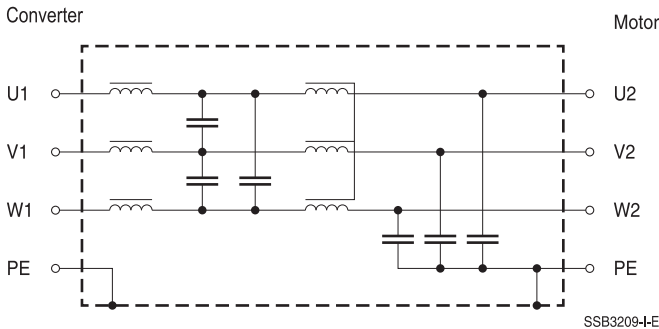
Figure 9   Principle of a sine-wave EMC filter

The term output filter is used in the majority of cases for filter applications on the converter output side in connection with the motors operated at them. The output filters are used in this application with the following targets:

- Protect the insulation of the motor
- Reduce EMC interference
- Reduce parasitic currents through capacitance of cable shielding
- Use unshielded motor cables
- Reduce motor noise

5.3 What is an active filter?

EMC input filters are generally designed as passive filters, i.e. their circuit is implemented with passive components such as inductors, capacitors and resistors.

In contrast, active filters also comprise active components such as transistors, operational amplifiers, processors, voltage converters etc. in addition to passive components.

When eliminating grid perturbations, two fields of application of active filters are currently represented on the market:

1. **Reducing leakage currents using LeaXield™ active leakage current filter**
   In converter-based drives, the individual components cause leakage currents, which together may lead to triggering of the RCD (residual current device) without a fault case occurring.

   This may mean that an RCD cannot be used or only with a great deal of additional effort. Using an active filter to reduce the leakage currents may provide a remedy here. TDK offers LeaXield™ active leakage current filter for this purpose.

   LeaXield™ can compensate leakage currents up to 1 A. The compensating effect covers a wide frequency range from around 150 Hz to 30 kHz.

   Thanks to its compact dimensions, LeaXield™ is also very well suited to retrofitting existing installations. The LeaXield™ active leakage current filter is installed between residual current devices and EMC input filters of the converter and can be operated without an external power supply, which keeps installation work to a minimum.

   LeaXield™ therefore offers a compact and cost-effective solution for compensating leakage currents in a wide frequency range. The use of residual current devices is thus enabled and plant availability is increased.

LeaXield™
active leakage current filter

Detailed information on LeaXield™ active leakage current filters can be found in the chapter entitled "Data sheets – Active filters" and online at
www.tdk-electronics.tdk.com/de/2487720/produkte/produktkatalog/emv-bauelemente/leaxield.
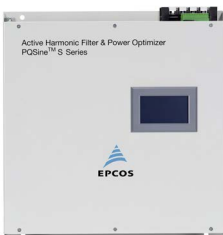
2. **Reduction of harmonics to 2500 Hz or 3000 Hz using PQSine™**

   To minimise harmonics up to the 50th order (2500 Hz in 50 Hz mains or 3000 Hz in 60 Hz mains), TDK offers the PQSine™ S-series.

   As well as reducing harmonics, if necessary these active harmonics filters cause a power factor correction of inductive and capacitive loads, load balancing between the phases and a reduction of the neutral conductor currents (at the 3P4W device). They also improve the network quality, maintain any standard limit values (such as EN 50160, IEEE 519 etc.) and ensure efficient and reliable use of energy.

   The PQSine™ S-series has a modular structure and is available for various nominal voltages up to 690 V (nominal filter currents from 25 A to 150 A per module; several modules can be switched in parallel in order to implement higher filter currents). The devices for wall mounting have an integrated 4.3" colour LCD touchscreen. A 7" colour LCD touchscreen with operating software is available for modules for switch cabinet installation.

PQSine™ wall-mounted

PQSine™ module for switch cabinet installation

   Further information on PQSine™ can be found at www.tdk-electronics.tdk.com/de/pqsine_presentation.

   Contact via the Product Inquiry screen on our homepage: www.tdk-electronics.tdk.com/de/192962/kontakt/produktanfrage

5.4   What is a choke for power electronics?

In electrical engineering, the term "choke" is used in the same way as "inductor".

The "Chokes for power electronics" term used in these documents describes chokes for power applications, i.e. currents from several amps.

Chokes for power electronics are predominantly constructed as laminated chokes. The properties of the chokes are defined by the type of core material. For laminations, it is the material thickness, the cutting procedure and the structural principles of the core. Depending on requirements, special materials such as grain oriented or amorphous electrical sheet, iron powder or ferrite can be used.

The most important chokes for power electronics are:

- Power line chokes
- Smoothing chokes
- Filter circuit chokes for power factor correction
- Filter chokes
- Regeneration chokes

Power line chokes are also known as commutation reactors, as they limit voltage drops in the commutation phase to permitted values. They also limit the peak currents. The current harmonics are also reduced by power line chokes, so that the sinusoidal line voltage is distorted as little as possible.

Smoothing chokes can be found in DC applications and reduce the harmonic component and current rise rate there.

Filter circuit chokes are used for series connection with PFC capacitors of compensating systems in order to prevent resonances in the power supply network. In order to attenuate individual harmonics, chokes can also be established for series resonant circuit applications.

Filter chokes are part of the above-mentioned sine-wave filters and LCL filters, but are also used for higher frequency applications as series resonant chokes.

In order to decouple the active infeed of pulse width modulated frequency converters from the mains and to smooth harmonics, special power line chokes are used, which are called regeneration chokes or AFE chokes.

Thanks to regenerative feedback, the mains connection is now actually the output of the converter. LCL filters are actually very similar to sine-wave filters, but are grouped with power line chokes due to their improved comparability. The principle of an LCL filter is illustrated in Figure 10.
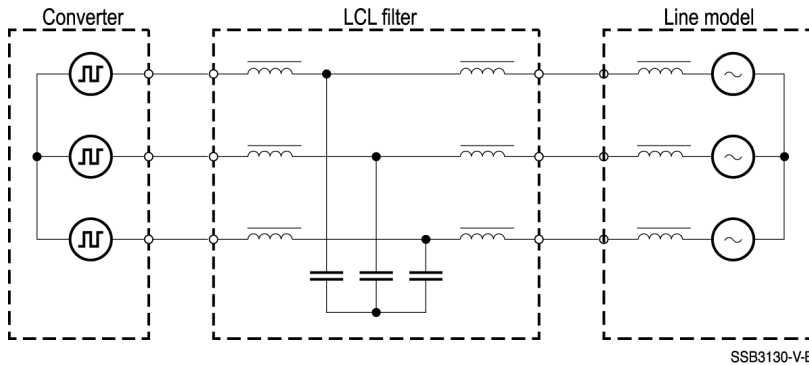

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Figure 10   Principle of an LCL filter

6   EMC measurement methods

Meeting the EMC limits defined by standards and regulations is proved so by appropriate measurement methods and test procedures.

A distinction between susceptibility testing and emission testing is generally made. Depending on the type of device or system to be tested, product standards may define different test conditions. As the entire topic is rather complex, merely a brief overview is provided below, which is by no means complete.

Examples for susceptibility tests

- Electrostatic discharges (ESD)
- High-frequency electromagnetic fields
- Fast transients (Burst)
- Surge voltages (Surge)
- Conducted high-frequency interference
- Magnetic fields with power frequencies and other magnetic fields (e.g. pulse form, …)
- Voltage dips, short interruptions and voltage variations
- Harmonics, interharmonics, damped oscillations

Examples for emission measurements

A distinction is generally made between the measurement of conducted and radiated emission:

■ Measurement of conducted emission

– In order to guarantee the comparability of results, the measurement at the power supply interfaces is aimed for with an artificial mains network (AMN). For AC power supplies, the line impedance stabilisation network −LISN) is used, which determines the impedance between each conductor and reference potential in a "V shape". In the case of other interfaces (e.g. communication), we refer to impedance stabilisation networks (ISN) to define the impedance in a determined frequency range.

– For interference voltage measurements, the disturbance signal V_S is usually decoupled from line impedance stabilisation network and measured at the radio disturbance measuring receiver according to CISPR 16-1-1. In special cases, a probe is used according to CISPR 16-1-2 to measure the interference voltage. It is however also possible to measure the interference current I_S with an RF current transformer.

– Limit requirements for conducted emission are usually given from 150 kHz to 30 MHz, for a number of products or certain customer requirements, they are also available in the frequency range of 9 kHz to 150 kHz.

– Generally, precise rules are to be followed for the test setup, in order to measure the test results in a reproducible manner.

The measurement curves below show the result of a conducted interference voltage. The upper line represents the limit value for the quasi peak, the line below marks the limit value for the average. The limit value lines show a linear curve over wide frequency ranges.

The two measurement curves below appear to be much more dynamic, whereby the upper peak value (PK) is represented and the curve below is the average value (AV). The measuring methods are defined in CISPR 16, the limit value lines follow the corresponding determinations in standards and are dependent on the product. The crosses below the peak curve represent remeasurement with the quasi peak detector.

The following information is added for a brief explanation of the measuring methods: The maximum measured value of each frequency is the peak value (PK). The quasi peak value (QP) determined for evaluation provides an evaluated peak value of the envelope of the IF voltage of the radio disturbance measuring receiver.

The second evaluation parameter Average (AV) is the output signal of the average detector and provides the arithmetic average of the envelope of the IF voltage of the disturbance amplifier.
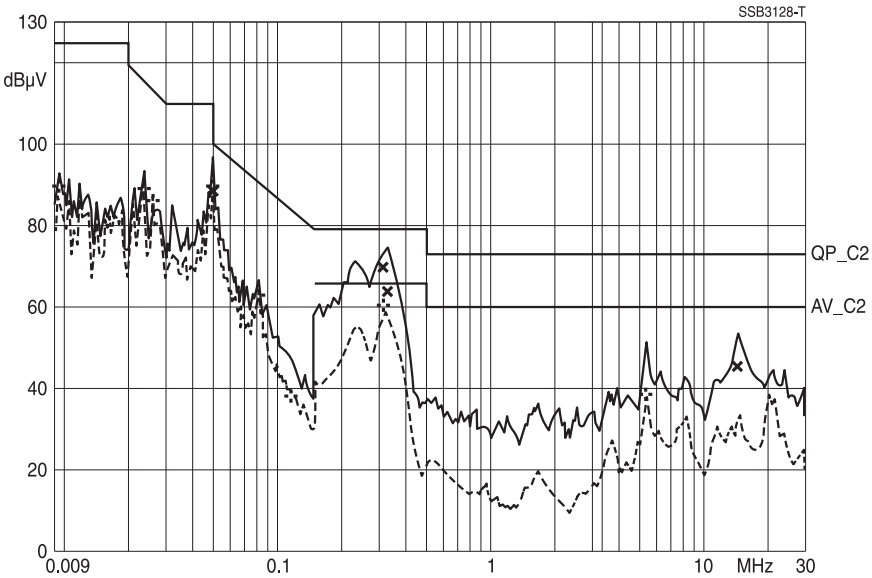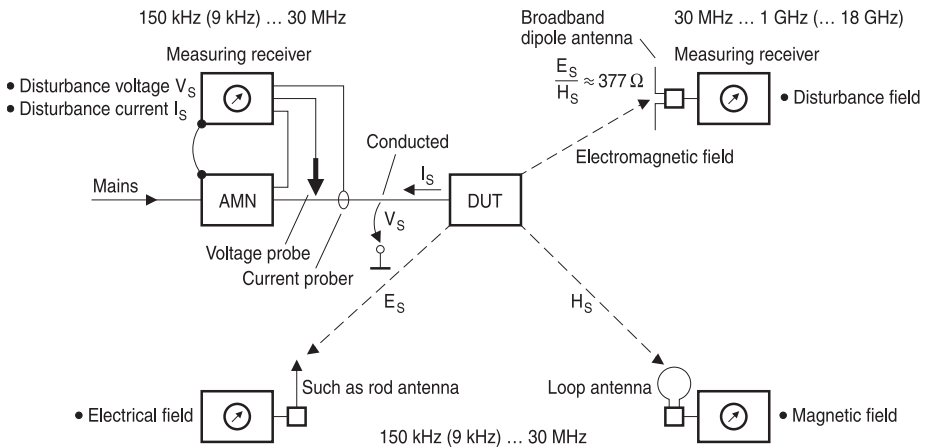
Figure 11 Measurement results of conducted emission from a converter with TDK EMC filter; upper curve measurement with peak detector (final measurements with quasi-peak detector = crosses), lower curve measurement with average detector with final measurement points; measuring range of 9 kHz to 30 MHz, limit value below 150 kHz customer-specific

■ Measurement of electromagnetic radiated interference
  – The most frequently used method here is measuring the electromagnetic interference field at a measuring distance of 10 m or 3 m, depending on the application and technology from 30 MHz to 1 GHz or even higher.
  – Measurement of the radiated emission is performed in a full anechoic room or a semi-anechoic chamber according to CISPR 16-1-4. The components of the radiated field are separately measured in the horizontal and vertical direction.

H_S = magnetic fields
E_S = electric fields
$E_S / H_S = Z_0 \approx 377\,\Omega$ = characteristic wave impedance
AMN = artificial mains network
DUT = Device under test

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Figure 12   Propagation of electromagnetic disturbance and EMC measurement methods

7 Key parameters of filters and chokes

7.1 Nominal voltage V_N

The nominal voltage is the voltage specified by the manufacturer or supplier for normal operation. This voltage is specified with a permissible tolerance. The nominal voltage in many European three-phase networks is thus 230/440 V +/- 10%. IEC 60038 "CENELEC standard voltages" for nominal voltages of a system describes the details.

7.2 Rated voltage V_R

The rated voltage V_R is either the maximum RMS operating voltage or the highest DC operating voltage which may be continuously applied to the filter or choke at temperatures between the lower category temperature and the upper category temperature. Filters which are rated for a frequency of 50/60 Hz may also be operated at DC voltages.

This rated voltage must never be exceeded, as otherwise damage may occur. Only small deviations are tolerated, such as a component with a rated voltage V_R of 250 V in a network 230 V +/- 10% (230 V +10% = 253 V). The difference between V_N and V_R is illustrated in Figure 13.
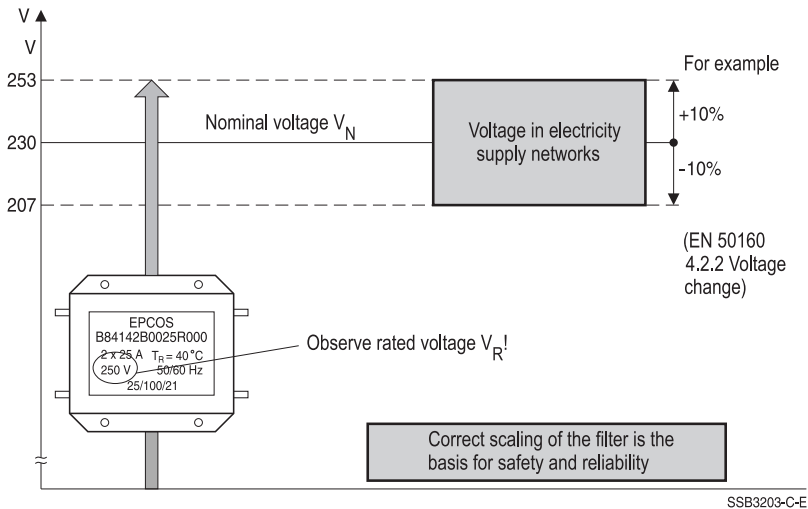

Figure 13   Difference between rated and nominal voltage

7.3   Rated current I_R

The rated current I_R is the highest DC or AC current at which the filter or choke can be continuously operated under the rated conditions. Above the rated temperature T_R, the operating current should be reduced according to the derating curves (see section "Current derating depending on the ambient temperature").

In 2- and 3-line filters and chokes, the rated current refers to the concurrent loading of all lines with the specified value. In 4-line filters, the sum current of the neutral line is considered to be close to zero.

In the event of operation with non-sinusoidal AC currents, higher thermal loads may be produced, which must be considered. The temperature increase of the filters and chokes at their rated current and temperature is measured by connecting them via test cross-sections on the basis of UL 508 "Industrial Control Equipment" (largely similar to IEC 60947-1).

7.4   Filter leakage current I_{LK}

The filter leakage current is the current which flows in the fault-free state at the rated frequency via the casing to the reference potential. In the majority of cases, this current is influenced by capacitors connected to the reference potential. Detailed explanations on leakage current can be found in the "Leakage current" chapter.

7.5   Rated temperature T_R

The rated temperature T_R is the highest ambient temperature at which the component can be operated at its rated current.

7.6   Rated frequency f_R

The rated frequency f_R is the highest frequency, at which the AC operating voltage may be on the terminals.

7.7   Insertion loss α

The insertion loss α is a measure of the efficiency of filters and components. The higher the insertion loss, the better the attenuation effect of the component. The insertion loss is usually represented as a curve over the frequency and is presented in the data sheets as a graphic.
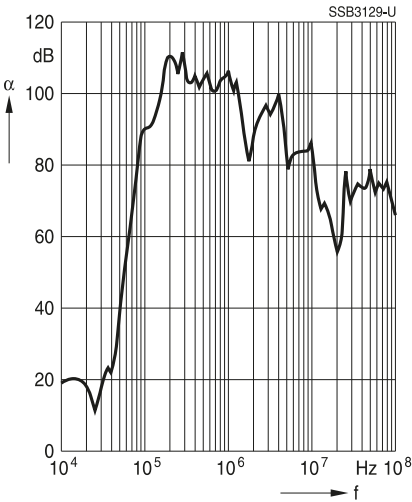

Figure 14   Example for differential insertion loss

The test procedure used to measure the interference suppression properties was updated in the IEC publication CISPR 17 in 2011 and was published as the EN 55017 standard. The insertion loss for a filter is defined as the ratio of voltages before and after the filter being tested. The measurement takes place in the same way as shown in Figure 16. The short circuit measurement represented in Figure 15 is used to illustrate how the formula is derived. Detailed information on insertion loss can be found in the "Insertion loss" section from page 82.

Measurement principle:
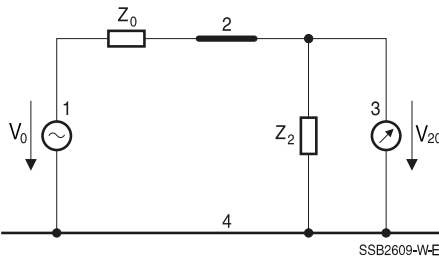

Figure 15   Test circuit for insertion loss;
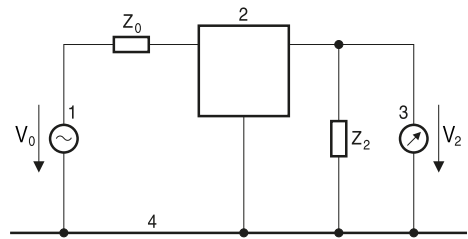   filter replaced by short circuit

Figure 16   Test circuit for insertion loss;
             measurement of the EMC filter

Legend

1	Signal generator
2	EMC filter (DUT)
3	Test receiver
4	Reference potential (metallic test surface)
V_0	Open-circuit generator voltage
V_2	Output voltage
V_{20}	Output voltage (with short circuit)
Z_0	Generator impedance
Z_2	Impedance of the receiver

Definition of the insertion loss in dB:

$$\alpha = 20\log \frac{V_{20}}{V_2} = 20\log \frac{V_0}{2V_2}$$

With the following simplification:

$$Z_0 = Z_2 = 50\ \Omega \text{ and thus } V_{20} = \frac{V_0}{2}$$

7.8   Rated inductance L_N

The rated inductance L_N is the inductance value which is designed for a choke. The specified measurement conditions are to be observed. The inductance varies depending on the test frequency, test current and temperature.

7.9   Test voltage V_{test}

The test voltage V_{test} is the DC or AC voltage applied to the filter or choke in the final production test for the specified test duration. If required, we recommend a single repetition of the voltage test at max. 80% of the specified value.

The rate of voltage rise or drop should be around 500 V/s. The time must be measured as soon as 90% of the test voltage permissible for the test has been reached. No dielectric breakdown should occur during the test. Capacitor healing effects are permissible.

7.10   Voltage drop of a choke v_k

The related voltage drop v_k of a choke is defined in % as follows:

$v_k = \dfrac{V_k}{V_N} \cdot 100\%$ where V_k = Voltage drop of the choke

                                          V_N = Nominal voltage

The voltage drop of a choke may be approximately calculated as follows:

$X_L = 2\,\pi \cdot f \cdot L$ where   f = Frequency (for specification of 50 Hz)

                                          L = Rated inductance of the choke

$V_R = p \cdot V_N$ where V_R = Rated voltage

                                          p = Factor for voltage tolerance 1.1

                                          (e.g. typical tolerance $\pm 10\%$)

For 1-phase chokes:

$V_R = I_R \cdot X_L$ where I_R = Rated current

For 3-phase chokes in the symmetrical three-phase network:

$V_k = I_R \cdot X_L \cdot \sqrt{3}$

Example for 3-phase power choke B86305L0230S000:

L = 0.15 mH   => $X_L = 2 \cdot \pi \cdot 50\ \text{Hz} \cdot 0.15 \cdot 10^{-3}\ \text{H} = 47.1\ \text{m}\Omega$

I_R = 230 A   => $V_K = 230\ \text{A} \cdot 47.1 \cdot 10^{-3}\ \Omega \cdot \sqrt{3} = 18.8\ \text{V}$

For a nominal voltage of 400 V AC, the example results in:

v_k = 18.8 V/400 V = 4.7%

7.11   Ohmic resistance R_{typ}

The ohmic resistance R_{typ} is the typical resistance of a filter or choke at 20 °C. The value is a reference value with a standard tolerance. The value is based on the measurement between the connections between the input and output of the same current path.
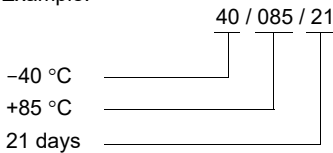
Please read *Important notes*
and *Cautions and warnings*
     24   8/22

7.12 Climatic category

The climatic usability of components is determined according to IEC 60068-1, Appendix A. It is formed by three defining parameters separated by slashes. These parameters are:

1. Temperature applied for the tests with cold
2. Temperature applied for the tests with dry heat
3. Stressing duration with moist, constant heat

Example:

$$40 \: / \: 085 \: / \: 21$$

−40 °C

+85 °C

21 days

- First defining parameter:
  Absolute value of the lower category temperature T_{min} as the test temperature for test Ab (cold) to IEC 60068-2-1 for 16 h.
- Second defining parameter:
  Absolute value of the upper category temperature Tmax as the test temperature for test Bd (dry heat) to IEC 60068-2-2 for 16 h.
- Third defining parameter:
  Stressing duration in days for test Cab (moist heat, constant) to IEC 60068-2-78 at 40 °C; testing accuracy - relative air humidity 85% or 93% depending on the specification.

7.13 Overload

The rated current may be briefly exceeded. The thermal overload and the frequency per unit of time are specified in the data sheet. If the rated current is exceeded, saturation effects may occur, which can lead to a change in the properties of the component.

7.14 Finger protection

Finger protection describes the level of protection in the area surrounding connecting cables. Depending on the applicable standards and regulations, this level of protection is required to prevent accidental touching of dangerous active parts. Finger protection means that test probe 11 (solid test finger) in accordance with EN 61032 cannot come into contact with live parts. This is defined in the data sheet with the "finger-safe terminals" entry.

7.15 Reliability and MTBF

You connect reliability in a technical manner as the properties of products in terms of the reliability or their fault rate. Depending on their use, the functional safety of devices and systems can also be required by standards or applicable directives.

The failure rates for corresponding parts and components under reference conditions are assumed based on the gathered empirical values.

These are to be adjusted to the actual environmental and operating conditions using calculation models.

The calculations are based on the IEC 61709 standard "Electric components – Reliability – Reference conditions for failure rates and stress models for conversion".

A typical key parameter used to describe product reliability is MTBF (Mean Time Between Failures). IEC 60050 defines MTBF as the expected operating time between two consecutive failures of a device type in hours. The value is not specified in the data sheets, but is available on request. The values are to be considered as empirical values for the entirety of the batches. In individual cases, clear deviations from the empirical values may occur within the scope of value distribution.

7.16 Insulation class

The insulation class is used to characterise the electrical insulation in relation to its properties under the influencing factor of temperature. An electrical insulation material (EIM) aims to isolate conductive materials of varying electrical potential. The EN 60085 standard uses the term "thermal class". The thermal class determines the maximum continuous service temperature in degrees Celsius.

The thermal class number value is defined by a letter. Common thermal classes are listed in the following table.

Thermal class in °C	Letter
90	Y
105	A
120	E
130	B
155	F
180	H

In particular, insulating systems of chokes for power electronics are also defined with the thermal class. An electrical insulation system (EIS) characterises one or more electrical insulation materials in connection with the corresponding conductive parts.

7.17   dv/dt value

The dv/dt voltage rise rate describes the slew rate in a system following a change in the system, such as a switching operation. The average rise rate results from the voltage change from 10% to 90% of the step height and corresponding time change as shown in Figure 17.

The voltage rise rate plays a role in many areas of electrical engineering. Here are a few examples:

- High dv/dt values stress the insulation of winding goods (chokes and transformers), but also of cables and motors. In many cases, limit values are specified by manufacturers.
- In the case of capacitors and therefore also filters, a rise in the voltage rate means a proportional rise in the current: $I = C \cdot dv/dt$.
- At motors operated on converters, it may result in voltage overshoots (V_{peak}), depending on motor lead lengths, rise rates and reflection factors. Standards or data sheet specifications of motors limit the peak voltage V_{peak} and rise rate t_r. The output filters can be used as an effective measure when limit values are exceeded.
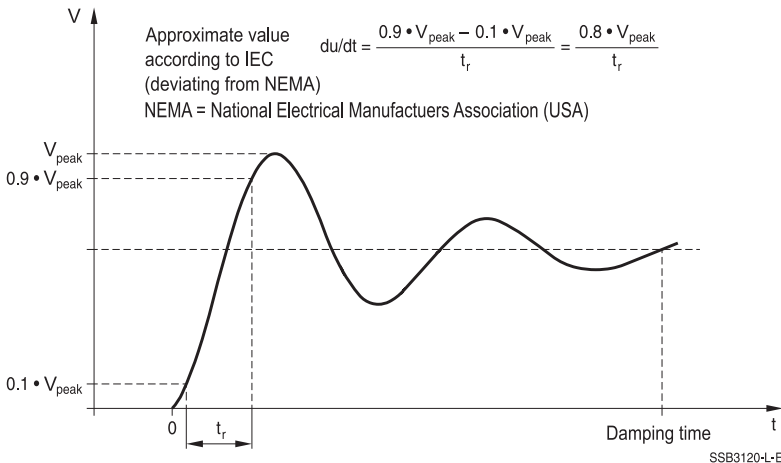
Approximate value according to IEC (deviating from NEMA)

NEMA = National Electrical Manufactuers Association (USA)

$$du/dt = \frac{0.9 \cdot V_{peak} - 0.1 \cdot V_{peak}}{t_r} = \frac{0.8 \cdot V_{peak}}{t_r}$$

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Figure 17   Voltage rise rate dv/dt; NEMA = National Electrical Manufacturers Association (USA)

8 Energy supply networks

8.1 Function of the networks

A) Transmission network: Extra-high voltage (220 kV, 380 kV … approx. 1200 kV)

High voltage (60 kV … 150 kV)

B) Distribution to regional transformer stations: Medium voltage (1 kV … 20 kV …30 kV)

C) Local distribution (e.g. households, industry):   Low voltage (e.g. 230 V, 400 V, 690 V)

These documents exclusively concern current supply systems with low voltages. The voltage limit is defined here as 1000 V AC or 1500 V DC.

⚠ The rated voltages specified for three-phase systems apply to the TN-S networks with symmetrically earthed star points usual in Europe! In the case of divergent network types, please check the suitability of the filters and the observance of the permissible voltages inclusive of possible fault cases such as earth faults or triggering of overcurrent protection equipment by other than all poles. In cases of doubt, contact your TDK partner, who will advise you on your specific filter application.

8.2 Designation of distribution systems (IEC 60364-1)

The information below on low voltage systems in Germany is explained in the DIN VDE 0100-100 standard.

TN − S

Third letter: Configuration of neutral conductor and protective conductor (if present)
S = The protection function is set up by a conductor which is separated from the neutral conductor or earthed line conductor.
C = Neutral and protective conductors are combined in a single conductor (PEN conductor)

Second letter: Earthing of the equipment
T = Direct connection of the equipment with earth
N = Direct connection of the equipment with earthed point of the power supply system (usually star point or earthed line)

First letter: Connection of the power supply system to earth
T = Direct connection of a pole to earth
I = System is separated from earth or earthed via the impedance

8.3 TN system

TN systems are directly grounded; the parts of the equipment to be grounded are connected to this point via protective conductors.

Three types of TN systems may be distinguished:

■ TN-S system: A separated protective conductor is used in the whole system.

■ TN-C system: The functions of the neutral and protective conductors are combined in a single conductor (PEN) in a part of the system.

■ TN-C-S system: The functions of the neutral and protective conductors are combined in a single conductor (PEN) in the whole system.

8.3.1 TN-S system with star current source and separated neutral and protective conductors

Current source   Distribution system   Installation

L1
L2
L3
N
PE

Equipment   Equipment

Grounding at the   Grounding in the   Additional grounding of the PE may be provided in the installation.
current source   distribution system

Grounding of the distribution system with
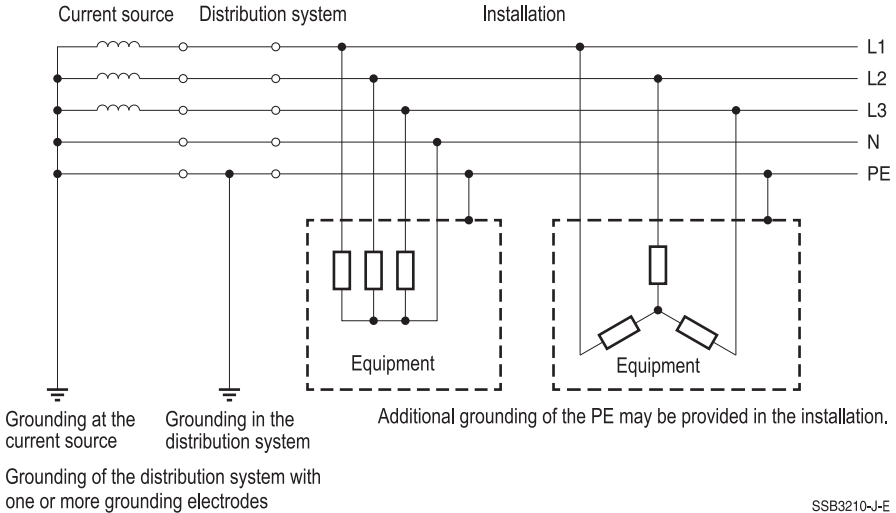one or more grounding electrodes

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Figure 18   TN-S system star with separated protective conductor

8.3.2 TN-S system with delta current source and grounded line conductor

Current source   Distribution system   Installation

L1
L2
L3

PE

Equipment   Equipment
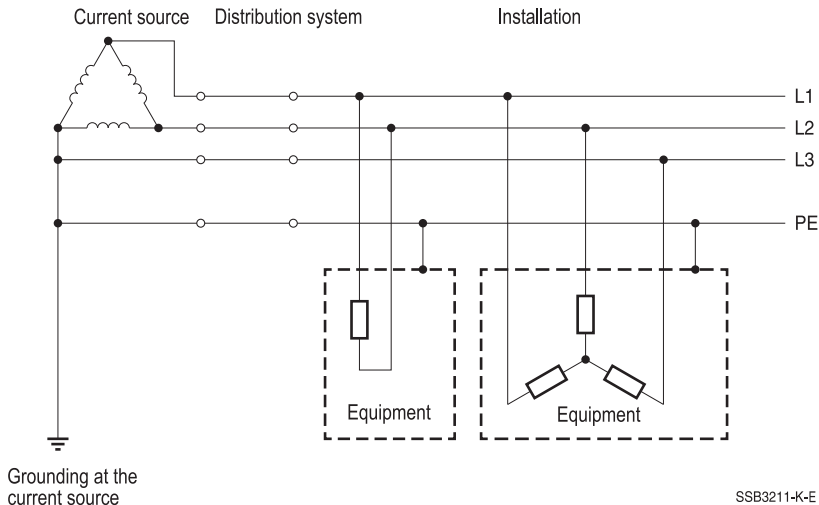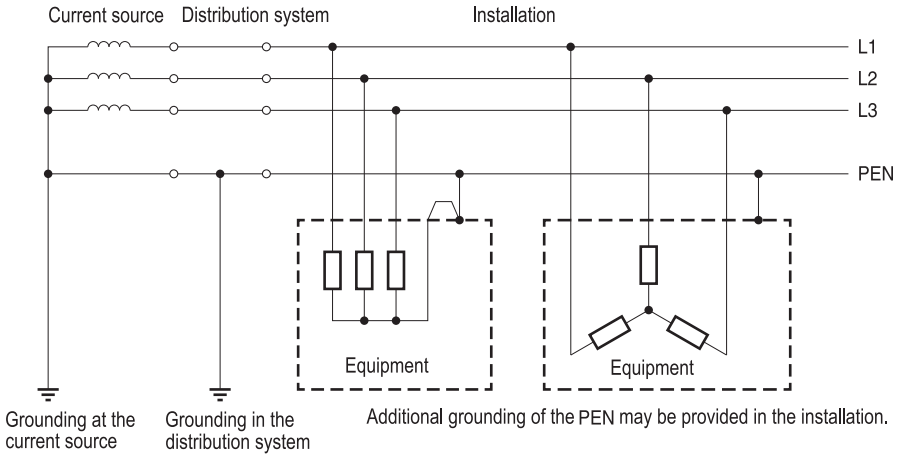
Grounding at the
current source

SSB3211-K-E

Figure 19   TN-S system delta with earthed line conductor

Technical information

8.3.3 TN-C system with star current source; neutral and protective conductor functions combined (PEN)

Figure 20   TN-C system with star current source; neutral and protective conductor functions combined (PEN)

8.3.4   TT systems

TT systems are directly grounded at a point. The parts of the equipment to be grounded are connected at the load location with ground, separated electrically from the grounding of the power supply network.
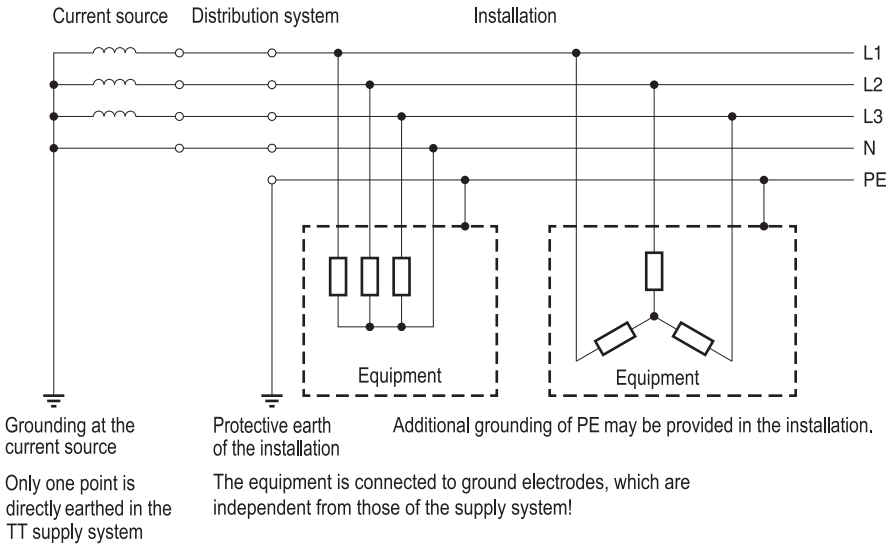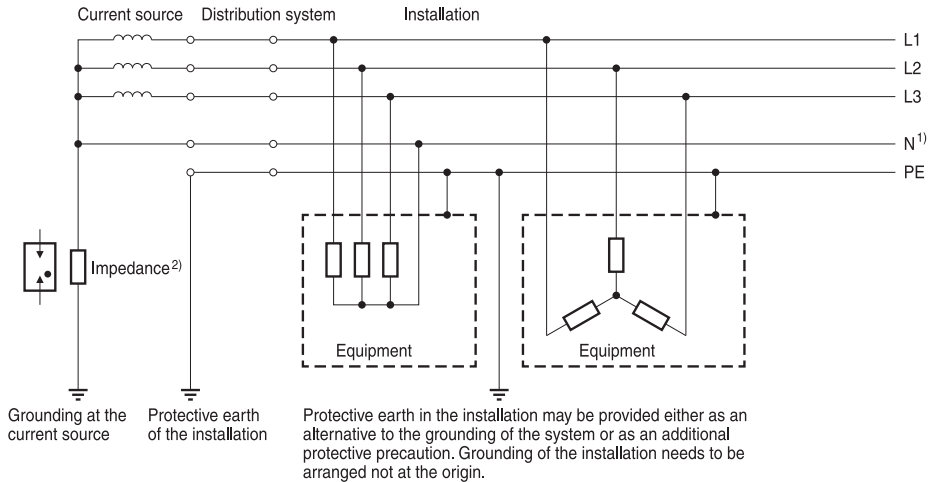
Current source   Distribution system   Installation

Grounding at the   Protective earth   Additional grounding of PE may be provided in the installation.
current source   of the installation

Only one point is   The equipment is connected to ground electrodes, which are
directly earthed in the   independent from those of the supply system!
TT supply system

SSB3213-M-E

Figure 21   TT system

8.4   IT systems

IT systems are separated from ground, but a point can be earthed via an impedance or a voltage limiter. The equipment to be earthed is connected at the load location with earthing elements.

8.4.1   IT system with star current source and neutral conductor

Current source   Distribution system   Installation

L1
L2
L3
N[1]
PE

Impedance[2]

Equipment   Equipment

Grounding at the   Protective earth   Protective earth in the installation may be provided either as an
current source   of the installation   alternative to the grounding of the system or as an additional
                                                 protective precaution. Grounding of the installation needs to be
                                                 arranged not at the origin.

[1] The neutral conductor may be, but does not need to be distributed.
[2] The system may be connected with ground via a sufficiently high impedance. This connection may be established, for example, at the centre or artificial centre or line conductor. In Germany, grounding of the IT system through sufficiently high impedance is only used for measurement and functional purposes.

SSB3214-N-E

Figure 22   IT system star with neutral conductor

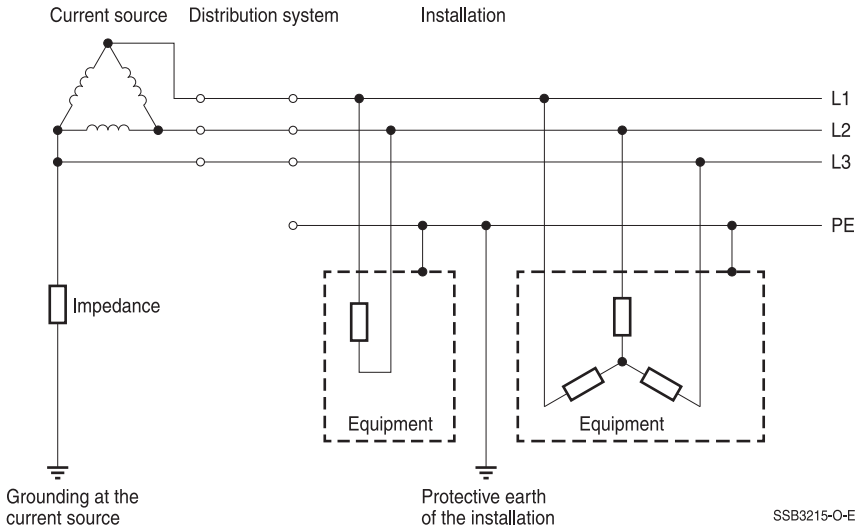## 8.4.2   IT system with delta current source

Figure 23   IT system delta

The notes and comments from Figure 22 apply in principle. The system can be ungrounded at the current source.

8.5 Special features of the IT system

The most important feature of the IT power supply system is the type of ground connection on the supplying system (such as the transformer) and the electrical equipment. In the IT power supply system, electrical connection does not take place between the active conductors and ground connection. An initial fault in the power supply system does not lead to shutdown.

Minimal spatial expansion is required for IT power supply systems. The network has a separate power supply, such as its own supplying transformer. The IT power supply system has good EMC properties and offers the highest level of protection against failure. The "classic" example is operating theatres in hospitals. However there are also numerous examples in the industry, where interruption to the power supply would cause severe commercial losses. Such applications are, for example, the chemical industry, glass production, smelting works, mining, ground water control and on board supplies on ships.

During the so-called first fault (earth fault or ground short circuit), no notable return current paths are produced and thus no dangerous contact voltage. The low residual current in this case is defined by the insulation resistances and capacitances of line to ground.

In Germany, the first fault must be reported by an IMD (Insulation Monitoring Device).
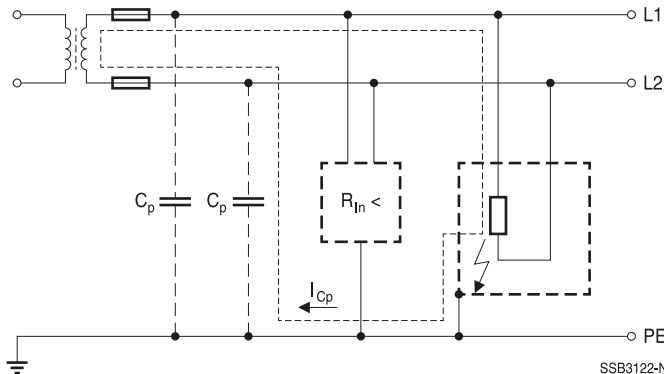
SSB3122-N

Figure 24   IT power supply system with insulation monitoring device and first fault
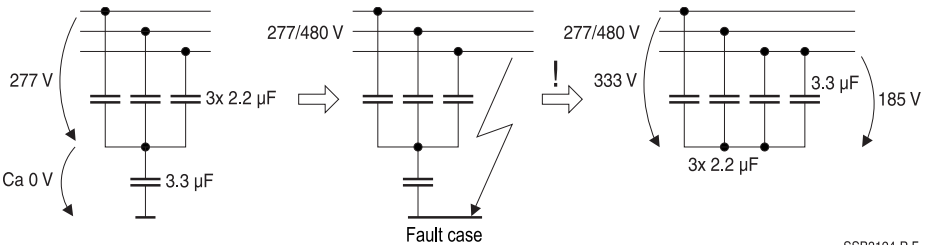
8.6 Suitability of filters for IT systems

EMC filters from TDK can be used in IT power supply operation if the following conditions are observed.

⚠ As illustrated in the following diagram, the voltages at the capacitors of the filters change in the IT power supply system in the event of a fault. **With this in mind, the rated voltages specified in the data sheets for grounded power supply systems cannot be used.**

Please note the "Rated voltage for IT power supply application" specification in the data sheet, which is applicable for this application. Should you fail to find a suitable specification, please contact your relevant contact at TDK or your distributor.

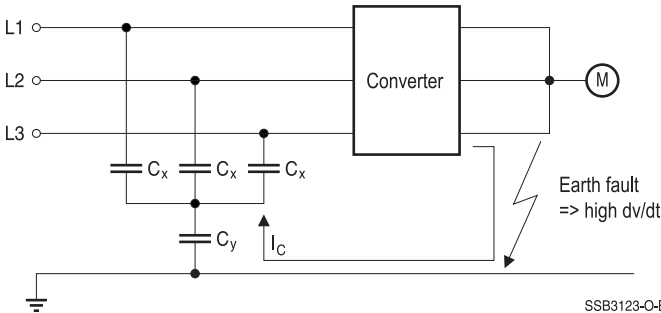**Example: Capacitor group in EMC filters**

Figure 25   Fault in the IT power supply changes the capacitor voltage

The specified rated current in the IT power supply system permits operation during an ground fault or ground short circuit on the line side. An exception here is the variable frequency drives. In the event of an ground fault on the output side of the converter or an ground fault on the input side of a regenerative drive without output filter, impermissible load situations may occur on the EMC filters.

In both cases, higher frequency switching frequencies may occur at an impermissibly high current through the capacitors of the EMC filter connected to ground. This also applies to other devices, which initiate high currents in the filter through higher frequency components. Overloading of the capacitors may lead to strong heating and failure of the capacitors.

Below is an example of an earth fault of the motor lead on the converter output. A high current I_C is generated by the earth fault through the capacitors C_Y, which may lead to an overload of the capacitor.

Figure 26   Earth fault on the converter output in the IT power supply system

For failures relating to the functional safety of EMC filters in a special application case with IT power supply, the conditions of normal operation and fault cases must be precisely known. In the case of special requirements, we would be more than happy to provide our customers with support.

8.7   Examples of deviating power supply configurations

Electrification goes back as far as the 1880s. Around this point in time there was no international harmonisation of standards, meaning that very different power supply systems have developed across the world. In spite of attempts to align the systems, there are still many specific national features. Many of the specific features are due to geographical constraints such as dry ground or long distances between the power supply and consumer.

When designing devices and systems, the potential power supply types and special features should be carefully checked for the locations of use. The differences in frequency at 50 and 60 Hz generally do not have a significant impact, but do however influence the leakage and touch current. For example, the open delta connection actually provides 3 phase voltages offset by 120°, however a greater voltage unbalance is to be expected.

During the evaluation, it is important that the maximum voltages line-to-line or line-to-earth occurring in the system are not greater than the rated voltage of the filter or choke defined in the data sheet. This means that for the rated voltage specification of 305/530 V AC that the line-to-earth voltage is limited to 305 V and the line-to-line voltage is limited to 530 V.

The example below of a delta power supply with grounded high leg delta should raise awareness of the topic for manufacturers of electrical equipment. A high proportion of the devices and systems are sold and used worldwide due to globalisation. The power supply system described here is also known as a "red leg delta" circuit, as the NEC (National Electric Code) calls for the red or orange marking of the L3 conductor with the maximum line-to-earth voltage.
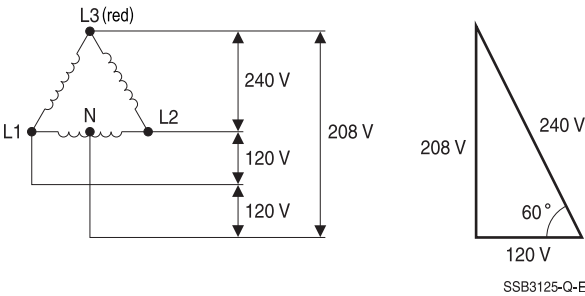

Figure 27   High leg delta circuit

9   Derating factors

The specification values specified in the data sheets are based on defined conditions. These conditions include:

- Ambient temperature of the component $\leq T_R$ (rated temperature)
- The share of higher-frequency voltage components (> f_R = 50/60 Hz) corresponds to the standard determination voltage characteristics of electricity supplied by public distribution networks EN 50160
- The altitude of the electrical equipment with the components used is $\leq$ 2000 m above standard zero elevation (NHN)

⚠ If one or more of these above-mentioned conditions is exceeded, when selecting the components consider the derating factors described below.

9.1 Current derating depending on the ambient temperature

Filters from TDK are designed for continuous operation at their rated voltage and rated frequency. They are designed to be operated at their full rated current up to the specified rated temperature (typically 40 °C).

When operated at higher ambient temperatures T_A than the specified rated temperature T_R, the maximum continuous operating current is obtained by multiplying the rated current by the corresponding derating factor k_{ct} (Figure 28 and Figure 29, indices "ct" "Current derating depending on temperature").

Non-observance of the current derating factor may lead to overheating and thus to the risk of fire.

Maximum current at increased ambient temperature:
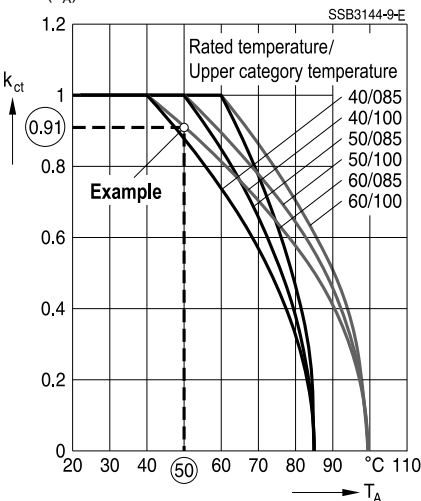
$$I_{max\,(T_A)} = I_R \times k_{ct}$$

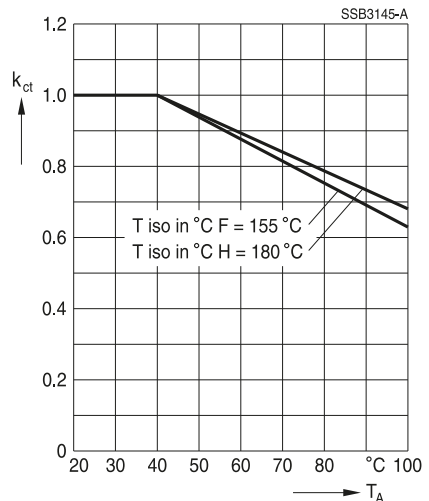Figure 28   Current rating factor k_{ct} depending on the ambient temperature T_A for EMC filters

Figure 29   Current rating k_{ct} depending on the ambient temperature T_A for chokes

The following curves are valid for the specified conditions:

Curve	Rated temperature T_R	Upper category temperature T_{UC} [2]
40/085	40 °C	85 °C
40/100	40 °C	100 °C
50/085	50 °C	85 °C
50/100	50 °C	100 °C
60/085	60 °C	85 °C
60/100	60 °C	100 °C

2) UC = "upper category"; mid-range number group in the climatic category (e.g. 25/085/21; 25/100/21) see "Climatic category" chapter
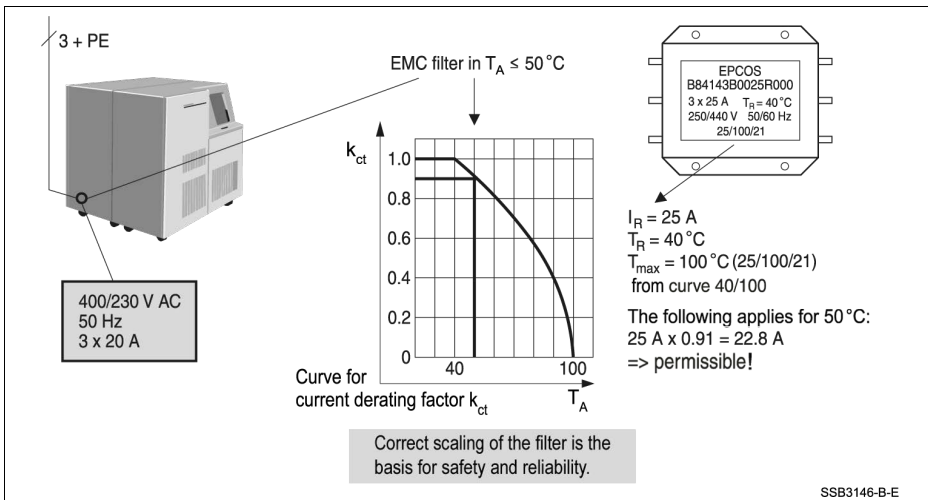

Figure 30   Application of the current derating charts

Given that:
- Filter B84143A0025R105 (I_R = 25 A)
- Switch cabinet with max. internal temperature of 50 °C
- Max. continuous current (RMS) at the converter input 20 A

Solution:
- From the data sheet of the filter B84143A0025R105:
- Rated current of 25 A at a rated temperature of 40 °C
- Upper category temperature of 100°C (climatic category 25/100/21)

From the current derating charts:

- Select applicable curve 40/100
- At an ambient temperature of 50 °C, read off the corresponding current rating factor $k_{ct} = 0.91$
- 25 A $\times$ 0.91 = 22.8 A (maximum permissible continuous current at 50 °C)
  –> Continuous current (20 A) < max. permissible current (22.8 A)

In this specific example, the filter can be used with a maximum continuous current of 20 A and is thus correctly dimensioned.

9.2 Current derating of 4-line filters with neutral line load

In 4-line filters (3 line conductors + 1 neutral conductor), the specified rated current refers to a three-phase load with a total current flowing through the neutral conductor close to zero. Specifically for applications with switched-mode power supplies such as computers and electronic ballasts, significant loading of the neutral conductor is to be expected, which in the worst case can exceed the magnitude of the phase currents.

Here, the rated current of the 4-line filter should be greater than the expected operating current. For an equal current flowing through the neutral and line conductors, a derating factor of $k_{cc} = 0.86$ is obtained (Indices "cc" = "**c**urrent derating depending on **c**onductors"). Current derating factors k_{ct} and k_{cc} are to be multiplied at simultaneously occurring ambient temperatures exceeding the rated temperature.

Example

Given that:

- $I_{L1} = I_{L2} = I_{L3} = I_N = 36$ A
- Filter B84144A0050R000 ($I_R = 50$ A)

I_{LX} = Current through conductors $L_1 \ldots L_3$
I_N = Current through neutral conductor

Solution:

Permissible load (3-phase + neutral):
$I_{max\ (c)} = k_{cc} \times I_R = 0.86 \times I_R = 0.86 \times 50\ A = 43\ A \Rightarrow 43\ A \geq 36\ A \Rightarrow$ permissible load

Use of the 4-line filter with $I_R = 50$ A with 3 x 36 A phase load + 36 A neutral conductor load is thus permitted.

9.3 Voltage derating depending on higher frequency load

9.3.1 Theoretical relationships

EMC filters are designed for operation at the rated voltage and frequency specified in the data sheet. This assumes an almost sinusoidal line voltage whose harmonic components lie within the limits approved by the power utilities.

Appropriate voltage derating must be applied where necessary to any higher voltages occurring in operation at frequencies higher than the rated frequency. They may be due to higher-frequency voltage components such as low-frequency system perturbations or voltage peaks generated by system resonances, such as may be caused by the clock frequency of an inverter in the network.
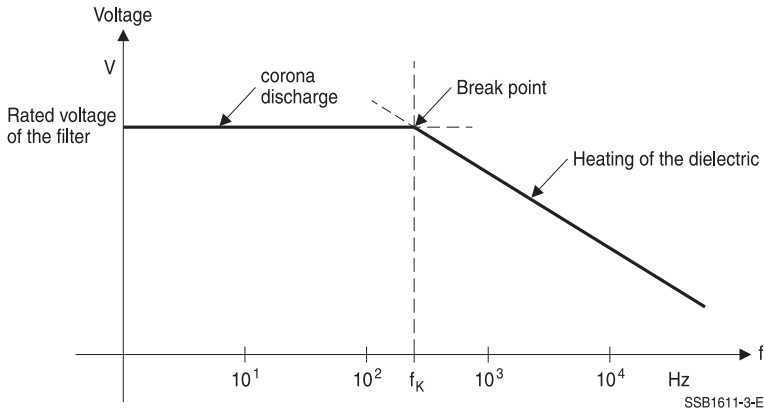

Figure 31   Theoretical relationships for voltage derating in filters

The maximum permissible voltage at the filter depends mainly on two limiting phenomena:

■ The horizontal line in the area up to the break-point frequency f_K represents the limit due to the corona discharge.

■ Above f_K, the permitted voltage declines with the frequency, the curve represents the permitted maximum voltage for any particular frequency. If the voltage lies exactly on the curve, the maximum permissible self-heating of 10 K is reached.

The above described curve is based on the physical principles of film capacitors.

In practice, several frequencies are applied to the filter (such as the harmonics of the switching frequency). To obtain the total heating and thus to determine whether the filter is still operated in its permissible operating range, all voltage amplitudes at each frequency must be calculated as described below.

⚠ **The total additional heating of the dielectric must not exceed 10 K.**

For a frequency point, the additional heating is calculated by the following formula:

$$\Delta T_n = \frac{10 \cdot (V_{Mn})^2}{(V_{Gn})^2} [K] \qquad\qquad \text{Formula 1}$$

V_{Mn} = Value measured at frequency f_n
V_{Gn} = voltage limit for frequency f_n
ΔT_n = Calculated heating of dielectric for frequency f_n
f_n = Selected frequency

This must be calculated and summed for all occurring $f_n \geq f_K$.

$$\Delta T_{ges} = \sum_{\nu=1}^{m} \Delta T_\nu = \sum_{\nu=1}^{m} \frac{10 \cdot (V_{Mn})^2}{(V_{G\nu})^2} [K] \leq 10 \text{ K} \qquad\qquad \text{Formula 2}$$

$V_{M\nu}$ = Value measured at frequency f_ν
$V_{G\nu}$ = Limit for frequency f_ν
ΔT_{ges} = Calculated heating of dielectric for all frequencies
f_ν = Frequency (with index ν 1 …. m)

9.3.2   Assessment of the permissible load

The actual load of a filter with higher-frequency voltages can be determined by calculating the temperature rise according to the above procedure on the basis of the measured voltages.

For this purpose, the RMS value of the voltage on the line and load side of the filter must be measured depending on the frequency. This is typically done with a network analyser that can directly display the various components at the individual frequencies, or by measuring the time function followed by a Fourier transform.

This measurement must be performed for all line/line and line/PE combinations and must be converted to the temperature rise for all these cases. The limits are then read off the applicable diagram from the "Derating curves" chapter at the corresponding frequency and inserted in the formula with the measured value. All the temperature values for each case are then summed. If this sum is below 10 K, there is no danger. If it exceeds this value, however, appropriate measures must be taken to reduce the voltage components accordingly. Another option is to select an EMC filter with a higher rated voltage.

Important:

The voltages must always be measured with an installed filter under operating conditions. Adjacent equipment must also be taken into account. Measurements without filters are at best useful as a rough guide. Thus resonances resulting from the network circuits (compensation capacitors, series reactors, transformers, leads) can change significantly after installation of a filter.

9.3.3 Calculation example

Example of a permissible load

A filter of type B84143B*S021 may be loaded with an effective 760 V line-to-line AC voltage (nominal voltage 690 V AC + 10%) and maximum permissible harmonics up to the 25th order according to DIN EN 50160.

Line/line load

The maximum permissible values for the harmonics according to DIN EN 50160 are used in this example, i.e. a kind of "worst-case" condition for low-voltage networks.

n	V_{Mn} V	Frequency Hz	ΔT K
2	8.8	100	0.0040
3	21.9	150	0.0270
4	4.4	200	0.0013
5	26.3	250	0.0582
7	21.9	350	0.0538
9	6.6	450	0.0065
11	15.4	550	0.0470
13	13.2	650	0.0433
17	8.8	850	0.0325
15, 21	2.2	750 ... 1050	0.0043
19, 23, 25	6.6	950 … 1250	0.0844
6, 8, 10, ... 24	2.2	300 … 1200	0.0172
Total 2 ... 25			0.3795

A temperature increase of about 0.4 K (permissible value 10 K) is calculated with formula 2: it is caused by all maximum permissible harmonics (DIN EN 50160). It should be noted that the applicable standard stipulates a maximum permissible total harmonic content of 8%. The above example with all maximum values has a THD (Total Harmonic Distortion) of over 11%.

This example shows that EMC filters from TDK are safely dimensioned and ensure a sufficient margin to the permissible limits in normal use under typical interference conditions.

Please note that every component has its physical limits, even when it is dimensioned with considerable safety margins, and these may be reached in the event of large higher-frequency voltage components or resonances.

9.3.4 Derating charts

The derating charts shown below are typical of many filters and should be seen as a guide for each filter group (2-, 3- and 4-line filters). The values for specific filters may differ from this data. This is because the voltage rating at higher frequencies depends on several parameters:

- The voltage derating of the capacitors used
- The configuration of the capacitors in the filter; e.g. several capacitors in series, in a star or delta circuit
- The rated voltage of the filter (line/line and line/PE)

If the self-heating of the capacitors calculated with the above equations is close to the limit of the permissible values, you should request the specific data for the relevant filter.
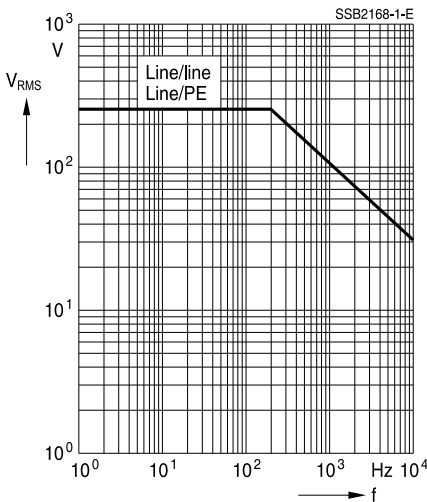
2-line filters

Figure 32   Derating chart for 2-line filters of 250 V

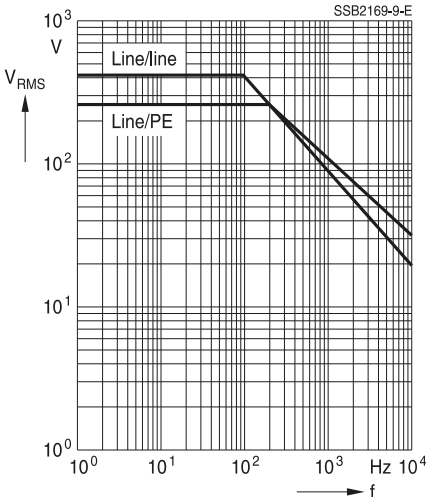### 3- and 4-line filters

Figure 33   Derating chart for
3- and 4-line filters of 440/250 V
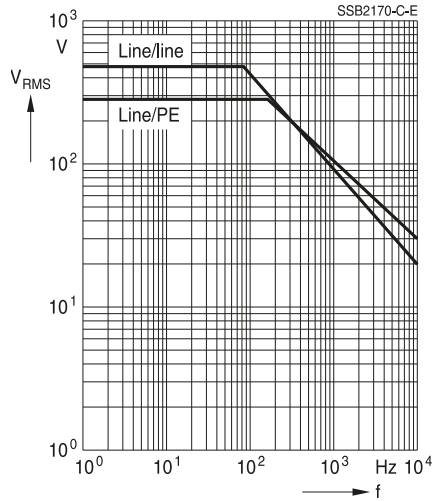

Figure 34   Derating chart for
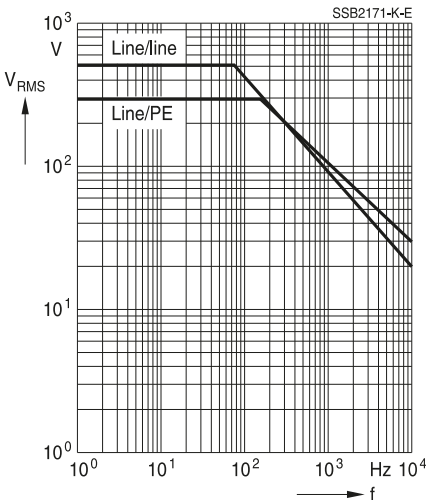3- and 4-line filters of 480/275 V

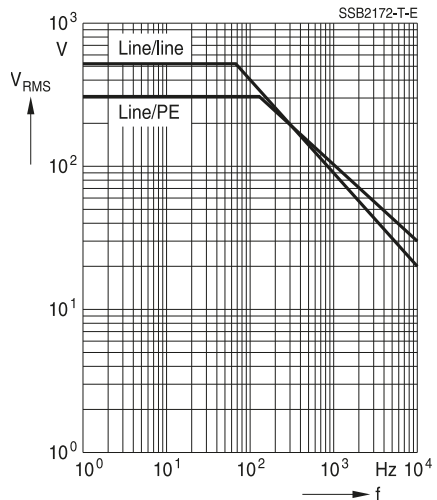Figure 35   Derating chart for
3- and 4-line filters of 500/290 V

Figure 36   Derating chart for
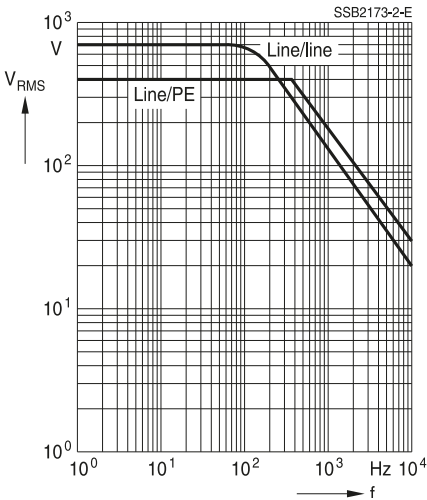3- and 4-line filters of 520/300 V

Figure 37   Derating chart for
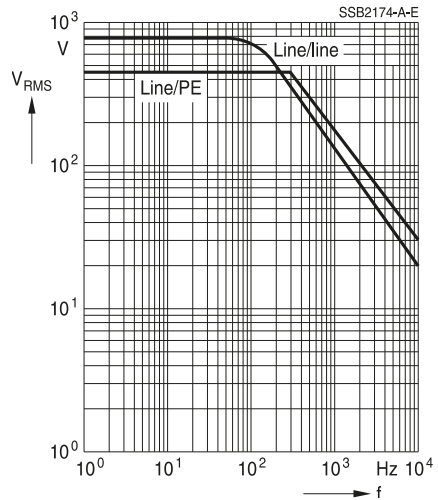3- and 4-line filters of 690/400 V

Figure 38   Derating chart for
3- and 4-line filters of 760/440 V

9.3.5   Danger during component overload

⚠ Experience has shown that European low-voltage networks rarely contain critical higher-frequency components. The maximum permissible values for the 2nd to 25th harmonics referred to in the DIN EN 50160 standard may be seen as a limit.

- However, it should be ensured that no resonant circuits are produced, for instance due to unmatched PFC capacitors, transformers, capacitive components of the filters or lines.
- In particular, care must be taken when using frequency converters that any possible resonant frequencies do not coincide with the clock frequency of the converter or its harmonics.
- If the permissible limits for the higher-frequency voltage components at the filter are exceeded, this could lead to damage or destruction.

9.4 Derating depending on the altitude

If filters or chokes are set up at altitudes > 2000 m above NHN[3], the physical conditions mean that the heat dissipation of the filters and chokes can no longer be assured to its full extent. When these components are used at altitudes > 2000 m, the following derating factors must therefore be considered. Values between the table entries should be interpolated.

Current derating as function of altitude

Altitude above NHN[3] m	Current derating factor
0 … 2000	1.000
2250	0.981
2500	0.963
2750	0.944
3000	0.925
3250	0.906
3500	0.888
3750	0.869
4000	0.850

Example calculation:

When using a filter or choke with a rated current of 600 A at an altitude of 2500 m above HNH[3], the maximum continuous current is 577 A; 600 A x 0.963 = 577 A.

Voltage derating as function of altitude

Altitude above NHN[3] m	Voltage derating factor
0 … 2000	1.000
2250	0.970
2500	0.940
2750	0.910
3000	0.880
3250	0.850
3500	0.820
3750	0.790
4000	0.760

Example calculation:

When using a filter or choke with a rated voltage of 760 V at an altitude of 2500 m above NHN[3] the maximum effective operating voltage is 714 V; 760 V x 0.94 = 714 V.

3) m above NHN = standard elevation zero; (NHN) is the altitude reference level

10 Insertion loss

10.1 Test circuits

Interference voltages and interference currents spread on different paths:

- Interferences between all lines and the reference potential are asymmetrical interferences, also known as common-mode interference. Mainly at frequencies from 1 MHz

- Interferences between two lines are symmetrical interferences, also known as differential-mode interference. Mainly in the range of several hundred kHz

- Interferences between a single line and reference potential are classified as unsymmetrical interferences (normal mode).

Depending on the different propagation types, the insertion loss is specified as a symmetrical, asymmetrical and unsymmetrical measurement in the data part. The test circuits below should illustrate the measurement principle.

The left circuit section 1 is the signal generator with open-circuit generator voltage V_0 and generator impedance Z_0. The middle circuit section is the device under test, in this case a 4-line filter. Part 3 indicates the test receiver, where the output voltage V_2 is measured via the impedance of the receiver Z_2.

a) Symmetrical measurement (*differential mode*) exemplified by a 4-line filter
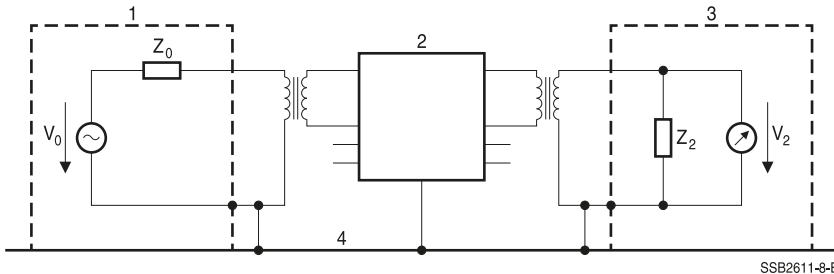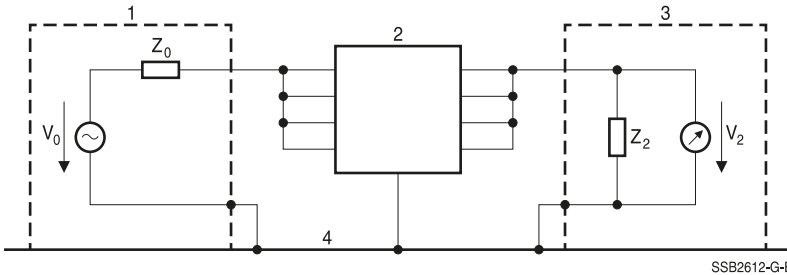

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Figure 39   Symmetrical measurement (according to EN 55017, Figure 6)

Every possible line pair is connected via isolating transformers (ratio 1:1), with the unused lines remaining unconnected.

b) Asymmetrical measurement (*common mode*) exemplified by a 4-line filter

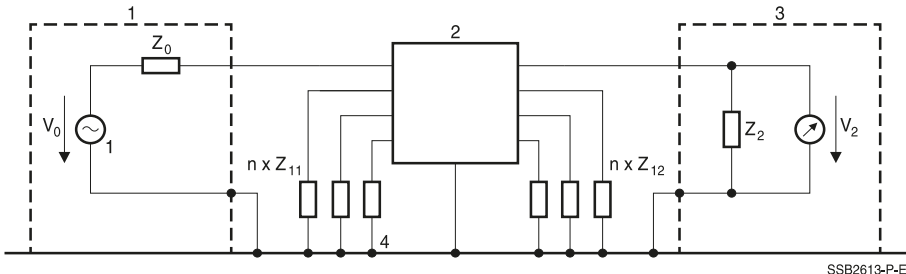Figure 40   Asymmetrical measurement (according to EN 55017, Figure 5)

All input and output lines are connected to each other for the measurement.

c) Unsymmetrical measurement (normal mode) exemplified by a 4-line filter

Figure 41   Unsymmetrical measurement (according to EN 55017, Figure 7)

Each line pair is measured, the unused lines being terminated with a defined impedance (usually 50 Ω).

10.2 Insertion loss in applications

As a rule, the previously described test circuits use impedance values of 50 Ω. In a few cases, the measurements are also specified with impedances of 0.1 Ω and 100 Ω. The image below shows the network impedances defined in the EN 61000-3-3 standard, however the actual impedances occurring in the application diverge from the assumed values.

Figure 42   Reference network according to EN 61000-3-3

The insertion loss curves shown in the data sheets thus have an informative character in order to allow various filters to be quantified and compared. A precise evaluation can only be achieved by measuring the interference voltage in the active application.

Figure 43 should illustrate the difference. In the left curve, the interference voltage is shown without EMC filters. The middle curve represents the attenuation characteristics of the filter. The insertion loss (middle) is deducted from the interference voltage (left) and results in the mathematically determined dashed line on the right. The actual measurement of the interference voltage (continuous line right diagram) does however show deviations from the mathematically determine interference voltage, significantly influenced by different impedances.

Figure 43   Insertion loss in practice

11   Leakage current
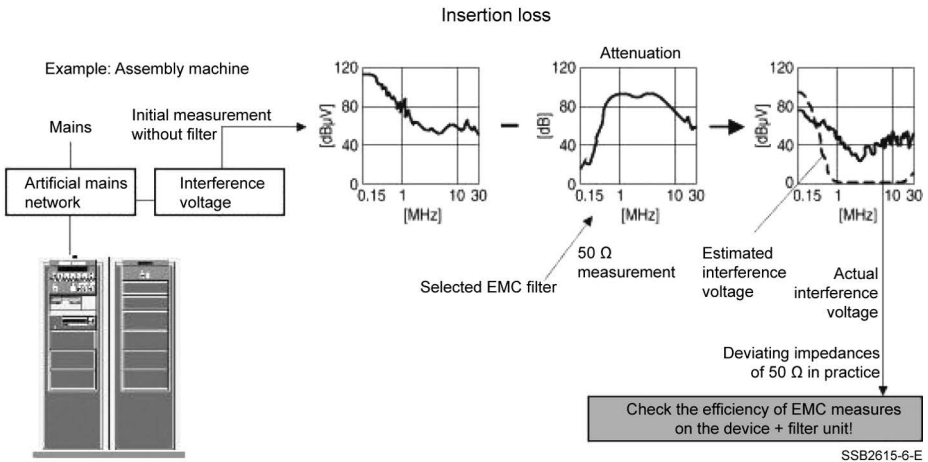
11.1   Definition of the leakage current

Leakage current is the current which flows to ground or to an external conductive part in a fault-free circuit. Leakage currents usually flow to a device or system regardless of a fault case and are related to the operation. They are initiated by different electrical components or circuits, for example, by parasitic effects of lines, casings etc. or by connecting capacitors to ground, as is the case for Y capacitors in EMC filters. The total leakage current results from the total of all leakage currents.

According to the International Electrotechnical Vocabulary (IEV), leakage current is defined as the electrical current in an unwanted conductive path under normal operating conditions [IEV 195-05-15].

Currents, which in contrast are generated due to an insulation fault and not during normal operating conditions, are known as residual currents.

The EN 60990 standard used to measure leakage currents defines "Methods of measurement of touch current and protective conductor current" and intentionally avoids using the term leakage current, as this cannot be clearly used in different contexts. As stated in the introduction to the German edition, the standard is envisaged for test determinations for measuring leakage currents. Instead of referring to leakage current, a distinction is made between two types of currents:

■ Touch current
Electric current through the human body or livestock, when this body touches one or more accessible parts or equipment. A touch current only occurs when the current path runs through the human body or a human model.

■ Protective conductor current
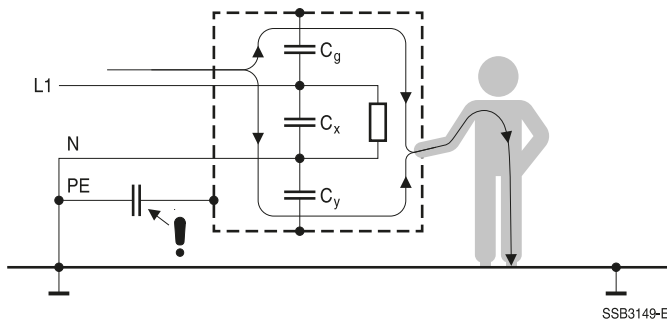Current flowing through the protective conductor.

Figure 44   Principle of the touch current

The principle of the touch current is illustrated in Figure 44: In the fault case represented here of a protective conductor interruption when the device is touched by a person, a touch current can pass through this person.

Both terms, touch current and protective conductor current were previously referred to as leakage current in the standard. In order to understand today's standard requirements, it is thus important to distinguish between the terms. In both cases, certain fault conditions are assumed in the standard definition of the leakage current deviating from the original.

11.2 Definition and calculation of the leakage current of EMC filters

Since different filter manufacturers have previously used different calculation models or measuring methods to specify the leakage current of the EMC filter, a uniform specification has been agreed on based on a calculation model and this model has been published in the EN 60939 standards for EMC filters.

11.2.1 Definition of the leakage current of EMC filters

According to DIN EN 60939-3 (VDE 0565-3-4):2016-09; 1.4.27, the **leakage current** I_{LK} is defined as the current at the rated frequency, which flows to ground or an external conductive part in a fault-free circuit.

Comment 1 on the term according to the standard: This current may have a capacitive component, which is predominantly initiated by using capacitors. This involves a theoretically calculated value for uniform specifications, for example, in catalogues. The calculation is based on the provisions given in Appendix A. The actual leakage current cannot be specified for individual cases.

Comment 2 on the term according to the standard: Further leakage currents, such as touch currents and protective conductor currents need to be specified according to the applicable standard (e.g. IEC 60990).

The definition results in: The values of leakage currents specified in the EMC filter data sheet are theoretically calculated values and are primarily used to compare different types of filters. In reality, many different influencing factors exist, meaning that a measured value according to IEC 60990 does not usually match the theoretically calculated value.

11.2.2 Calculation method for the filter leakage current I_{LK}

The calculation formulas given below are taken from Annex A of the IEC 60939-3 standard. They refer to systems with no loads connected to the filter output. The following is expressed in the DIN EN 60939-3 standard: "**The actual leakage current in applications cannot be specified, as it depends on many parameters.**"

The mathematically determined value I_{LK} is thus a benchmark for the qualitative differentiation of different EMC filters with regard to the leakage current, in a similar way to the insertion loss, comp. "Insertion loss" chapter on page 55.

Please note that:
The filter leakage current I_{LK} is added to the leakage currents, such as the parasitic capacitances of cables, leakage currents through motor windings, converters of other loads.

Calculation of filter leakage current for 1-line filters

The filter leakage current is obtained from the ratio of the rated voltage and the capacitive imped-
ance to ground.

$I_{LK} = 2 \cdot \pi \cdot f_R \cdot V_R \cdot C_Y$

I_{LK}	Filter leakage current
f_R	Rated frequency
V_R	Rated voltage
C_Y	Nominal capacitance to earth

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Figure 45   Leakage current for 1-line filters

Calculation of filter leakage current for 2-line filters

The filter leakage current is obtained from the ratio of the rated voltage and the capacitive imped-
ance of a Y capacitor.

$I_{LK} = 2 \cdot \pi \cdot f_R \cdot V_R \cdot C_Y$

I_{LK}	Filter leakage current
f_R	Rated frequency
V_R	Rated voltage
C_Y	Nominal capacitance to earth

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Figure 46   Leakage current for 2-line filters

Calculation of filter leakage current for 3-line filters

The filter leakage current is obtained from the ratio of the voltage between the capacitor neutral point and reference potential and the capacitive impedance of the Y capacitor. The standard defines a voltage difference between the phases of 6%, which corresponds approximately to a voltage unbalance of 2%.

$$I_{LK} = 2 \cdot \pi \cdot f_R \cdot V_{NM} \cdot C_Y = 2 \cdot \pi \cdot f_R \cdot \frac{0.06 \cdot V_R \cdot C_X}{3 \cdot C_X + C_Y} \cdot C_Y$$

$$C_X = C_{X1} = C_{X2} = C_{X3}$$

I_{LK} Filter leakage current
f_R Rated frequency
V_R Rated voltage Phase to ground
V_{NM} Resulting voltage Neutral point to ground
C_X Nominal capacitance to star point
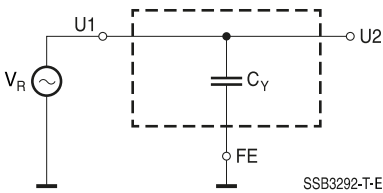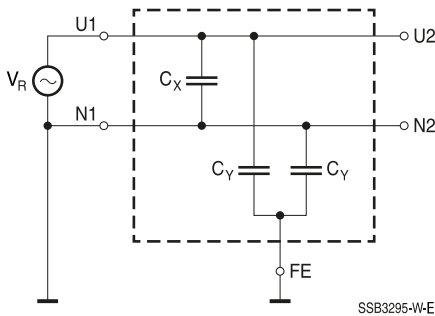C_Y Nominal capacitance to earth
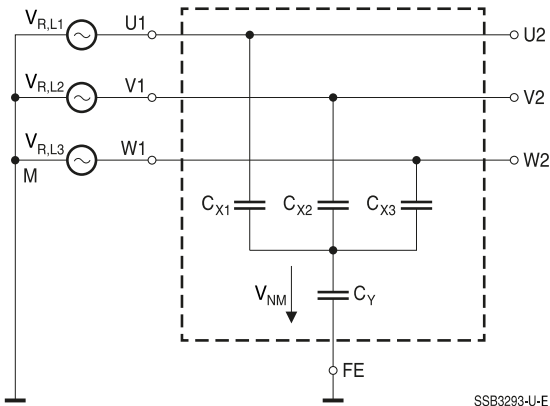

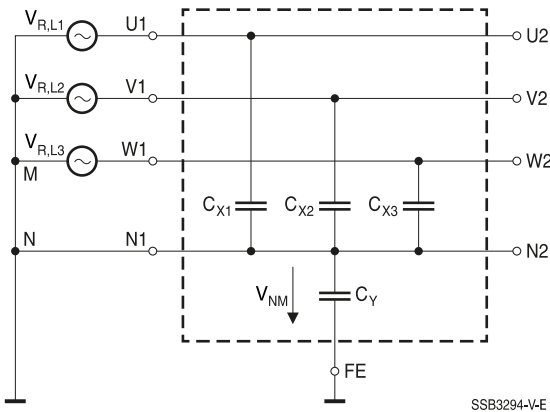Figure 47   Leakage current for 3-line filters

Calculation of filter leakage current for 4-line filters

The filter leakage current is obtained from the ratio of the voltage between the neutral conductor and ground and the capacitive impedance of the Y capacitor. As the neutral conductor and reference potential are connected at the supply transformer, the expected potential differences between them are small; the standard defines a value of 10 V across the board.

$$I_{LK} = 2 \cdot \pi \cdot f_R \cdot V_{NM} \cdot C_Y$$

$$V_{NM} = 10 \text{ V}$$

I_{LK}	Filter leakage current
f_R	Rated frequency
V_{NM}	Neutral point to earth
C_Y	Nominal capacitance to ground

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Figure 48   Leakage current for 4-line filters

11.3   Active reduction of leakage currents

Frequency converters are used in numerous applications for variable and energy-optimised frequency control along with a residual current device (RCD) for corresponding protection functions. At variable frequency drives, leakage currents are to be expected from upstream EMC filters, from the converter itself, from the shielded motor cable and even from the motor itself. The total of the leakage currents occurring often exceeds the lower tolerance limit (typically 50% of the nominal value) for triggering the residual current device. Consequently, an unintentional shutdown of the equipment occurs and therefore also considerable disruption to the process. This principle is illustrated in Figure 49.

Figure 49   Leakage currents of individual components in a converter application

The resulting aim is to reduce the leakage currents. Various conventional options can be used as a remedy, such as using a high-quality low capacitance cable or an isolating transformer. These options are expensive or in the case of the isolating transformer, additional installation volume is required for simultaneous energy losses.

TDK offers an electronic solution with the LeaXield™ active leakage current filter, which measures the leakage current and subsequently generates an inverted signal of the same amplitude. As the schematic representation in Figure 50 shows, this procedure leads to a reduction in leakage currents for the residual current devices used, which increases system availability.

Figure 50   Leakage currents of individual components in a converter application while using LeaXield™ active leakage current filter.

The LeaXield™ active leakage current filter can represent a cost-effective solution for eliminating the described problems, as it is possible to add it to an existing system without measures such as motor cable replacement or similar. An external power supply is not required. Further information on LeaXield™ active leakage current filters can be found under "Active filters" on the TDK website.

11.4 Safety notes relating to leakage currents

⚠ Bear in mind that the maximum leakage current of the electrical equipment or installation as a whole is limited for safety reasons. The applicable limits for your application may be obtained from the relevant specifications, regulations and standards. As a rule, the following principles apply. However, some equipment specifications may involve divergent requirements, and different country-specific regulations may apply. You must check these out for your specific application.

- Before putting the equipment in operation, first connect the protective conductor to the filter casing.
- Connect the protective conductor according to DIN VDE 0100-540 (IEC 60364-5-54).
- At leakage currents I_{LK}[4] > 10 mA, a fixed connection between the protective conductor and the load network is required. A connection via plug connectors is consequently impermissible. The protective conductor must have a minimum cross-section of 10 mm² Cu or 16 mm² Al across its entire length. Alternatively two separate protective conductors can also be connected with the specified minimum cross-section.
- Connection type and running conform to the specifications for PEN conductors according to DIN VDE 0100-540 (IEC 60364-5-54).
- At leakage currents of 3.5 mA < I_{LK}[4] ≤ 10 mA, the following solutions are possible:
  - Fixed device with fixed connection
  - Fixed device with type B plug connection (industrial plug connection according to IEC 60309) and cross-section ≥ 2.5 mm²
  - Fixed device with type A plug connection (non-industrial plug connection) and additional second protective conductor connection
  - Mobile device with type A plug connection and additional second protective conductor connection in premises with restricted access
- When residual current devices are used, the leakage current of the total equipment or system maximum must not exceed half the rated triggering current of the protective device.

4) I_{LK} = leakage current

11.5 Limit values for leakage currents

Two examples of leakage current limits from the relevant standards are shown below.

⚠ In all cases, the standards and specifications relating to the application must be observed. Thus the standards for medical equipment often have lower limit levels.

Electrical appliances for household and similar use according to EN 60335-1, Chapter 16

Protection class		Appliance type; Connection type	Leakage current[5]
Class	Explanation		
0[6]	Appliance with basic insulation without protective conductors	–	0.5 mA
0I[6]	Appliances with basic insulation without protective conductors, but with protective conductor terminals	–	0.5 mA
I	Appliances with protective conductors	Mobile	0.75 mA
		Stationary motor devices	3.5 mA
		Stationary heating appliances	0.75 mA or 0.75 mA/kW max. rated current 5 mA
II	Appliances with double or reinforced insulation without protective conductors	–	0.25 mA
III	Devices with low safety voltage (SELV)	–	0.5 mA

5) Test current circuit according to Fig. 4 IEC 60990: Touch current rated for perception or reaction.
6) Protection classes 0 and 0I are not permitted in Europe.

"Protection against electric shock – Common aspects for installations and equipment" is defined in IEC 61140. The limits are specified here as follows for **Limitation of the steady-state touch current and charge** (Chapter 5.2.7):

a) The following values are proposed for a touch current

– A steady-state current, which flows between simultaneously touchable conductive parts and does not exceed the perceptibility limits of AC 0.5 mA or DC 2 mA.
– Values, which do not reach the pain threshold of AC 3.5 mA or DC 10 mA, must be determined as deviating conditions or fault conditions.

b) For a stored charge between simultaneously touchable conductive parts, according to IEC/TS 60479-2:2007, Figure 19, the following values are proposed:

– 0.5 mJ, which corresponds to the pain threshold, and
– 5 µJ, which corresponds to the perceptibility threshold.

Comment: For medical electrical equipment, which falls under the scope of the IEC 60601 series, other limit values may be necessary.

The current limit values are based on the limit value lines a for the AC-1 or DC-1 areas or Figures 20 and 22 of IEC/TS 60479-1: "Effects of current on human beings and livestock – Part 1: General aspects".

Protective conductor current for systems and equipment with a rated frequency of 50 Hz or 60 Hz according to EN 61140

Maximum alternating current share of the protective conductor current for frequencies up to 1 kHz

Maximum rated current of the electrical equipment AC	Maximum protective conductor current for frequencies up to 1 kHz
I ≤ 2 A	1 mA
2 A < I ≤ 20 A	0.5 mA/A
I > 20 A	10 mA
	≤ 5% of the rated current per line conductor, if defined in the product standard

Maximum DC share of the protective conductor current

Rated current for equipment AC	Maximum protective conductor current DC
I ≤ 2 A	5 mA
2 A < I ≤ 20 A	2.5 mA/A
I > 20 A	50 mA

In this EN 61140 standard, the term protective conductor current is also defined in more detail and also forms part of the "International Electrotechnical Vocabulary" in this formulation, term number 826-11-21: **Protective conductor current,** *electric current appearing in a protective conductor, such as leakage current or electric current resulting from an insulation fault.*

11.6 Practical handling of the leakage current topic

⚠ **The filter leakage current specified here is intended merely as a guide for users. Every specific application must be checked for compliance with the limits stated in the applicable standards with respect to the interaction between all components!**

For permanently connected equipment with protective conductor currents > 10 mA, a fixed protective conductor connection of at least 10 mm² Cu (or 16 mm² Al) or two conductors of standard cross-section connected to separate terminals is required.

The key difference:

■ The calculated value of the leakage current for EMC filters is used by the user as a benchmark and to compare the various filters.

■ The leakage current is to be measured for the device or installation as a total of all leakage current components with a test circuit according to IEC 60990.

What do you need to know about the result of the leakage current measurement?

■ The result applies at the time of the measurement under the existing environmental conditions. Measurements at another time may produce different results.

■ The result of the leakage current measurement is influenced by the following aspects, among others:
  – Harmonic component and voltage symmetry of the power supply
  – Capacitances and parasitic capacitances in devices/installations
  – Pulse frequency and pulse pattern of variable frequency drives, switch-mode power supplies etc.
  – Parasitic capacitances of motor leads with shielding
  – Parasitic capacitances of motors

Below is an example of measurements made on three EMC filters from different production series of type B84143B0050R110 in an industrial TN-S network (400 V/230 V, 50 Hz) and in a synthetic network. Adjacent to this you will find the mathematically determined value I_{LK}, comp. "Calculation of filter leakage current for 3-line filters" chapter.

Power supply and time of measurement	Measurement of 3 filters from different production lots[7]				Data sheet
	Touch current according to EN 60990			Differential current[8]	Filter leakage current I_{LK} according to data sheet
	Unweighted	Perception and reaction	Let-go		
	mA	mA	mA	mA	mA
Industrial network time 1	2.14 … 2.22	1.82 … 1.86	1.56 … 1.58	12.05 … 12.50	3.1
Industrial network time 2	2.14 … 2.18	1.76 … 1.82	1.44 … 1.50	11.82 … 12.27	
Industrial network time 3	2.06 … 2.10	1.72 … 1.76	1.40 … 1.44	11:36	
Synthetic network	0.22 … 0.28	0.20 … 0.27	0.20 … 0.27	0.30 … 0.41	

The example shows that the tolerance of the measured values of filters from three production lots is very low, indicating the consistently high production quality of EPCOS filters. The harmonic component of the industrial network leads to differences to the synthetic network in the order of magnitude of a power of ten. The filter leakage current specified for this filter corresponds approximately to the measured values in the industrial network and thus assures a sufficient safety margin.

12   Systems with residual current devices

12.1   Residual current device — definition

A residual current device cuts off the monitored circuit at all poles when a defined difference current is exceeded (with the exception of the protective conductor). The terms RCD (residual current device) and RCCB (residual current operated circuit-breaker) are also often used here. Precise definitions are given in the group of IEC 61008 standards. Residual current monitors (RCM) are also used, but these have no built-in turn-off unit for the load circuit.

[7] Measurement by testing laboratory
[8] Vector sum of the momentary currents flowing through all active conductors at the line-side filter input (L1, L2, L3); assessed as a function of frequency (measured with leakage current meter 5SZ9 300 from Siemens

12.2   Principle of residual current devices

These devices make use of the property that the sum of the currents flowing in both directions is zero in an ideal circuit. A summation current converter on the phase and zero lines detects the differential current, which may involve a leakage current related to operation as well as a residual current. The definition of the current types can be found in the "Leakage current" chapter. An additional winding on the converter is part of the trip circuit and activates the switching mechanism with the contacts when the limit is reached. The diagram below shows the principle involved.
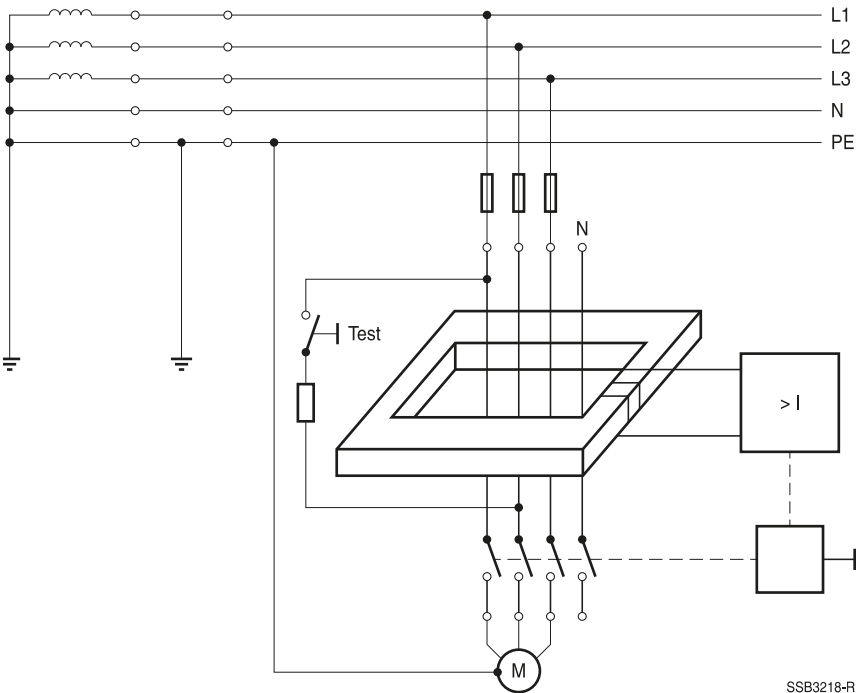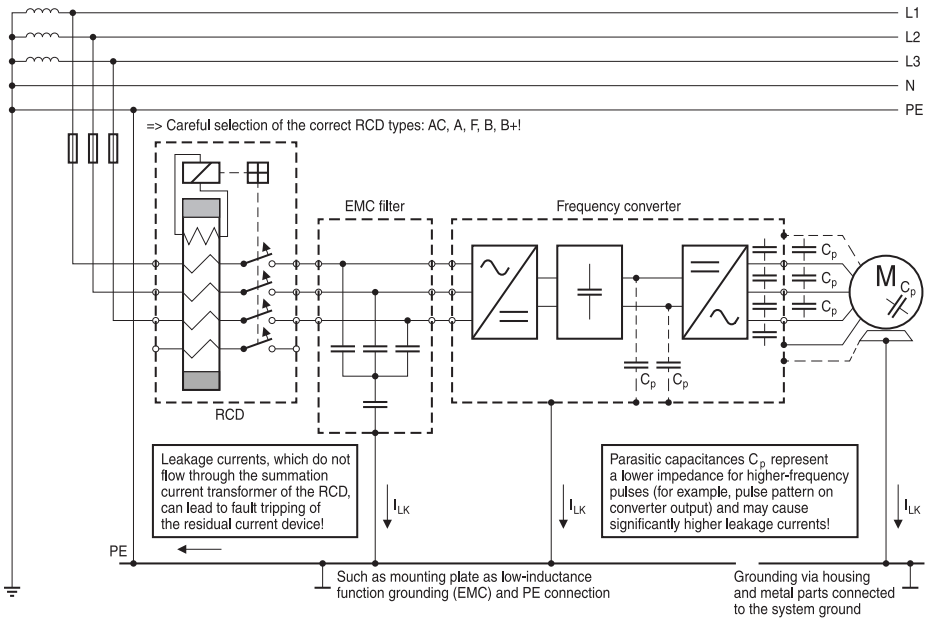
Figure 51   Principle of residual current devices

12.3   Example of a power drive system

Power drive systems (PDS) are increasingly used to utilise energy efficiently. They can change the engine speed continuously. In principle, an AC voltage is rectified, smoothed in the link circuit and its pulse shape and frequency are converted by electronic switching elements.

This is associated with conducted interference, and international standards require the noise levels to be limited, which as a rule requires the use of EMC filters. Figure 52 shows the block diagram of such a drive system.

Figure 52   Block diagram of drive system

The block diagram shows that the leakage currents in this drive system are not identical to the specifications in the data sheet for the leakage current of the EMC filter. This specification was standardised in IEC 60939 in 2010 as a calculating method, which however takes into account only the leakage current with respect to the line frequency when the filter is connected to the power supply. To this the leakage currents flowing through additional components must be added such as converters, cables and motors. As such, the leakage current of the entire system is higher than the leakage current initiated by the EMC filter.

Depending on the rectifier circuit, these leakage currents include frequency components as multiples of the line frequency; for example, a three-phase B6 circuit typically produces harmonics of 150 Hz, 450 Hz and 750 Hz. These are known as stationary leakage currents, as they remain virtually constant regardless of the operating state of the system. The clock frequencies, which are often in the range of 1 kHz ... 16 kHz, cause significantly higher frequency leakage currents, especially in the cable and motor capacitances. These are known as variable leakage currents, which vary depending on the clock frequency of the converter.

12.4 Objectives of residual current devices

Using residual current devices has two primary aims:

1. Protection against electric shock (personal protection)

2. Fire prevention

The personal protection (protection against electric shocks) for electrical equipment and systems as a rule consists of a combination of two protection modes, basic and fault protection. The basic protection (against direct contact) prevents people touching live parts, e.g. via insulation. The fault protection (additional protection against indirect contact) aims to prevent a hazardous voltage being applied on conductive parts within a defined time in the event of a fault, e.g. by turning off the supply voltage.

The limits for the maximum permissible current come from the specifications of IEC TS 60479 "Effects of current on human beings and livestock". They give various current strengths as a function of the frequency, all of which provide an identical protection level. This differentiation allows residual current devices to be developed with defined trigger characteristics depending on the frequency of the residual current.

A distinction is typically made between three ranges:

- 0.1 Hz ... 100 Hz with a 30 mA limit
- 100 Hz ... 1000 Hz with a limit increasing from 30 mA … 300 mA
- 1 kHz ... 100 kHz with a 300 mA limit

Various specifications give a limit of 300 mA in order to prevent fires. This limit also allows systems with clock frequencies in the kHz range to be protected by residual current devices.
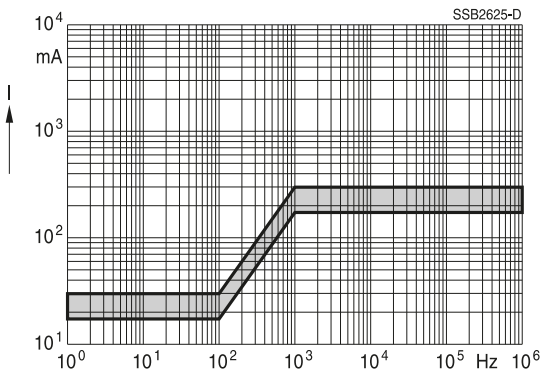

Figure 53   Example: RCCB tripping characteristic

12.5 Types of residual current devices

■ Type AC = Alternating current sensitive: Detects only sinusoidal AC residual currents!
NOTE! Not approved for residual-current protection in some countries!

■ Type A = Pulse current sensitive: Detects sinusoidal AC residual currents + pulsating DC residual currents
Application: Single-phase rectifiers, single-phase thyristor controllers (without smooth residual currents)

■ Type B = Universal current sensitive: Residual currents like Type A + smooth DC residual currents
Application: Multiphase systems and rectifier circuits

■ Type B+ = Universal current sensitive: Properties of Type B + tripping conditions to 20 kHz

■ Brief delay types: Turn-off slightly delayed (approx. 10 ms)
Application: For brief pulse currents in normal operation

■ Selective types /S/: Defined turn-off delay
Application: Series circuit of several protection devices to ensure selective turn-off sequence.

12.6 Practical solutions

As it can be difficult to distinguish fault currents from operation-caused leakage currents, the protection device can trigger erroneously, thus reducing the equipment availability or increasing the risk of failure.

Suggested solutions:

■ Reduce leakage currents caused by operation by using a leakage current filter **LeaXield™** from TDK

■ Measure the leakage currents in the system; by identifying the cause, the selection of measures to be taken is simplified. Use suitable measurement devices for this purpose. The upper limit frequency of the measuring device should be dimensioned sufficiently for any expected significant components of the leakage current.

■ Select a suitable type of residual current device for your application.

■ Switching operations in multiphase systems can be subject to staggered switching due to mechanical contacts and thus cause transient leakage currents. In such cases, use residual current devices with brief delay times.

■ Check the best choice of EMC filter with your EMC expert. Note that filters with low leakage currents for the same attenuation properties have a more complex design and are as a rule more expensive.

■ Compare the technical data of the motor leads used, especially with respect to the capacitances. Less expensive cables with higher capacitance ratings may have to be compensated by expensive measures.

- An optimal switching frequency should be selected at the converter as far as possible. Inductors at the converter output (output chokes and output filters) can reduce the leakage current; the SineFormer® filter series B84143V*R127 in particular has proved its worth many times in practice. Please refer to the special requirements of your application, e.g. with respect to the motor dynamics.
- Avoid unnecessary motor lead lengths. Run the motor lead shielding along a large area and on both sides to the converter and motor ground connections. Minimise inrush currents by suitable means (inrush current limiting).

13   Short circuit withstand strength

13.1   Causes, effects and types of short circuits

An electrical short circuit is a low electrical impedance connection between two electrically conducive parts with different potential. The following section only involves unintentional short circuits resulting from a fault.

What causes short circuits?

- Damaged insulation, such as due to ageing, thermal stress, mechanical external influences
- Influence of moisture or conductive contaminations with creepage distances at the start
- Continuous stress of insulation materials following partial discharge in the active field of the electrical fields
- Human error such as incorrect switching, conductive tools and failure to observe safety rules

Potential effects of a short circuit:

■ Thermal effect through heating of the affect conductors with risk of fire

■ Mechanical applied force to conductors through the magnetic fields connected with a high current flow

■ Accidental arcs may occur with vaporised metals and ionisation of the ambient air

Types of short circuits:

■ Single pole short circuit: If a short circuit occurs between line and ground, this is known as a short circuit to earth.

■ 2-pole short circuit: Usually between two lines, but an additional ground fault is also possible (e.g. as a consequence).

■ 3-pole short circuit: The short circuit between three lines of the system poses the highest load for the power supply and the surge protection devices. This case is usually checked when testing the short circuit withstand strength.

13.2   Protection against the effects of short circuits

In order to limit the effects of short circuits, surge protection devices are required to protect EMC power components. Typical surge protection devices include:

■ Fuses, predominantly safety fuses here

■ Miniature circuit breakers (electromechanical overcurrent devices)

■ Power switches with corresponding monitoring functions for the current.

These limit the duration of high short-circuit currents and thus the stresses due to electromagnetic effects. They aim to protect the system components as far as possible before they are damaged and move to a dangerous state in the event of the fault case caused by a short circuit.

13.3   Calculation of the short circuit withstand strength

Estimating the short-circuit currents calls for detailed knowledge of the power supply equipment, wiring and cable systems as well as knowledge about the surge protection devices used. The IEC 60909 series of standards includes "short-circuit currents in three-phase a.c. systems" and provides information on calculating them. The aim is to assess the stress situation. The behaviour for the two stresses is to be clarified

■ Highest short-circuit current to be expected

■ Lowest short-circuit current to be expected.

To estimate the short-circuit stress, the cross-section and length of the conductors play a decisive role, as illustrated in the following drawing.

Figure 54   Estimating the short-circuit stress

For planning reasons, specification of the **short-circuit current I$_{SC}$** (uninfluenced short circuit alternating current) is needed at the power supply; alternatively the value can be calculated from the transformer power or generator power.

13.4   Varying definition of short circuit currents in global standards

IEC specification:

The currents are measured by the device concerned here. The two current specifications

- **Rated short-time withstand current I$_{cw}$** (considers the thermal effects of the short circuit current)

- **Rated peak withstand current I$_{PK}$** (considers the dynamic effect of the short circuit current)

must be greater or equal to the short circuit current I$_{SC}$.

The definitions are listed in detail in the EN 61439-1 standard "Low-voltage switchgear and controlgear assemblies – Part 1: General rules" Section 3.8 "Characteristics".

UL[1] specification:

The current and power factor are adjusted here on the generator by means of the jumper. The current through the device is lower due to line and device impedance.

In the American market, the short circuit withstand strength is specified as the SCCR value:

SCCR (short circuit current rating), is a key parameter of the short circuit withstand strength of components, which specifies the maximum short circuit current that components can withstand.

The SCCR value is tested according to the UL 508 standard "Industrial Control Equipment" Section 52. This value gains significance, as US legislation with NFPA[2] 70 NEC[3] Section 409.11 has specified the SCCR marking (short circuit current rating) for all switch cabinets.

For frequency converters, the North American Directive UL 508C (Power Conversion Equipment) stipulates the following minimum SCCR values:

Output[4]		Three-phase motor current at voltage[5]			SCCR[6]
hp	kW	360 ... 380 V A	440 ... 480 V A	550 ... 600 V A	kA
15 ... 50	1.1 ... 37.3	3.3 ... 83	3.0 ... 65	2.4 ... 52	5
51 ... 200	39 ... 149	... 320	... 240	...192	10
201 ... 400	150 ... 298	... 636	... 477	... 382 ...	18
401 ... 600	299 ... 447	... 786 ...[7]	... 590 ...[8]	... 472 ...[8]	30
601 ... 900	448 ... 671	... 1290	... 1060	... 850	42
901 ... 1600	672 ... 1193	.. 2300	... 1880	... 1500	85
1601	1194 ...	2301 ...	1881 ...	1501 ...	100
					125
					200

1) UL = Underwriters Laboratories
2) NFPA = National Fire Protection Association
3) NEC = National Electric Code
4) To UL 508C Table 45.1
5) To UL 508C Table 42.1
6) To UL 508C Table 45.1
7) Motor current specified for 500 hp
8) To UL 508C Table 42.1

SCCR specification values for EMC filters

As a basis for specifying the SCCR values of EMC filters, sample measurements of the short circuit properties of individual filters from various series are used in accredited test laboratories. Simulation models for short circuit stress of EMC filters were then created based on these tests and verified by means of comparison with the measured results. The simulation results are shown in the table below and can be applied to all EMC filters, for which an SCCR value is not specified in the data sheet.

Furthermore, there are also filters tested for SCCR, where the SCCR value is explicitly specified in the data sheet, such as filter series B84243A*000 and B84243A*N107.

SCCR values

Rated current	SCCR value
$2\,A \leq I_R < 6\,A$	10 kA
$6\,A \leq I_R < 16\,A$	18 kA
$16\,A \leq I_R < 32\,A$	30 kA
$32\,A \leq I_R < 600\,A$	42 kA
$600\,A \leq I_R < 1000\,A$	85 kA
$1000\,A \leq I_R < 1200\,A$	100 kA
$1200\,A \leq I_R < 1600\,A$	125 kA
$1600\,A \leq I_R < 2500\,A$	150 kA
$2500\,A \leq I_R$	200 kA

14   Protection against residual voltages

In the manufacture of our components we always aim to satisfy the highest safety requirements. However, the diverse applications of our customers mutually exclude certain requirements. Thus some applications need high insulating resistors (e.g. insulation monitoring), whereas others require the permissible residual voltages to be considered.

14.1   Normative specifications

IEC 60204-1 "Safety of machinery. Electrical equipment of machines – Part 1: General requirements" makes the following stipulations in Section 6.2.4 "Protection against residual voltages":

■ 5 s following switch-off, residual voltage < 60 V; exception charge volume $C \leq 60$ µC.

■ Reduction in the discharge time to 1 s for exposed cables, for example, when removing connectors.

■ For higher discharge times related to functioning, this is to be indicated by a corresponding hazard warning.

The EN 50178 standard "Electronic equipment for use in power installations" includes the same requirement in Section 5.2.5 "Discharge of capacitors" but this charge is limited to 50 µC.

14.2 Discharge resistors in EMC filters

The EMC filters manufactured by TDK are supplied with internal high-impedance discharge resistors (unless otherwise requested by the customer). However, their connection alone does not as a rule fulfil the requirements of all the relevant standards, regulations and specifications, but simply discharges the capacitance within a specific time period.

When using EMC filters or additional tests, it may be necessary to perform an additional discharge. In order to optimise the circuits of EMC filters, there are also series circuits of capacitors with the charging shift effect. Following the discharge, these can also lead to an increase in the voltage again above the permitted limits. To avoid this, a low-resistance connection should be set up immediately after the discharge from the casing or PE terminal to the voltage-carrying filter terminals. The safety specifications must be observed.

Information on the configuration of discharge resistors can be found in the typical wiring diagram of data sheet. Values for the discharge resistors can be requested, if needed, from your TDK contact or distributor.

Furthermore, specific filters are available with optimised discharge times, which reach a residual voltage <60 V in 1 s, such as the B84243A*000, B84243A*N107 and B84143A*R107 series. The discharge time is explicitly specified in the data sheet for these filters.

15 Overvoltage protection

15.1 Causes of overvoltage

Overvoltages can damage electrical equipment and devices and impair their correct operation. They can be caused by several factors, such as:

- Lightning strikes, lightning current and overvoltage surges
- Induction due to inductive coupling (influence of magnetic fields)
- Influence of capacitive coupling (influence of electric fields)
- Electrostatic charges
- Voltage changes due to switching operations

15.2 Overvoltage categories and rated surge voltages

To help manufacturers select components, the IEC 60664-1 standard provides information on the expected stresses, including a specification of the rated surge voltage as a function of the power supply system and the mounting position. The mounting positions are assigned to overvoltage categories depending on the hazard they represent.

Overvoltage category	Description	Examples
IV	At or close to the power supply; before the main distributor (in the current direction)	Electricity meters; overcurrent protective devices; centralized tele-control signal devices
III	Equipment forming part of a fixed installation for which increased availability is expected	Distribution panels; power switches; distribution cabinets; equipment for industrial use; stationary motors
II	Equipment designed for connection to the fixed installation of a building	Domestic appliances; portable tools
I	Equipment connected to circuits already protected with transient overvoltage limiters.	Electrical control equipment with no internal overvoltage protection

In the following table, the overvoltage categories are assigned to an expected rated surge voltage corresponding to the power supply system (based on IEC 60664-1)

Overvoltage limitation through internal or equivalent protective limitation:

Star circuit 4-line system with grounded neutral conductor	Delta circuit 3-line system unearthed	Single-phase 2-line system	Rated surge voltage for equipment			
			Overvoltage category			
V	V	V	I	II	III	IV
120/208	115	**100**	800	1500	2500	4000
127/220	120	**110**				
	127	220				
220/380	200	220	1500	2500	4000	6000
230/400	220					
240/415	**230**					
260/440	240					
277/480	380					
	400					
	440					
	480					
347/600	500	480	2500	4000	6000	8000
380/660	577					
400/690	600					
	660	1000	4000	6000	8000	12000
	690					
	1000					

Voltage specifications in bold: CENELE[2] standard voltages according to IEC 60038

15.3   Overvoltage at EMC filters

With the exception of a few special applications, the EMC filters produced by TDK correspond to the IEC 60939 standard. This specifies the use of suitable EMI suppression capacitors. These capacitors are designed for pulse voltages in the power line and are subject to a pulse test to IEC 60384-14 for their type approval (see the table below; based on the standard). The pulse strength of the entire EMC filter is usually significantly higher due to the structure of the filter.

C/µF	Peak value surge voltage Vp/kV			
	X1	X2	Y1	Y2
1	4.00	2.50	8.00	5.00
2.2	2.70	1.69		
3.3	2.20	1.38		
4.7	1.85	1.15		
6.8	1.53	0.96		
8.2		0.87		
10		0.79		

[2] CCENELEC = French: Comité Européen de Normalisation Électrotechnique, European Committee for Electrotechnical Standardisation.)

15.4   Normative regulations on overvoltage protection

When are surge protection devices to be installed?

The IEC 60364-4-44 standard "Low-voltage electrical installations – Part 4-44: Protection for safety. Protection against voltage disturbances and electromagnetic disturbances – Clause 443: Protection against transient overvoltages of atmospheric origin or due to switching" describes the "Overvoltage control" in Section 443.4.

Protection against transient overvoltage **must** be provided if the consequences of overvoltage affect the following:

■ Human life, e.g. safety services, medical care facilities.

■ Public services and cultural heritage, e.g. loss of public services, IT centres, museums.

■ Commercial or industrial activity, e.g. hotels, banks, industries, commercial markets, farms.

■ A large number of individuals, e.g. large buildings, offices, schools.

■ Individuals e.g. in residential buildings and small offices if overvoltage category I or II equipment is installed in these buildings (It is to be assumed that in residential buildings equipment of the overvoltage category I or II is connected to the fixed installation).

■ Protection against transient overvoltage should be also considered for buildings with fire risks. (For fire hazardous locations, see DIN VDE 0100-420).

■ Protection against switching overvoltages should be considered in the case of equipment likely to produce switching overvoltages or disturbances exceeding the values according to the overvoltage category of the electrical installation.

Selection and erection of surge protection devices (SPDs)

Details on this topic can be found in the IEC 60364-5-53 standard "Low-voltage electrical installations – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control – Section 534: Devices for protection against transient overvoltages" Chapter 534.4.

16   Output filters

16.1   Variable frequency drives

Variable frequency drives are used wide-ranging industrial areas due to their improved functional characteristics and energy efficiency, but also in other applications such as domestic appliances and medical engineering.

In a number of applications such as pumps or air conditioning systems, the investment costs pay for themselves in a very short time.

16.2   Disadvantages of variable frequency drives

Manufacturers of converters provide devices on the market with a high level of energy efficiency. For this purpose, rapid switching semiconductor components are used in the converters. This is often associated with the following problems:

- The output voltages of the converters are no longer sinusoidal, but a series of pulses of varying width. The voltage rise rate dv/dt is considerably higher and stresses the insulation of the motor cable and motor.

- The switching frequency for pulse width modulation (PWM) is typically in the range of several kHz. The parasitic earth currents in the motor cable are therefore increased against the cable shielding as well as in the motor itself. As well as a number of other effects, these leakage currents may cause the residual current devices to be triggered.

- Leakage currents also flow through the motor bearings and may cause considerable damage to the motor bearings.

- Parts of the system are often electroacoustically excited by output pulses and in this way generate noise interference in the audible range.

- These steep pulse edges generate a correspondingly broad interference spectrum. In the majority of cases, operation is only possible with expensive shielded motor leads. The sine-wave EMC filter SineFormer® offers an alternative.

- Depending on the motor lead length, overvoltage peaks may occur at the motor up to the double DC link voltage.

- Eddy current losses increase in the motor.

Technical information

16.3 Selecting output filters

The following characteristics should be observed when selecting the output filter solution:

■ The dv/dt chokes reduce the slope steepness of the output voltage (line-to-line). This reduces the load on the insulation.

■ The dv/dt filter reduces the slope steepness of the output voltage (line-to-line) more strongly than the chokes. This also reduces the probability of motor failure. The frequency of the overshoot is typically reduced below 150 kHz.

■ The sine-wave filter produces a sinusoidal phase voltage at low extra cost. The overshoot is completely eradicated. At the same time, the RF interference voltage with respect to ground is reduced somewhat.

■ In terms of the overall performance, the sine-wave EMC filter SineFormer® offers the best solution. If only the component costs of the various output filter solutions are compared, at first sight it appears to be the most expensive solution. Yet if the overall system costs (lead, filter, motor) are considered, there are clear cost benefits for SineFormer® technology: The series of SineFormer® filters B84143V*R127 has the best price-performance ratio of any output filter and choke solutions.

Output filter type	Line-to-line voltage	Line-to-ground voltage	Radiated interference	Reduction in motor bearing currents	Reduction in noise
dv/dt choke	Reduces the slope steepness	No effect	Hardly any improvement (only parasitic influences)	None	Hardly noticeable
dv/dt filter	Significantly reduces the slope steepness	No effect	Hardly any improvement (only parasitic influences)	None	Hardly noticeable
sine-wave filter	Virtually sinusoidal output voltage	Minimal improvement	Hardly any improvement (only parasitic influences)	Low	Significant
Sine-wave EMC filter SineFormer®	Virtually sinusoidal output voltage	Significant improvement	Significant improvement	Significant	Significant

Output filters are particularly important if the motors used do not meet the Technical Specification IEC TS 60034-25 "Rotating electrical machines" – Part 25: "Guide for the design and performance of cage induction motors specifically designed for converter supply". This primarily affects existing installations or used universal motors.

dv/dt filters reduce the rise time with increasing cable length, however the peak voltage increases as a result of the low-pass response of the cable. With this in mind, the cable length in the system is to be checked (typically a maximum of 100 m).

In applications with motor lead lengths >100 m, we recommend sine-wave filters or SineFormer® sine-wave EMC filters. They considerably reduce the clock frequency noise of the drive. They may contribute towards extending the service life of the drive by preserving the motor insulation, reducing eddy current losses in the motor (lower temperature) and reducing bearing currents.

16.4   dv/dt chokes

A dv/dt choke is a differential mode choke on the motor side of the frequency converter. The general structure of a dv/dt choke is illustrated in Figure 55. The total motor current flows through it. Steep voltage and current edges are somewhat flattened by the inductance. The parasitic capacitances of the connected cable are less strongly charged and discharged. This choke has practically no effect on the reference potential. The leakage current and the radiated interference are not reduced.

■ As a rule, motor leads of up to 50 m are possible

■ The motor lead must be shielded

■ Almost no improvement in EMC interference

Data sheets on dv/dt chokes may be found in the "Selection guide" under "Output filters".
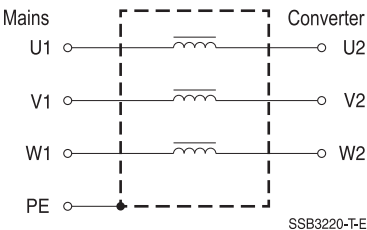
Figure 55   Block diagram of a dv/dt choke

16.5   dv/dt filter

A dv/dt filter consists essentially of an LC low-pass filter whose limit frequency is greater than the clock frequency of the converters (block diagram, Figure 56). The filter increases the rise time of the voltage pulses on the line, the voltage spikes at the motor are reduced, and the dv/dt of the output voltage drops.

The effect of this filter is limited to the voltage steepness between the conductors. It has practically no effect on the reference potential. It does not reduce the leakage current or the radiated interference.

■ Motor leads of up to 100 m length are typically possible

■ The motor lead must be shielded

■ The EMC interference is hardly improved

As a rule, dv/dt filters must be matched to the converters or the application. TDK offers customer-specific solutions upon request.
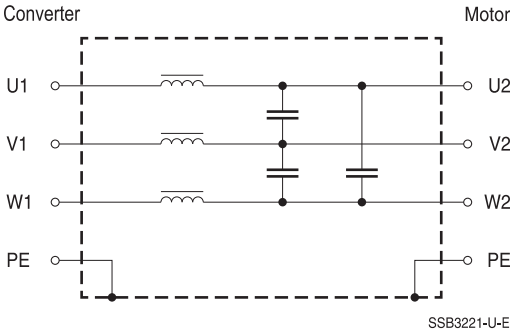

Figure 56   Block diagram of a dv/dt filter

16.6   Sine-wave filter

A sine-wave filter has the same basic circuit as a dv/dt filter in Figure 56, with the difference that the limit frequency is placed between the output and converter clock frequencies. This increases the values of the inductors and capacitors, but also makes the filter more powerful. The share of the switching frequency in the phase-to-phase voltage is clearly reduced (Figure 57).
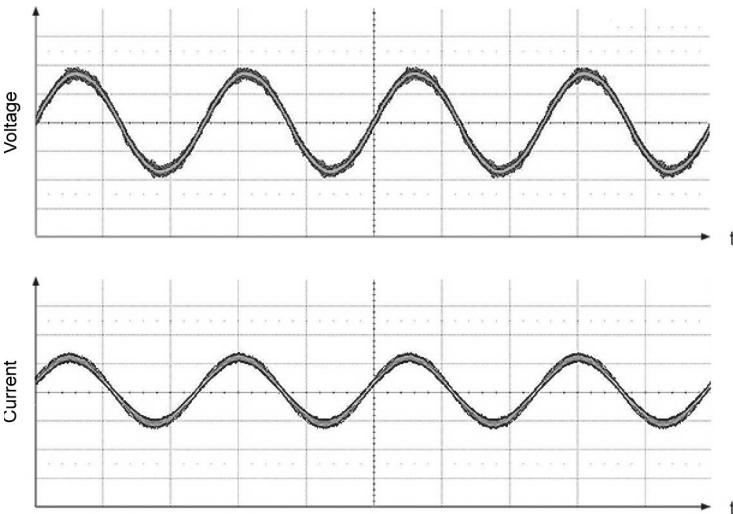

Figure 57   Phase-to-phase voltage and current after a sine-wave filter

As the sine-wave filter mainly affects the symmetrical interference between the lines, the interference acting on the phase-to-ground voltage is hardly reduced at all (Figure 58).

- Motor leads longer than 100 m are possible
- The motor leads must be shielded
- The motor noise and eddy current losses are reduced
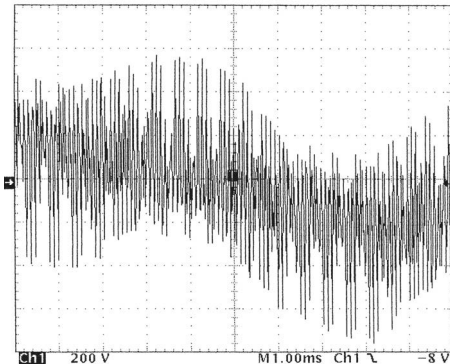- The filter expenditure on the line side may be reduced

Figure 58   Phase-to-earth voltage after the sine-wave filter

For data sheets for sine-wave filters, see our website under "Output filters".

16.7   Sine-wave EMC filter SineFormer®

In order to reduce the asymmetrical interference on the motor lead sufficiently and to dispend shielded motor leads, a sine-wave EMC filter must be used. The sine-wave filter is then complemented by a current-compensated choke and capacitors with respect to ground.
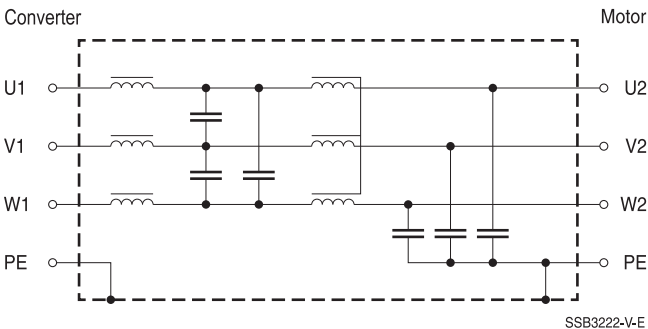

Figure 59   Block diagram of the sine-wave EMC filter SineFormer®

For further technical data on the SineFormer® filters, see data sheet B84143V*R127.

Technical benefits of the EMC concept with SineFormer®:

- Reduction of the dv/dt to <500 V/μs
- Reduction of the motor noise
- Significant reduction of eddy current losses
- Significant reduction of motor bearing currents
- Preventing interference coupling from the motor lead to other power and signal lines
- Radio interference emissions from the motor line remain within the standard limits
- Optimal reduction of interference (conducted and radiated) compared to other output filters
- No feedback to the converter link circuit needed

Cost benefits of the EMC concept with SineFormer®:

- Unshielded motor leads can be used, thus reducing the mounting cost and reducing cable costs
- A smaller motor can be used
- The operating life of the motor can be significantly extended
- Longer motor leads can be used (up to 1000 m for unshielded measurements)
- No maintenance cost, as the SineFormer® dispenses with forced cooling
- Compact filter (no modular system), hence lower volume and weight
- Reduced requirements on line filters
- Higher system availability
- Also suitable for retrofitting

SineFormer® ensures optimal interference suppression and reduces system costs

The possibility to dispense with shielded leads is a particular advantage, as depending on the cross-section and length of the lead, the use of a SineFormer® is more cost-effective than using shielded leads.

The filter cost is in many cases already compensated from a lead length of about 100 m with the use of an unshielded cable. A simple cost comparison of the SineFormer® and the unshielded leads with that of a sine-wave filter and shielded leads shows that break-even can already be reached for leads shorter than 50 m, excluding the higher mounting cost of the shielded leads.

Figure 60 shows the line-side interference voltage measurement at a frequency converter with an EMC power filter and 100 m unshielded motor lead without an output filter. (The measurement results depend on the position of the motor lead, referred to the limits according to EN 55011 Class A/Group 1 or EN 61800-3 Category C2.)
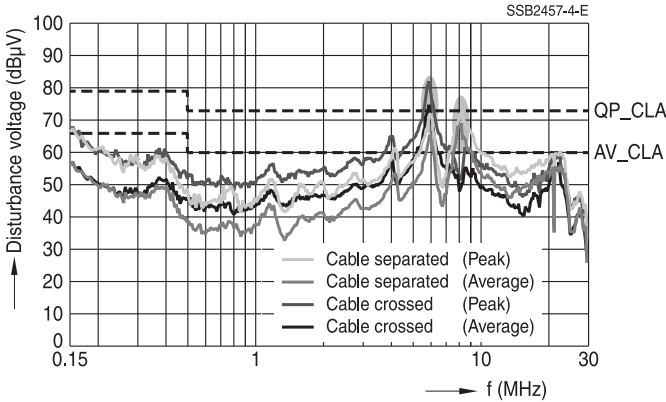
Figure 60   Interference voltage test with unshielded lead

A comparison of Figure 60 and Figure 61 is proof of the superior SineFormer® technology operating mode. The limits (here to EN 55011, Class A/Group 1 or EN 61800-3 Category C2) are safely observed even if the power line crosses the unshielded motor lead or they run in parallel for 80 cm as specified by EN 61800-3. The optimal efficiency of this filter technology is shown unequivocally by the fact that essentially no coupling occurs. The use of SineFormer® filters can mean a final goodbye to the use of shielded leads. System costs can consequently be reduced and the system availability increased.
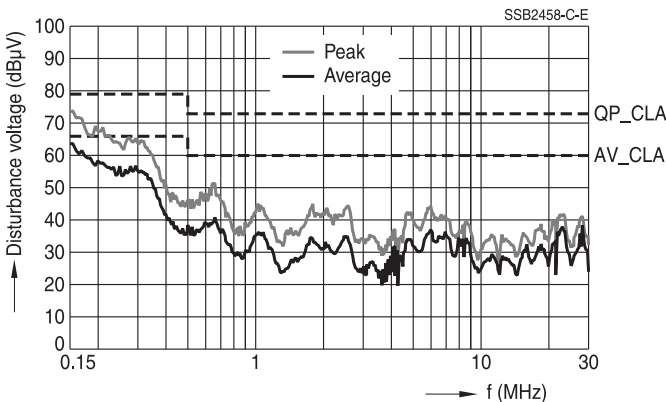
Figure 61   Interference voltage test on network connection with SineFormer® on the converter output. Despite the unshielded cable, the permissible limits are observed.

Common-mode interference generates bearing currents in the motor due to parasitic capacitances. These bearing currents can significantly reduce the operating life of the motor. The SineFormer® technology suppresses this interference and thus minimises the bearing currents in the motor, hence extending the motor life in an optimal way.

Figure 62 shows typical values measured at the output of a frequency converter in the time and frequency ranges. The high asymmetrical currents, measured here as bearing currents, are clearly apparent.

Figure 62   Bearing currents without an output filter

Figure 63 shows the asymmetrical currents flowing with the use of a sine-wave filter. The bearing currents are only partially reduced and cannot contribute to any significant increase in the motor's operating life. Compare Figure 62.

Figure 63   Reduction of bearing currents with a sine-wave filter

Figure 64 shows typical values of the bearing currents when using a sine-wave SineFormer® EMC filter. Compared with Figure 62 and Figure 63, significant improvements can be seen: only the sine-wave EMC filters such as SineFormer® can minimise the motor bearing currents.

Figure 64   Minimising the bearing currents with the sine-wave EMC filter SineFormer®

17   Chokes for power electronics

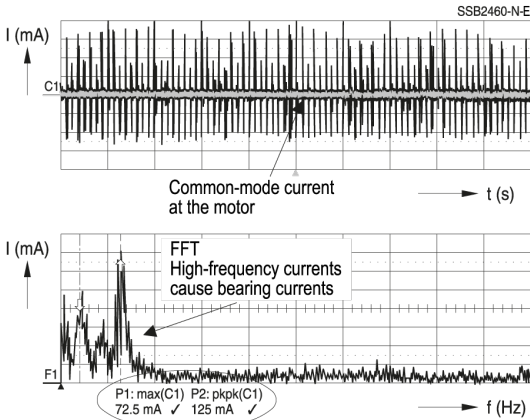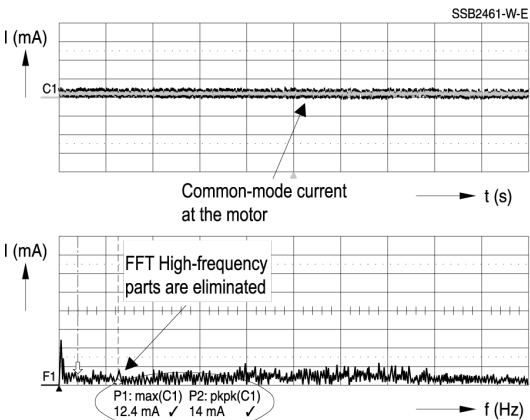Chokes are inductors with the function of current limitation, intermediate energy storage, filtering or impedance matching. The term "Chokes for power electronics" is used to distinguish those from inductors for EMC applications (from 9 kHz).

Figure 65
Example for 3-phase choke

Below you will find the typical designations explained for choke constructions, whereby the application often influences the name of the choke.

17.1   Power line chokes

Power line chokes are used to limit current and limit the system perturbations through non-linear loads.

Non-linear loads (such as power semiconductor on the converter input) cause a non-sinusoidal current, which corresponds to a distortion reactive power that negatively influences the voltage quality for other loads. The requirements on voltage quality in Europe are governed by the EN 50160 standard. In order to ensure good voltage quality at a reasonable cost, the distortion reactive power is to be reduced to a minimum.

For devices with a current consumption between 16 and 75 A, in the EN 61000-3-12 standard the limit values for the respective individual harmonics are specified (e.g.

5th harmonics: 250 Hz at basic frequency of 50 Hz) but also for the total harmonics for connection to public grids.

Depending on the ratio of the connection power to the network short-circuit capacity and the type of devices, various limit values are defined. For the majority of applications, it is sufficient to connect an uncontrolled power rectifier with a power line choke with v_k values of approx. 4%.

At $v_k = 2\%$, the THDi value is actually suppressed from over 130% to under 80%, which in individual cases clearly reduces the total value of machine interference, but is on its own not sufficient to fulfil applicable standards.

In addition to the function to suppress the distortion reactive power, power line chokes are also used as commutation reactors. This function reduces the voltage drops (flicker) in the case of slow current transfer between two power semiconductors (commutation). Due to the development of fast rectifier diodes, this function is still needed for thyristors and rectifiers for very high currents.

Power line chokes for active infeed converters are particularly comparable with the filter chokes in terms of the requirements on saturation resistance and power dissipation and are handled separately in section 17.5.

17.2   Smoothing chokes

In the IEC 60076-6 definition of terms, it is:

Smoothing choke: Reactor, which is connected in series to a DC network in order to reduce harmonic currents and transient switching overvoltages. The frequency of the harmonics is decisive for the design and selection of the core material here. Furthermore, limiting short circuit currents, by limiting the voltage rate rise is another task of the smoothing reactors.

Instead of power line chokes, smoothing chokes are used to reduce the current harmonic component THDi, for this purpose these are used in frequency converters in the DC link circuit.

17.3   Filter circuit chokes for power factor correction

For low-loss transmission of energy in public networks, the sinusoidal supply voltage is to be observed as closely as possible as well as the simultaneity of the voltage and current curve. In order to meet these requirements, PFC systems are installed at large consumers, which compensate the inductive phase shift and in part the harmonics at the consumer.

In order to minimise the negative effects for network stability due to high capacitance, the individual branches of PFC systems comprise a series connection from the capacitor and filter circuit choke. They are structured as a resonant circuit with defined frequencies, which must not be in resonance with the network harmonics. A constant inductance in a defined current range is therefore very important for this application.

17.4   Filter chokes

These type of chokes cover a broad range of applications. In actual fact, a power line choke is also a filter choke, but these should apply here for filter chokes, at which the frequencies of the fundamental wave and the frequencies to be filtered out differ by at least two powers of ten.

In so as these chokes are combined with capacitors, they are described in further detail in chapter 16 "Output filters" or Section 17.6 "LCL filters".

17.5   Power line chokes for regenerative feedback (regeneration choke, AFE choke)

Provided the regenerative feedback takes place with one or two commutations per network half wave, no higher requirements are placed on power line chokes than on uncontrolled input rectifiers.

Once the network connection is established via a pulse width modulated inverter, special regeneration chokes or regenerative filters, also known as LCL filters, are used.

The network and frequency converter have very low internal resistances and generate high balancing currents during direct connection, which greatly change the sinusoidal line voltage and may influence the behaviour of other loads due to interference currents in the network. The interferences in the network are substantially reduced by using a choke, which stores the energy of the voltage differences and limits the current rise.

If requirements on the harmonic component are very high, such as THDI < 5%, then the regeneration choke needed does not make economic sense. In addition, this generates an inductive voltage drop for the effective power at the line frequency, which the frequency converter needs to compensate as reactive power. An LCL filter should be used to bypass these disadvantages.
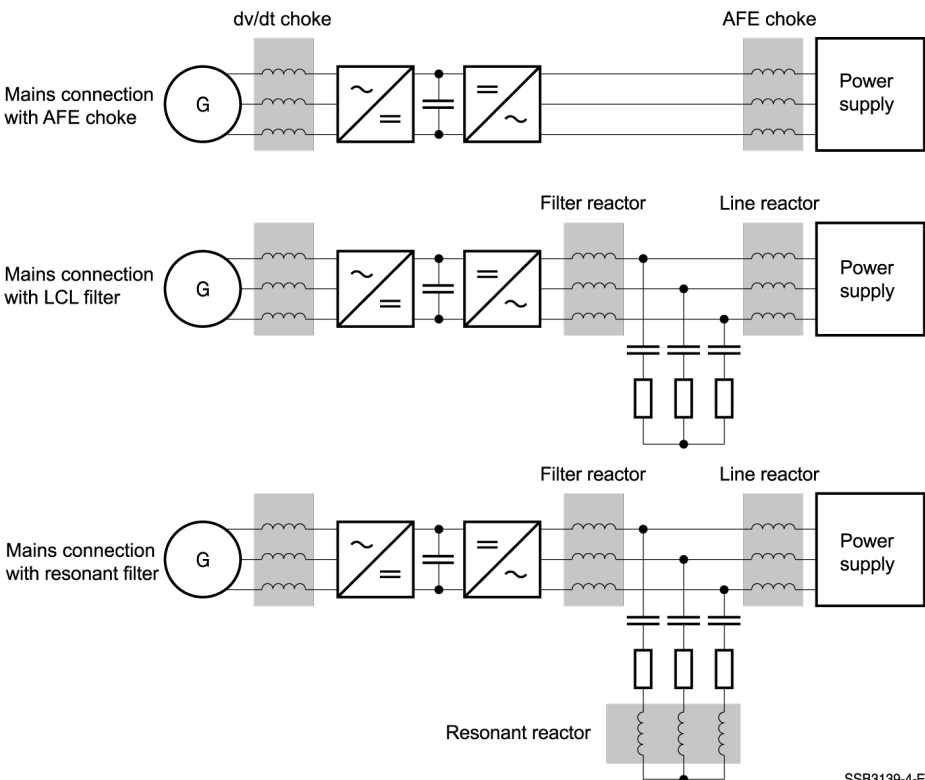
In contrast to power line chokes, in a similar way to filter chokes, the inductance must be kept virtually constant, as otherwise the choke will be saturated. Saturation of the choke leads to additional distortion of the current form, which generates further predominantly higher frequency harmonics, rather than attenuating them. Regeneration chokes are therefore considerably larger and heavier than standard power line chokes.

17.6   LCL filters

Using an LCL filter prevents voltage drop at the line frequency and provides improved THD values due to higher filter expenditure. This type of filter requires a second inductor to prevent resonance in the power supply.

For large systems in the megawatt range, it is worth specifically suppressing interference with one or more series resonant circuits. The choke connected to the main circuit is much smaller and the overall costs for the filter may also be reduced in the case of high requirements on the harmonic content.

Figure 66   Comparison of regeneration choke/LCL filter

Technical information

The solution with just one regeneration choke (Figure 66, top row) represents the lowest cost, but also needs to be checked in terms of suitability of requirements for power quality (harmonic component). This solution is cost-effective if the technical requirements are fulfilled.

The concept with LCL filter is used increasingly frequently on the line side (Figure 66 middle) to maintain THDI limit values with very good results. The damping resistors represented in the circuit are only needed in critical cases.

The lower block diagram (in Figure 66, lower row) once again shows the LCL filter on the line side, whereby the middle components from capacitors, resistors and inductors represent a dampened series resonant circuit. Critical undesired frequency components can therefore be filtered out much more effectively. Such frequency components could occur, for example, through the clock frequency of the active infeed converter on the line side.

The chokes used in LCL filters have already been described above. Only the series resonant circuit has not been previously mentioned, as this does not require any other design than for filter chokes. The installation situation is actually comparable with that of filter circuit chokes for power factor correction but these can be designed in smaller dimensions due to the significantly lower frequencies.

The series resonant circuit choke is matched to the clock frequency with capacitors. Several series resonant circuits may be necessary depending on the modulation. Resistors can be used to adjust the attenuation and sensitivity of the filter. However the losses in the choke are often sufficient to stabilise the system. As a result of the high resonant frequency component, the core is subjected to strong thermal stress, the line frequency component is comparably low.

18   Mechanical properties

18.1   Recommended tightening torques for screw connections - reference values

Most EMC filters from TDK have metallic casings. The screw mounting is used for mechanical fixing and simultaneously sets up, via the casing contact, the large-area connection to the reference potential (see also Chapter "Mounting instructions", page 133). A distinction must be made here between the functions of mechanical fixing, ground connection and the PE connection to ensure protection against excessive contact voltages.

For the standard screw connections to the filter and choke attachment, we refer to state-of-the-art solutions, as the tightening torques depend on the nominal size, length, strength class, corrosion protection and lubricants. It should be noted for face-side press nuts mainly for EMC-compliant assembly that additional attachments are needed for filter weights > 10 kg. In all cases, the equipment installer must check its strength with respect to loads (e.g. vibrations, impacts).

Unless stated otherwise in the data sheets, we recommend the tightening torques shown in the following tables.

Recommendation for tightening torques for press nuts/press bushings

Nominal size of press nuts	Tightening torque in Nm (tolerances for setting values)
M 4	1.5 (1.43 … 1.58)
M 5	3.0 (2.85 … 3.15)
M 6	5.1 (4.90 … 5.40)
M 8	12.6 (12.00 … 13.20)

Please read *Important notes*
and *Cautions and warnings*
89   8/22

Screw connections via PE threaded bolts

For electrically conductive and PE terminals on 2-, 3- and 4-line filters contacted via threaded bolts, we recommend the following tightening torques:

Nominal size of threaded bolts	Tightening torque in Nm (tolerances for setting values)
M 4	1.2 (1.10 … 1.30)
M 5	2.0 (1.90 … 2.10)
M 6	3.0 (2.85 … 3.15)
M 8	6.0 (5.70 … 6.30)
M 10	10.0 (9.00 … 11.00)
M 12	15.5 (14.00 … 17.00)

For tightening torques for feedthrough filters, see the introductory text to the chapter on "Feed-through filters".

Screw connections of busbars

For some filters and chokes with rated currents >100 A, aluminium or copper busbars are used as connection elements.

We recommend the following materials for busbar screw connections according to DIN 43673-1:

Part	Recommended material
Busbar	Copper
Screw	Strength class 8.8 or higher according to DIN EN ISO 898-1; Corrosion protection tZn (hot-galvanised)
Nut	Strength class 8 or higher according to DIN EN ISO 898-2; Corrosion protection tZn (hot-galvanised)
Spring element on screw and nut side	Spring washer according to DIN 6796; corrosion-protected
Lubricant	Based on MoS_2

To ensure the required area pressure, we recommend the following tightening torques:

Nominal size of threaded bolts	Tightening torque in Nm (tolerances for setting values)
M 8	15.0 (13.5 … 16.5)
M 10	30.0 (27.0 … 33.0)
M 12	60.0 (54.0 … 66.0)

All electrical contact points must be uncoated with a defined surface roughness. We recommend Scotch Brite™ 7447 PRO (7100023339) for processing copper contact surfaces. The contact surfaces must then be immediately cleaned with a clean, dry cloth. The contact surfaces must offer the same contact force over the entire area. The contact point can be applied with contact grease if corrosive environmental impacts or moisture can attack the contact.

18.2 General tolerances

The data sheet contains dimensional diagrams for each filter or choke. The following points should be noted:

- All dimensional specifications in mm
- 1 inch corresponds to 25.4 mm and 1 mm corresponds to 0.03937 inches; accuracy 5 digits after the decimal point
- Linear and angular dimensions without individual tolerance indication have tolerance class "c" to ISO 2768-1
- Tolerance for form and position without individual tolerance indication have tolerance class "L" to ISO 2768-2

Limit measures for length measure (values in mm):

Tolerance class	Limit measure for nominal sizes								
c (rough)	< 0.5	0.5 ... 3	> 3 ... 6	> 6 ... 30	> 30 ...120	> 120 ... 400	> 400 ... 1000	> 1000 ... 2000	> 2000 ... 4000
	1)	± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2	± 3	± 4

1) For nominal sizes < 0.5 mm the limit measures are to be indicated directly at the nominal sizes.
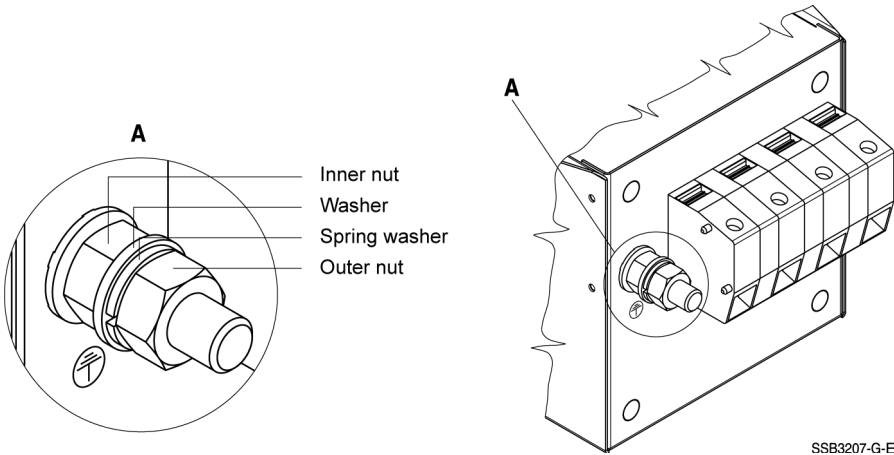
General tolerances for straightness (values in mm):

Tolerance class	General tolerances for nominal size ranges					
L	≤ 10	> 10 ... 30	> 30 … 100	> 100 … 300	> 300 … 1000	> 1000 ... 3000
	0.1	0.2	0.4	0.8	1.2	1.6

General tolerances for symmetry (values in mm):

Tolerance class	Symmetry tolerances for nominal size ranges			
L	≤ 100	> 100 … 300	> 300 … 1000	> 1000 ... 3000
	0.6	1	1.5	2

18.3 PE connection installation instructions

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1. Release the outer nut while you hold the inner nut.

2. Position the cable lug between the two washers.

3. Tighten the outer nut according to the table in the section "Screw connections via PE threaded bolts" on page 123, while you hold the inner nut.

SSB2839-V

19   Standards overview

Efforts are being made worldwide to harmonise the standards for products and installations. This is increasingly being done in IEC standards by the International Electrotechnical Commission. These standards are in most cases subsumed in regional (e.g. EN = European standards) and national standards, often together with specific comments. The IEC standards stipulate the minimum requirements on the products. The technical details of the implementation in most cases remain the responsibility of the manufacturers.

The procedure on the North American market differs from this. The regional safety system includes the interests of the local authorities, manufacturers, insurance companies and end customers. National legislation takes place via NEC (National Electrical Code), CEC (Canadian Electric Code), NFPA (National Fire Protection Association), as well as via individual supplements by local authorities. Thus the USA requires approval for all electrically controlled equipment and systems. This approval can be carried out by recognized test laboratories such as UL and CSA.

TDK has a large number of products with the corresponding approvals. These are noted both on the data sheet and the product label. Further information on this can be found in the chapter "Labelling and ordering code system - Safety test marks".

19.1   Terms from standards and laws

The EU directives and the national laws derived from them as well as technical standards make use of some key terms which may diverge somewhat from their current everyday use. The main terms from EMC Directive 2014/30/EU of 26.02.2014 as well as from the EU's "Blue Guide" (Guide to the implementation of product regulations from the EU 2016") are therefore summarized below. Additional terms and explanations may be found in the relevant EU directives or in the "Blue Guide".

Equipment (EMC Directive)

"Equipment" designates an item of apparatus or a fixed installation.

Apparatus (EMC Directive)

"Apparatus" means any finished appliance or combination there of made commercially available as a single functional unit, intended for the end user and can produce electromagnetic interference or whose functionality/operation can be impaired by electromagnetic interference.

The term "apparatus" in the sense of the EMC Directive also applies to:

1. "Components" or "sub-assemblies" intended for incorporation into an apparatus by the end user, which are liable to generate electromagnetic interferences, or the performance of which is liable to be affected by such interference;

2. "Mobile installations" defined as a combination of apparatus and, where applicable, other devices, intended to be moved and operated in a range of locations.

Fixed installations (EMC Directive)

"Fixed installation" means a particular combination of several types of apparatus and, where applicable, other devices, which are assembled, installed and intended to be used permanently at a pre-defined location.

Manufacturer (EMC Directive)

"Manufacturer" shall mean any natural or legal person who manufactures a product or has a product designed or manufactured, and markets that product under his name or trademark.

Placing in the market and putting into service (EMC Directive or Blue Guide)

Placing in the market is the first-time entry of a product onto the Union market. Putting into service implies the first use of the equipment by the end user in the area of the Union. However, the necessity to assure within the scope of the market overview that the products satisfy the stipulations of the directive at the time of putting into operation is restricted.

A product is put into circulation on the Union market for the first time for the purpose of harmonising legislation.

Placing in the market thus refers to the individual item of equipment to which this directive applies, irrespective of the time and place of manufacture and of whether it was manufactured in single or series production. Putting into circulation does not refer to the setting up and presentation of an item of equipment at exhibitions and trade fairs.

Appliance filters (DIN EN 60939-3)

Filters are intended to be factory-installed as a component part of end-use appliances or equipment connected to (supplied by) the branch circuits of a building wiring system. Included in this category are filters installed in medical and dental equipment, office appliances and business equipment, data processing equipment and household appliances such as mixers, vacuum cleaners, hand-tools, and the like.

Facility filters (DIN EN 60939-3)

Filters installed as part of the service, feeders or branch circuitry of a building wiring system.

Cord connected filters (DIN EN 60939-3)

Filters provided with a supply cord having an attachment plug for connecting the filter to a branch-circuit receptacle. It is also provided with one or two receptacles for distribution of the filtered voltage to an external (appliance or other equipment) load.

Direct plug-in filters (DIN EN 60939-3)

Filters provided with blades or pins at the filter body that plug directly into a branch-circuit receptacle. It is also provided with one or two receptacles for distribution of the filtered voltage to an external (appliance or other equipment) load.

19.2 Component standards

Document	Title
IEC 60339	Passive filters for suppressing electromagnetic interference
IEC 60339-1	Part 1: General requirements and measuring methods
IEC 60939-2	Part 2: Sectional specification: Passive filter units for which safety tests are appropriate
IEC 60939-2-1	Part 2-1: Blank detail specification
IEC 60939-2-2	Part 2-2: Blank detail specification, safety tests only
IEC 60939-3	Part 3: Passive filter units for which safety tests are appropriate
UL 1283	Electromagnetic interference filters
UL 60939-3	Passive filter units for electromagnetic interference suppression - Part 3: Passive filter units for which safety tests are appropriate
IEC 60076-6	Power transformers – Part 6: Reactors
DIN EN 61558-2-20	Safety of power transformers, power supply units and similar devices
IEC 60384-14	Fixed capacitors for use in electronic equipment – Part 14: Sectional specification – Fixed capacitors for electromagnetic interference suppression and connection to the mains supply
CSA C22.2 No. 8-13	Electromagnetic interference (EMI) filters

Scope of standards for EMC filters:

Standards	Scope
IEC 60939-3 EN 60939-3 DIN EN 60939-3; VDE 0565-3-4 UL 60939-3	Appliance filters
IEC 60939-2 EN 60939-2 DIN EN 60939-2; VDE 0565-3-1 UL 1283	Facility filters
	Cord connected filters
	Direct plug-in filters

19.3 EMC standards

Harmonised European standards have been referenced in conjunction with the European EMC Directive or national EMC legislation. These specify limits or test levels for both the emissions and susceptibility of electrical equipment, installations and systems. Further standards describe the measurement methods and test procedures which are referenced in harmonised standards.

The subdivision of the European standards into various categories (see following tables) makes it easier to find the rules that apply to the respective equipment. The generic standards apply invariably to all equipment.

If the equipment is within the scope of a specific product family standard or dedicated product standard, these may be used for assessing the conformity.

The basic standards contain information on interference phenomena and general measuring methods.

With the exception of the standards for harmonic and flicker assessment, they contain no limit specifications and are consequently not listed as harmonised standards in the EU's Official Gazette.

The following standards and specifications form the basis for the conformity tests:

Generic standards

define the EMC environment in which equipment may be appropriately operated.

Topic	Limitation	EMC standards	
		Europe	World
Emissions	Residential area	EN 61000-6-3	IEC 61000-6-3
	Industrial area	EN 61000-6-4	IEC 61000-6-4
Susceptibility	Residential area	EN 61000-6-1	IEC 61000-6-1
	Industrial area	EN 61000-6-2	IEC 61000-6-2

Basic standards

contain physical phenomena and measuring methods.

Topic	Limitation	EMC standards	
		Europe	World
Measuring equipment		EN 55016-1-x	CISPR 16-1-x
Measuring methods	Emissions	EN 55016-2-x	CISPR 16-2-x
	Susceptibility	EN 61000-4-1	IEC 61000-4-1
Susceptibility parameters, e.g. ESD		EN 61000-4-2	IEC 61000-4-2
EM fields		EN 61000-4-3	IEC 61000-4-3
Burst		EN 61000-4-4	IEC 61000-4-4
Surge		EN 61000-4-5	IEC 61000-4-5
Induced RF fields		EN 61000-4-6	IEC 61000-4-6
Magnetic fields		EN 61000-4-8	IEC 61000-4-8
Voltage dips		EN 61000-4-11	IEC 61000-4-11

Acronyms:

ESD = electrostatic discharge
EM = electromagnetic
Burst = Pulse sequence (e.g. with rise rate of 5 ns and pulse duration of 50 ns)
Surge = Shock wave (e.g. with 1.2/50 µs or 8/20 µs rise/fall rate)

Product family standards contain limits for emissions and susceptibility.

Topic	Limitation	EMC standards	
		Europe	World
ISM equipment	Emissions	EN 55011	CISPR 11
	Susceptibility		
Domestic appliances	Emissions	EN 55014-1	CISPR 14-1
	Susceptibility	EN 55014-2	CISPR 14-2
Lighting	Emissions	EN 55015	CISPR 15
	Susceptibility	EN 61547	IEC 61547
Multimedia devices[1]	Emissions	EN 55032	CISPR 32
	Susceptivility	EN 55035	CISPR 35
Harmonics	$\leq$ 16 A	EN 61000-3-2	IEC 61000-3-2
	16 A < $I_R \leq$ 75 A	EN 61000-3-12	IEC 61000-3-12
Flicker	$\leq$ 16 A	EN 61000-3-3	IEC 61000-3-3
	16 A < $I_R \leq$ 75 A	EN 61000-3-11	IEC 61000-3-11
Road vehicles[2]	Emissions	EN 55025	CISPR 25
	Susceptibility	-	ISO 11451
		-	ISO 11452
Frequency converters (variable frequency electrical drives)	Emissions Susceptibility	EN 61800-3	IEC 61800-3
EMC requirements for electric vehicle conductive charging systems	Emissions Susceptibility	EN 61851-21-2	IEC 61851-21-2

1) Some equipment comes under the Radio and telecommunications terminal equipment directive.
2) The EU directive on electromagnetic compatibility of motor vehicles 2004/104/EC also contains limits and susceptibility requirements.

Acronyms/comments:

ISM equipment = High-frequency equipment in Industrial, Scientific and Medical areas
ITE equipment = Information Technology Equipment

Technical information

The most important **susceptibility** standards are listed below.

Topic	Test characteristic	Phenomena	EMC standards	
			Europe	World
Conducted inter-ference	5/50 ns (Single pulse) 5 kHz or 100 kHz	Burst Pulse packets Cause: Switching processes	EN 61000-4-4	IEC 61000-4-4
	1.2/50 ms (open-cir-cuit voltage) 8/20 ms (short-circuit current)	Surge (high-energy transients) Cause: Lightning strike, switching processes	EN 61000-4-5	IEC 61000-4-5
	1; 3; 10 V 150 kHz to 80 MHz (or 230 MHz)	High-frequency coupling, narrowband interference	EN 61000-4-6	IEC 61000-4-6
Radiated inter-ference	3; 10 V/m 80 to 1000 MHz or to 6 GHz	High-frequency interference fields	EN 61000-4-3	IEC 61000-4-3
	to 100 A/m 50/60 Hz	Magnetic interference fields with power frequencies	EN 61000-4-8	IEC 61000-4-8
Electrostatic dis-charges (ESD)	to 15 kV	Discharge static electricity	EN 61000-4-2	IEC 61000-4-2
Instability of the supply voltage	E.g. 40% V_N for 1 … 50 periods	Voltage dips	EN 61000-4-11	IEC 61000-4-11
	0% V_N for 0.5 periods	Short-term interruptions		
	e.g. 40% V_N or 0% V_N (2 s reduction, 1 s reduced voltage, 2 s rise)	Voltage fluctuations		

20 Mounting instructions

When mounting and dismantling our filters, we recommend observation of the rules that apply generally for the operation of electrical equipment. This includes setting up and ensuring a no-voltage state and observing the five safety rules described in EN 50110-1.

The following steps should be carried out in the specified sequence unless important reasons require a divergence from this sequence:

- Disconnect
- Ensure that no reconnection is possible
- Ensure that no voltage is present
- Grounding and short-circuiting[3]
- Cover or separate adjacent live parts.

Figure 67 Pictograms for work protection

EMC is not only achieved by using EMC filters. It should be considered as an integral system and is required to ensure careful planning and preparations. Measures such as shielded motor leads, earthing and spatial separation inevitably form part of an integral concept.

Plan your EMC!

- Specify the interference sources (with emissions) and disturbed equipment (electrical equipment or components with limited susceptibility).
- Assign the interference sources and disturbed equipment to zones (mounting positions), and separate these spatially from each other.
- Plan the cabling in wiring categories according to emissions and susceptibility.
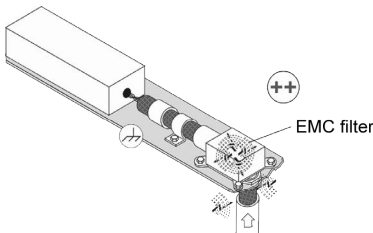
3) In low-voltage installations, earthing and short-circuiting are not necessary, unless the risk exists that a voltage may be applied to the installation (e.g. second feed).

EMC has become an essential quality feature. Even in the development phase of the system, legally stipulated protection requirements and technical risks must be taken into consideration. The following information is important for producing the electromagnetic compatibility of the entire system[4] :

1. **The filter casing should have a large-area connection to ground and other equipment.**
   For example, provide a common metallically bright mounting plate for filter and converter, fully ground and connect with large area of the switch cabinet at low inductance. If necessary, use short ground straps and EMC seals (for example, connection to switch cabinet doors).

EMC filter

2. Make a distinction between:
   ■ the protective conductor connection of the EMC filter (see also chapter "Technical information; Safety notes relating to leakage currents"), which serves as a protective measure to protect against hazardous body currents and

   ■ the large-area grounding of the filter, which is necessary for the interference suppression function of the filter.

⚠ At operating currents >250 A, we recommend not executing the PE connection between the power supply (filter: line) and output (filter: load) via PE bolts in the filter casing. The reason for this is the limited area of the cable lug on the PE connection for the filter casing. The PE conductor of the supply is preferably to be connected with the PE conductor of the output on a protective conductor connection rail, on which the PE connections of the EMC filter are also connected.

The quantity of PE connections required for the filter depends on the cross-section and magnitude of the leakage current (see also chapter "Safety notes relating to leakage currents"). The protective conductor connections must meet the requirements defined in IEC 60364-5-54. At currents >1000 A and/or short circuit currents >25 kA, it is not permissible to "loop through" the PE conductor via the filter casing.

4) The figures in the "Mounting instructions" chapter were provided by Rittal GmbH Co. KG, Herborn as well as Invensys Systems GmbH EUROTHERM, Limburg/ Lahn
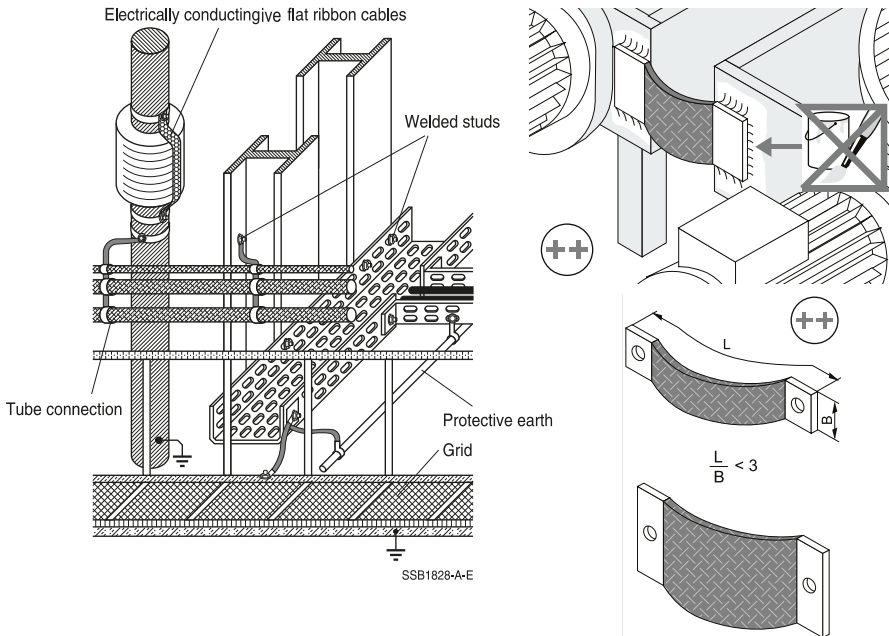
3. **Create connections in your system with the same reference potential** to reduce galvanically coupled interference. All metallic reference potential from casing, machine and system parts should be connected with low impedance, suitable for high frequency and as meshed as possible.

Establish large-area metallic connections, use equipotential bonding bars and establish short connections over flat ribbon grounding cables.

There are:

■ Large-area conductive fixing

■ Low-inductance connection
(a rectangular copper flat ribbon cable is preferred over round conductors)

■ Short connections (rule of thumb: Length divided by width < 3)

4. **Keep lines from source of interference as short as possibl!**

Examples:

■ Short connection from converter to EMC filter, ideally flanged filters to avoid emission.

■ Interconnections as short as possible between the converter output and motor (even to reduce asymmetric currents through parasitic capacitances of the cable shield).

5. **Disturbance-contaminated lines must be shielded!**

    Examples:

    ■ Interconnections between frequency converter and motor if a corresponding output filter is not used.

    ■ Connection between filter and converter on line side, as long as not directly flanged.

    ■ Please note that the shielding effect of different cables varies greatly (foil shield, shielding braid with different overlapping, combinations).
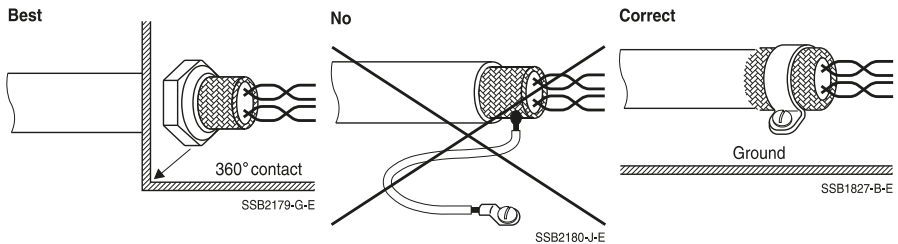
6. **Connect shielded lines on both sides and across large area with reference potential, as direct or close as possible to the casing inlet or outlet.**
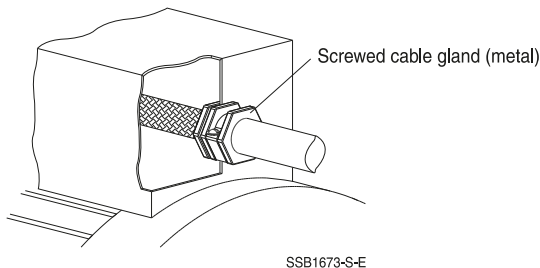
    Use:

    ■ EMC-compliant cable glands (wrap-around contact)

    ■ EMC base plate

    ■ EMC shield rails with large area contacting of the cable shield by means of corresponding metal clamps.

    Avoid shielded connections via stubs!
    (Twisted shielding braid; soldered cable lugs etc.)

Best	No	Correct
360° contact		Ground
SSB2179-G-E	SSB2180-J-E	SSB1827-B-E

Also ensure that there is an EMC-compliant cable gland on the terminal box of the motor. These must meet the degree of protection of the respective location of use. The motor terminal box must be made of metal. The connection between the cable gland and terminal box must cover a large area. When removing the coating, the corrosion protect must be re-applied, if necessary.
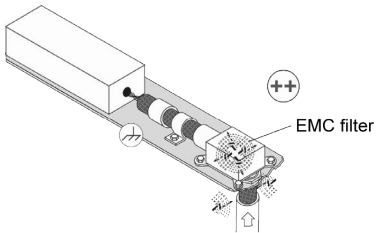
Screwed cable gland (metal)

SSB1673-S-E

7. **Layout of EMC filters as direct as possible to the casing inlet or outlet.**

Examples:

- Mains connecting side of the filter protrudes out of casing opening. (Ensure shock hazard protection!)
- Use of appropriate EMC filters
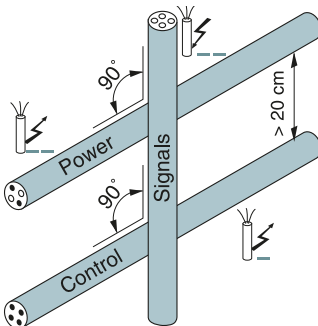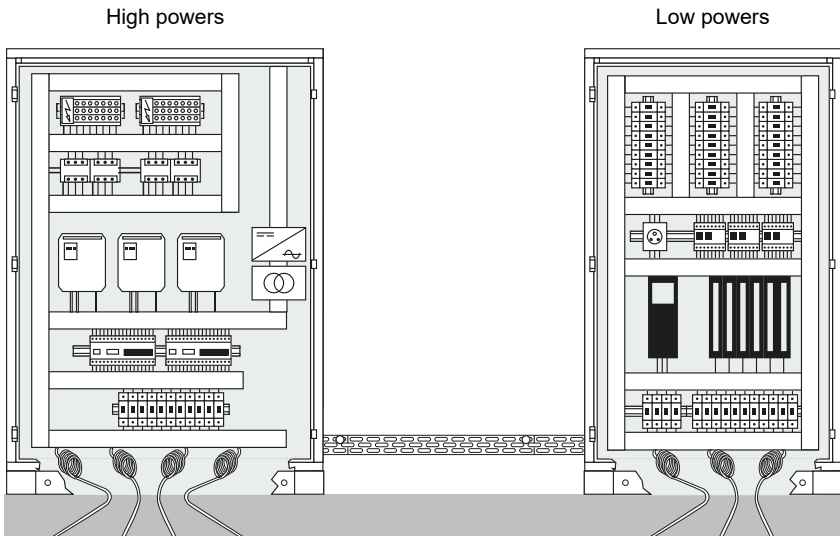- Use of corresponding case adjustments to achieve shield attenuation (upon request)

8. Provide **spatial separation** between lines contaminated with disturbances and "clean" lines (lines contaminated with disturbances includes lines between converter and filter, "clean" lines between mains connection and filter).

Avoid parallel running (reduction in coupled disturbances).

Ensure that signal and power cables are run with spatial separation between them in order to prevent coupling lines (recommended minimum distance 20 cm). If necessary, provide metal sheeting; ground this over a wide area.

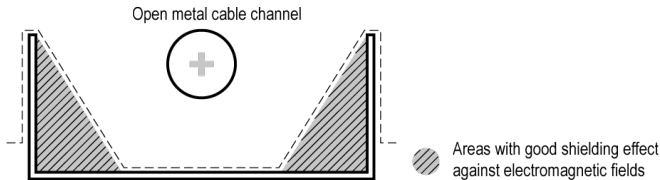Run crossings, where possible at a right angle and with spacing.

High powers   Low powers

9. To reduce interference couplings, run the **lines as close as possible to metal sheeting**, which is connected with the reference potential (mounting plates, switch cabinet casing, etc.)

   Conductive lines should also be run as closely as possible to the reference potential (reduction in inductively coupled interference).

   In order to improve electromagnetic compatibility, cable ducts, cable troughs and installation pipes made of metal are to be preferred over plastic parts.

Open metal cable channel

Areas with good shielding effect against electromagnetic fields

SSB2447-W-E

10. For unshielded signal lines (supply and return conductors), use twisted 2-wire lines in order to keep the area between the conductors as small as possible (to avoid magnetic coupling). The same applies for avoiding cable loops.

11. Switched inductors (such as contactors, relays, magnetic valves etc.) should be connected close to the source of interference with corresponding suppressors.

12. For control signals in the area of a high interference level, use corresponding switching technology, such as symmetrical transmission systems with twisted wire pairs in connection with data line chokes (see also our "Inductors" data book), transmit digital signals according to the RS-422 standard or in extreme cases, cross the interference area using optical fibres.

13. ⚠ Pay attention to the installation location of the filters!
    Assembly must as a general rule be performed in such a way that natural convection is not impaired. This includes taking louvres in the filter casing and sufficient spacing to other installations into consideration. Overhead assembly is generally excluded. In the case of special installation situations, testing of the thermal conditions is required in consultation with TDK.

14. Noise minimisation
    An essential frequency-dependent filter component is the choke with very different core materials. In AC applications, electroacoustic effects are to be expected. The materials and processing technologies used generate a reasonable noise level when maintaining the harmonic components according to the EN 50160 standard for use in industrial areas. These may increase considerably at higher harmonic components. In the case of sensitive applications, such as assembly in offices, consultation from TDK should be considered.
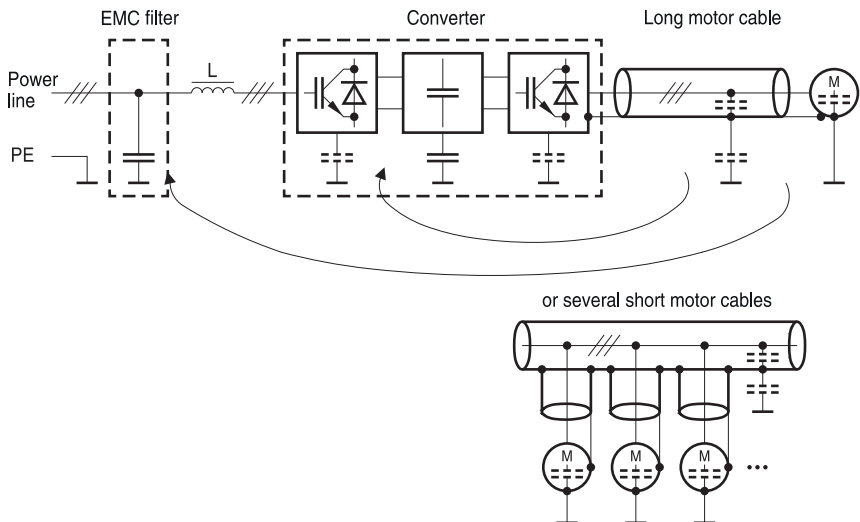
15. Motor leads and motor types

Output voltages are generated in converter applications, which have virtually right angled curve shapes. These are primarily characterised by the rate rise as a dv/dt value and the switching frequency of the converter. The cables and motors in the output network of the converter and their inductive and capacitive components basically define the EMC properties of the system. Resonances of cable and motor combinations can in many cases be found again as resonance of the interference voltage measurement at the converter input side.

⚠ The parasitic capacitances of the cable and motor should be given particular attention. While the parasitic capacitances of the motor are dependent on the design, cables are dependent on the insulation material, the cable structure and the type of shielding and particularly on the length. A higher frequency current flows through the earthed system parts depending on the switching frequency, the dv/dt value and the magnitude of the parasitic capacitances.

⚠ The following effects may occur here:

■ As the parasitic currents flow through the ground connections of the system, the total input currents in the filter is no longer equal to zero. This can lead from a certain magnitude of the parasitic current to saturation of the current-compensated chokes in the filter and consequently exceeds the permitted interference level. The interference voltage measurement should be performed at the installed systems.

■ The parasitic currents also flow via the filter casing and the capacitors connected in the filter to the source of interference. Impermissibly high currents can lead to overload of capacitors and therefore a hazard!

SSB3223-W-E