



EMC Construction advice

General use of EC directives

EMC

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1 Introduction

1.1 General information

EMC stands for "electromagnetic compatibility" and, according to the definition of the EMC Directive, describes "the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment".

Because of the increasing use of power electronics equipment in combination with microelectronics equipment in systems that are becoming more and more complex, electromagnetic compatibility is becoming increasingly important to the trouble-free functioning of complex systems and installations.

For this reason, it is absolutely necessary to consider electromagnetic compatibility as early as the planning stage for the device or system. For example, EMC zones must be defined, cable types and cable routing must be specified, and filters and other interference suppression measures must be provided for if necessary.

This chapter of the document supports the planning and installation personnel of control cabinet manufacturers and system integrators in complying with the provisions of the EMC Directive when using FESTO drives in systems and installations.

The modular concept of the CMMx device series enables a large number of possible device combinations, so it is not possible to describe every conceivable combination. Therefore, this chapter should provide basic principles and generally applicable rules that can be used to construct device combinations in an electromagnetically compatible manner. Some typical examples are presented and explained at the end of this chapter in order to provide clarification. The devices CMMP-AS, CMMS-ST and CMMS/D-AS described in this document are not "apparatuses" within the meaning of the EMC Directive, but rather "components" that are intended to be installed in a complete system or a complete installation. Nevertheless, the common term "apparatus" may be used for better understanding.

1.2 EC directives

EC directives are published in the Official Journal of the European Communities and must be adopted into the national legislation of the EC member states for the purpose of facilitating free trade and flow of goods within the European Economic Area. Therefore, EC directives and their implementation in national legislation form the legal basis within the European Economic Area. There are two published EC directives for low-voltage adjustable speed electrical power drive systems:

- Low Voltage Directive 2006/95/EC
(laws of the Member States relating to electrical equipment)
- EMC Directive 2004/108/EC
(laws of the Member States relating to electromagnetic compatibility)
The EMC Directive is discussed in more detail in this chapter.
- Machinery Directive 2006/42/EC
(establishes a uniform level of safety for accident prevention for machines when placed on the market)

1.3 CE marking

The CE marking confirms the conformity with all applicable EC directives. The manufacturer or the party that places the product or the system on the market is responsible for the CE marking. A prerequisite for the CE marking is a self-certification, i.e., a declaration of the manufacturer, that all European standards relevant to the device are complied with. Only standards officially listed in the Official Journal of the European Communities may be cited in this declaration (manufacturer's certificate, manufacturer's declaration, or declaration of conformity).

1.4 EMC Directive

All electrical and electronic devices and systems that contain electrical or electronic components that can cause electromagnetic interference or whose operation can be affected by such interference must comply with the provisions of the EMC Directive. This includes the FESTO devices described in this document.

Compliance with the EMC Directive can be demonstrated by applying appropriate EMC standards, wherein product standards take precedence over generic standards. The EMC product standard EN 61800-3 for adjustable speed electrical power drive systems (**P**ower **D**rive **S**ystems, abbreviated PDS), EN 61000-6-2 (Immunity for industrial environments) and EN 61000-6-4 (Emission standard for industrial environments) apply to FESTO devices. If FESTO devices are built into a final product for which a special EMC product standard exists, the EMC product standard of the final product must be applied.

Because FESTO devices are considered "components" of a complete system or a complete installation – similarly to transformers, motors or controllers, for example – the manufacturer does not have a marking obligation with regard to compliance with the EMC Directive. However, the manufacturer of "components" has a special obligation to provide adequate information about the electromagnetic properties, use and installation of its "components". This chapter of the document provides all relevant information needed by OEM customers, control cabinet manufacturers and system integrators in order to integrate FESTO devices into their system or installation in such a way that the complete system or the complete installation fulfils the EMC Directive.

This means that the OEM customer or the system integrator bears sole and final responsibility for the electromagnetic compatibility of the complete system or complete installation. This responsibility cannot be transferred to the suppliers of "components".

1.5 EMC product standard EN 61800-3

EMC product standard EN 61800-3 for adjustable speed electrical power drive systems (**P**ower **D**rive **S**ystems, abbreviated PDS) applies to FESTO devices. This standard applies not only to the converter itself but rather to a complete adjustable speed power drive system, which comprises the motor and other equipment in addition to the converter.

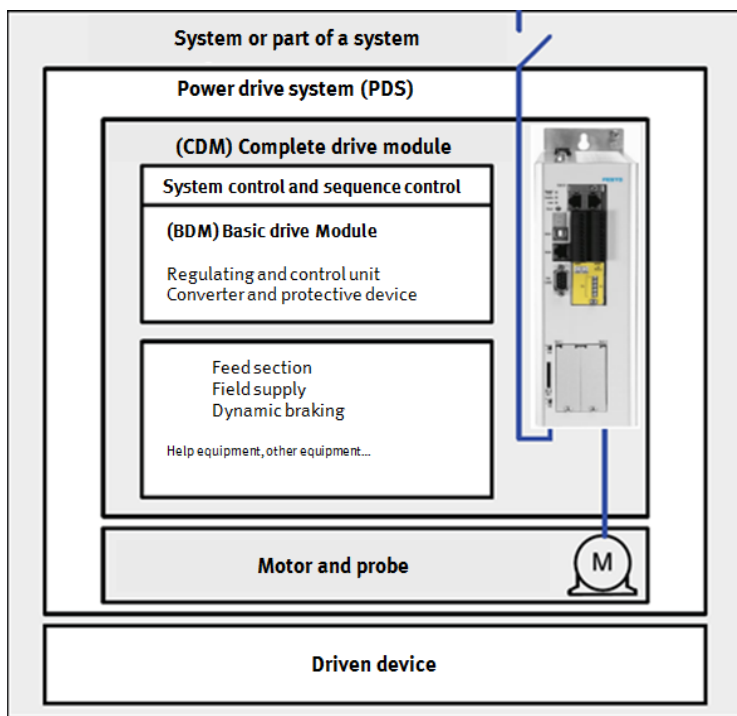


Fig. 1-1: Definition of the installation and the power drive system according to EMC product standard EN 61800-3

The EMC product standard uses the following terms:

- PDS = Power Drive System (complete power drive system comprising a converter, motor, shaft and additional equipment)
- CDM = Complete Drive Module (complete converter device, e.g., CMMP-AS including braking resistor)
- BDM = Basic Drive Module (e.g., CMMP-AS)

In the EMC product standard, evaluation criteria for the performance under the influence of interference are defined and interference requirements and interference emission limits are defined according to the environmental conditions at the installation location, wherein a distinction is made between the first environment and the second environment in regard to the installation locations.

1.5.1 Definition of the first environment and the second environment

Environment	Definition
First environment (residential area)	Residential buildings or locations in which the power drive system is connected directly to the public low-voltage power supply network without intermediate transformers.
Second environment (industrial area)	Locations outside of the residential area, or industrial areas that are supplied from the medium-voltage power supply network through their own transformer.

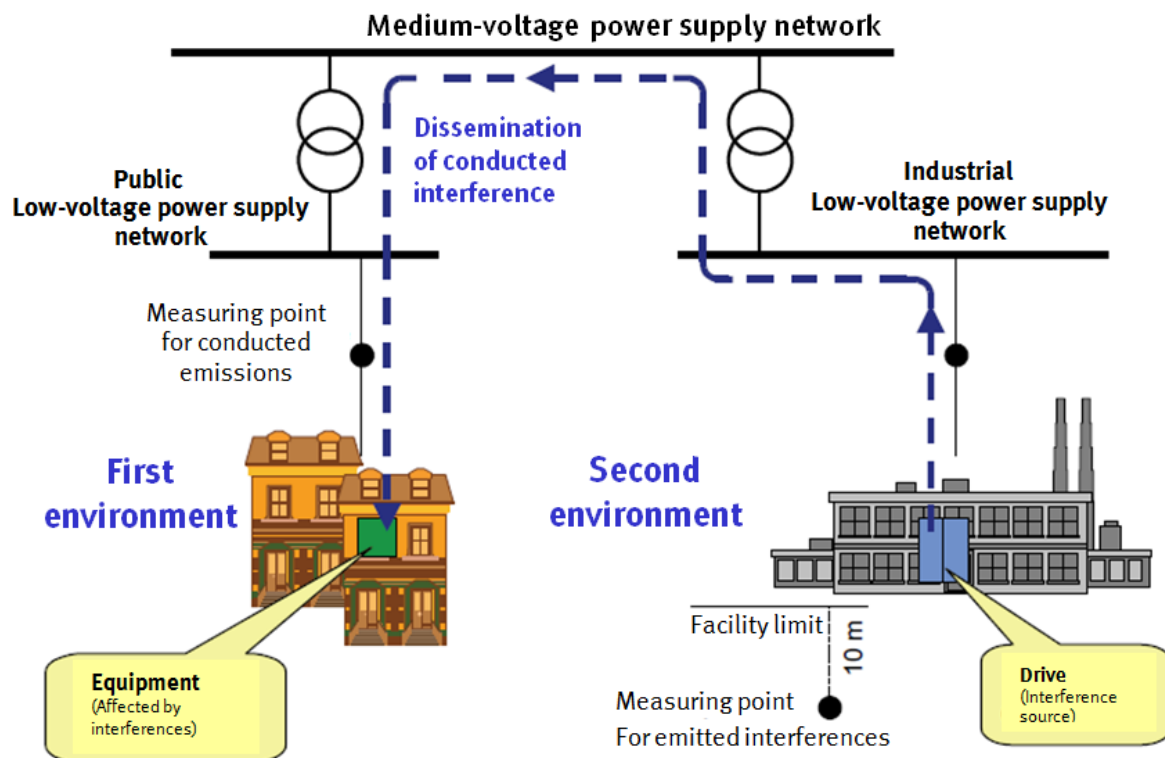


Fig. 1-2: First and second environments according to the definition of EMC product standard EN 61800-3
Four different categories are defined in EMC product standard EN 61800-3 according to the installation location and the power of the adjustable speed power drives.

1.5.2 Definition of categories C1 to C4

Category	Definition
C1	Power drive systems (PDSs) with nominal voltages < 1000 V for unrestricted use in the first environment.
C2	Fixed power drive systems (PDSs) with nominal voltages < 1000 V for use in the second environment. Use in the first environment is possible if the system is sold and installed by professional personnel. The warnings and installation instructions provided by the manufacturer must be followed.
C3	Power drive systems (PDSs) with nominal voltages < 1000 V for exclusive use in the second environment.
C4	Power drive systems (PDSs) with nominal voltages ≥ 1000 V or with nominal currents ≥ 400 A for use in complex systems in the second environment.

Adjustable speed electrical power drive systems PDS				
	C1	C2	C3	C4
Environment	1. Environment (Living -, business - and commercial area)		2. Environment (Industry area)	
Voltage or Current	< 1000 V			≥ 1000 V Or ≥ 400 A
EMV knowledge	No requirements	Installation and commissioning must be carried out by trained personnel		

Fig. 1-3: Overview of categories C1 to C4 according to EMC product standard EN 61800-3

In the first environment (i.e., in the residential area), the permissible interference level is lower. Therefore, devices for use in the first environment must have lower interference emission but require only relatively low interference immunity. In the second environment (i.e., in the industrial area), the permissible interference level is higher. Devices for use in the second environment may have relatively high interference emission but require high interference immunity.

1.5.3 Environments for FESTO converters

Category	Definition
C2	The FESTO converters described in this document are intended for use in the second environment. However, with additional, optionally usable mains filters or EMC filters (radio-interference filters) suitable for TN or TT networks with a grounded star point, it is also possible to use the FESTO converters in the first environment according to category C2 of EMC product standard EN 61800-3; the customer is responsible for verifying this. The use of shielded motor cables and a closed control cabinet is absolutely necessary to comply with category C2.
C3	The FESTO converters described in this document are intended for use in the second environment and come standard with mains filters or EMC filters (radio-interference filters) according to category C3 of EMC product standard EN 61800-3. This applies to all FESTO converters including the associated plug-in cards. The use of shielded motor cables is necessary to comply with category C3.
C4 and IT networks	FESTO converters can also be used in ungrounded networks (IT networks). In this case, the system manufacturer and system operator must agree upon an EMC plan, i.e., customised, system-specific measures for ensuring electromagnetic compatibility.

2 Basic principles of EMC

2.1 Definition of EMC

Electromagnetic compatibility (EMC) depends on two properties of the involved devices. These are the **interference emission** and the **interference immunity**. Electrical devices can be divided into interference sources (transmitters) and interference sinks (receivers). There is always electromagnetic compatibility if the interference sources present do not impermissibly influence the function of the interference sinks present. A device can also be an interference source (e.g., power section of a converter) and an interference sink (e.g., control section of a converter) at the same time.

2.2 Interference emission and interference immunity

2.2.1 Emitted interference

Interference emission describes interference emitted to the environment by electrical devices.

The **high-frequency interference emission** of frequency converters is governed by EMC product standard EN 61800-3. This standard defines limits for:

- High-frequency conducted interference at the network connection point (radio-frequency interference voltages)
- High-frequency electromagnetically radiated interference (radio-frequency interference radiation)

The defined limits depend on the environmental conditions (first environment or second environment).

The **low-frequency interference emission** of frequency converters – usually called network feedback – is governed by different standards. EN 61000-2-2 can be used for public low-voltage power supply networks, and EN 61000-2-4 can be used for industrial networks. Outside of Europe, IEEE 519 is referenced very frequently. In addition, the specifications of the local power supply company must be observed.

2.2.2 Resistance to interference Interference immunity describes the behaviour of electrical devices under the influence of electromagnetic interference acting on the converter via the environment. This interference can be high-frequency conducted interference (interference voltages) or high-frequency electromagnetic radiation (interference radiation). The requirements and evaluation criteria for the behaviour under the influence of this interference is likewise governed by EMC product standard EN 61800-3.

3 The frequency converter and its EMC

3.1 The frequency converter as an interference source

3.1.1 Mode of operation of FESTO frequency converters (CMMP series)

The frequency converters of the CMMP series comprise a network-side rectifier, which feeds a direct-voltage intermediate circuit. The following inverter produces an output voltage U consisting of nearly rectangular voltage blocks from the intermediate circuit voltage according to the method of pulse-width modulation. Because of the smoothing effect of the motor inductance, a largely sinusoidal motor current I results.

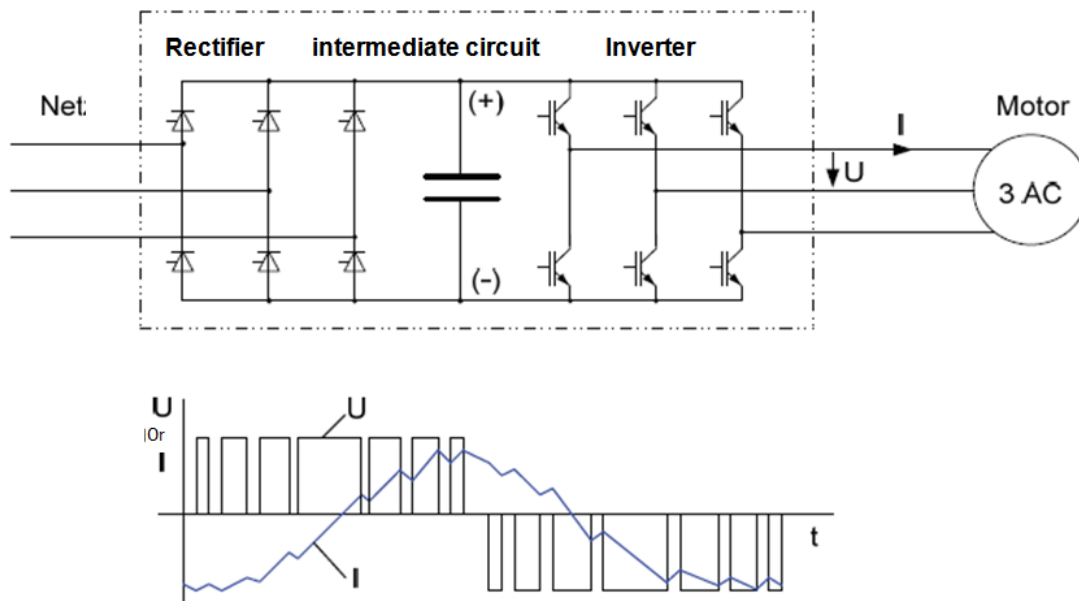


Fig. 3-1: Mode of operation of FESTO frequency converters and basic representation of output voltage U and motor current I

3.1.2 Festo CMMP PFC ("Power Factor Control")

With the help of the PFC, a nearly sinusoidal mains current profile is achieved. In addition, the PFC acts as a boost converter and produces a stabilised intermediate circuit voltage of approx. 360 V even for a mains input voltage of 115 V AC.

The PFC stage is an active mains power converter that is required for conformance to EN 61800-3 for limiting mains harmonics. The PFC stage also performs active regulation of the intermediate circuit voltage. The PFC stage operates using the boost chopper principle and provides a regulated nominal intermediate voltage of 360 VDC. This voltage is independent of the quality of the mains voltage, also when the mains voltage fluctuates or with mains grid undervoltage. This is a significant advantage when selecting the servo motor because, compared to a device with passive mains feed, higher speeds are achievable or a higher torque constant can be selected. The active PFC stage in the device also makes it suitable for a wide operating range, with mains voltages as low as 100 VAC. However, the limiting of the effective power consumption due to the permissible maximum current of the PFC stage should be noted.

In operation, the power consumption of the CMMP-AS servo positioning controller is monitored via the PFC stage. The mains current is regulated by an analogue control circuit so that the shape of the curve reflects that of the mains voltage sine wave and the phase shift is 0° . The amplitude is adjusted according to the specified effective power.

A higher-level digital controller regulates the intermediate circuit voltage to an average value of approx. 360 VDC. To relieve the relatively sluggish voltage regulation under changing loads (acceleration/braking of the drive), the power delivered to the motor from the CMMP-AS servo positioning controller is measured and used to pre-control the PFC stage.

3.2 The frequency converter as a high-frequency interference source

The main interference source for high-frequency interference is the fast switching of the IGBTs (insulated gate bipolar transistors) in the motor-side inverter, which causes very steep voltage edges. Each voltage edge produces a pulse-shaped leakage or interference current I_S across the parasitic capacitances (arrangements in which the capacitive coupling of two electrodes is not the direct objective or is undesired) at the inverter output.

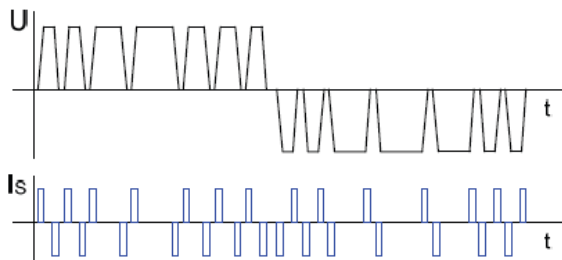


Fig. 3-2: Basic representation of inverter output voltage U and interference current I_S

The interference current I_S flows across the parasitic capacitances C_P from the motor cable and motor winding to ground and must return to its source, the inverter, via a suitable path. On its return path, the interference current I_S flows across the ground impedance Z_E and the mains impedance Z_N , wherein the mains impedance Z_N consists of the parallel connection of the transformer impedance (line-to-ground) and parasitic capacitances of the mains supply cable. The interference current itself and the interference voltage drops caused at the impedances Z_E and Z_N can influence or interfere with the mains voltage and thus other devices connected to the same mains and grounding system.

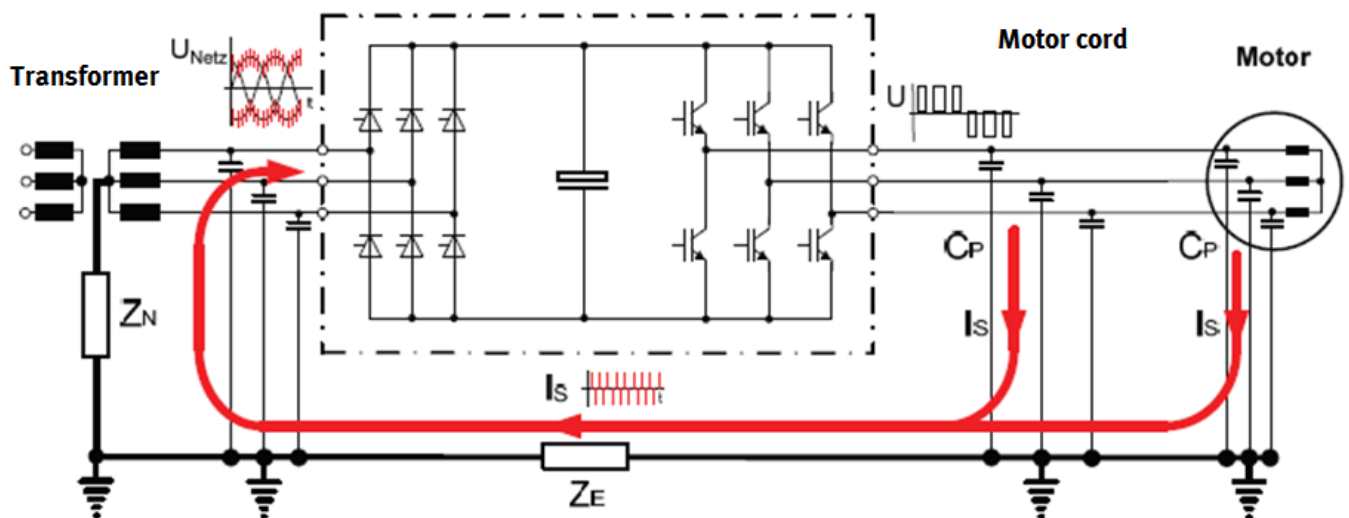


Fig. 3-3: Basic representation of the emergence of the interference current I_S and its path back to the inverter

3.2.1 Measures for reducing the high-frequency conducted interference emission

If unshielded motor cables are used, the interference current I_s – as shown in the preceding figure – flows back to the inverter in an undefined manner across cable racks, the grounding system, and the mains impedance and can produce significant interference voltages across the impedances Z_E and Z_N because of its high frequency. The interference effect on the grounding system and the mains by the interference current I_s can be significantly reduced by leading the high-frequency interference current I_s back to the inverter through a **shielded motor cable** in such a way that the voltage drops across the impedances Z_E and Z_N are minimized. In **combination with the mains filter or EMC filter (radio-interference filter) that comes standard in the FESTO devices** according to category C3 of EMC product standard EN 61800-3, a low-impedance return path to the inverter within the power drive system is provided for the high-frequency interference current I_s so that most of the interference current I_s flows across the shield of the motor cable, the PE or EMC shield bus bar, and the mains filter. The standard mains filters are installed in the FESTO converters. As a result, the grounding system and the mains are loaded with much lower interference currents and the interference emission is thus significantly reduced. Additional mains filters for cable lengths > 15 m or special requirements are available under part number #176041 (single-phase MRC-NF-1-BSM-BSC) or part number #176042 (three-phase MRC-NF-3-BSM-BSC).

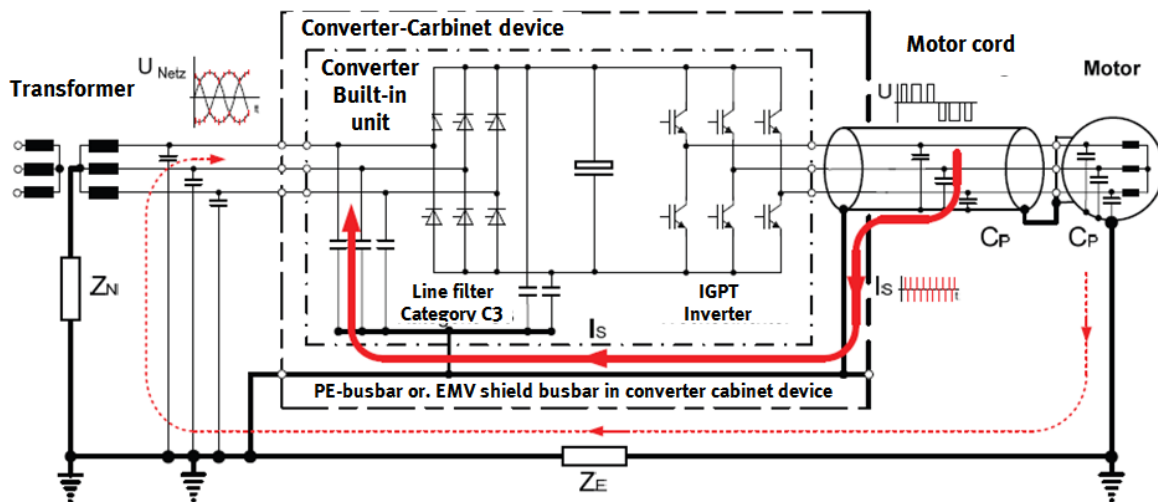


Fig. 3-4: Path of the interference current if a shielded motor cable is used in combination with an EMC filter in the converter

In order for the intended interference reduction to be achieved, the installation must ensure that the interference current I_s , on its way from the shield of the motor cable across the PE or EMC shield bus bar of the converter cabinet and the mains filter, finds a continuous low-inductance path back to the inverter that is not interrupted by any weak points of high impedance. Therefore, conformance to EMC product standard EN 61800-3 requires a shielded cable as the connecting cable between the converter and the motor.

Shielded cables are ideal, such as the cable from FESTO shown, NEBM-T1G7-E-1-N-LE7.



Fig. 3-5: Shielded three-phase cable with PE conductor

Good, low-inductance screen contact is always required. This is achieved by establishing extensive contact of the shield with the terminal box of the motor using EMC cable glands and by establishing extensive contact with the EMC shield bus bar at the FESTO converter using EMC shield clamps. An alternative shield connection to the grounding bus bar of the converter exclusively by means of long braided pigtails is less advisable, especially if the pigtails are very long, because this type of shield connection provides relatively high resistance for high-frequency currents.

Other additional shield contacts between the converter and the motor, e.g., in intermediate terminal boxes, absolutely must be avoided, because otherwise the shield can perform its task of keeping the interference currents in the power drive system only to a very limited extent.

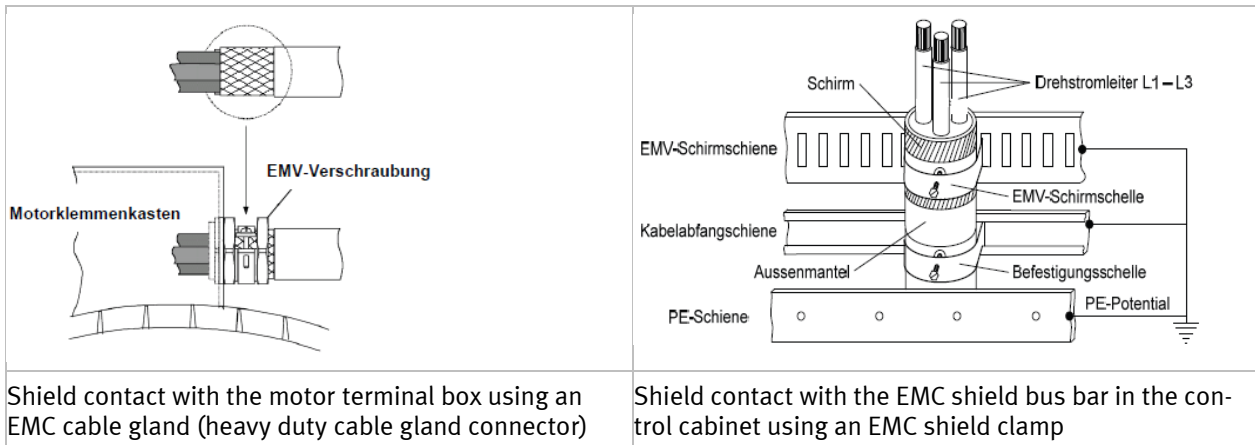


Fig. 3-6: Shield contact

Within the cabinet devices, the housings of the converters that contain the standard mains filter for category C3 must be connected to the grounding bus bar and the EMC shield bus bar in such a way as to ensure the lowest inductance possible. An extensive connection can be made using the metal construction of the cabinet devices, wherein the contact surfaces must be bare metal and must have a minimum cross section of several cm² per contact point. Alternatively, this connection can be made with short ground wires of large cross section (≥ 95 mm²) that have a low impedance over a wide frequency range, such as fine-wire braided round copper lines or fine-wire braided flat copper ribbons.

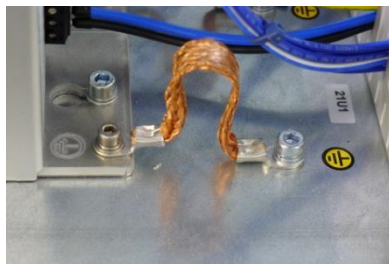


Fig. 3-7: Grounding with flat copper ribbon on base plate

FESTO converters are designed to ensure a sufficiently low-inductance connection of the housings of the installed devices to the grounding bus bar and the EMC shield bus bar.

If an optional mains filter of category C2 is used, the same rules applying to the connection of the installed devices to the grounding bus bar and the EMC shield bus bar also apply to the connection of the mains filter to the grounding bus bar and the EMC shield bus bar. The optional mains filter of category C2 must always be used in combination with a mains choke, because otherwise the full effectiveness of the mains filter would not be achieved.

3.2.2 Measures for reducing the high-frequency electromagnetic interference emission

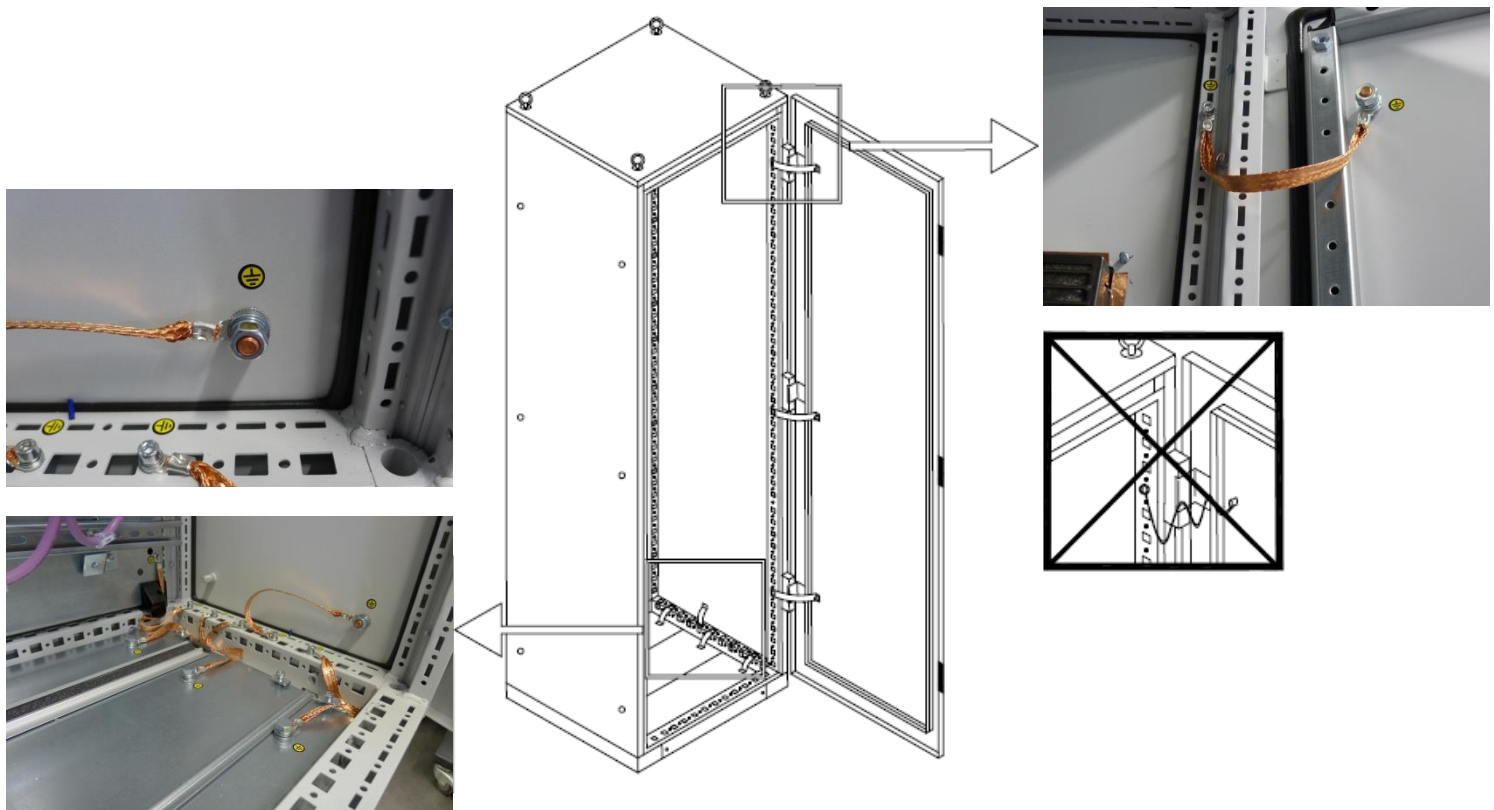
In addition to the steep switching edges of the IGBTs in the inverter, switched-mode power supplies clocked at high frequency and microprocessors clocked at extremely high frequency in the control part of the FESTO converters are causes of the high-frequency electromagnetic radiated interference.

In addition to the use of shielded motor and signal cables, the shields of which must be extensively attached at both ends, **closed cabinets** acting as a Faraday cage are also required in order to limit this radiated interference.

If FESTO converters are installed in open cabinet frames, the radiated interference of the converters is not sufficiently limited. In order to adhere to category C3 of EMC product standard EN 61800-3, a suitable design of the operating space must then ensure sufficient screening (e.g., installing the open cabinet frame in a closed metal container).

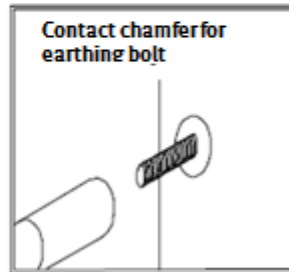
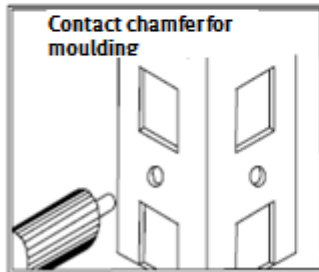
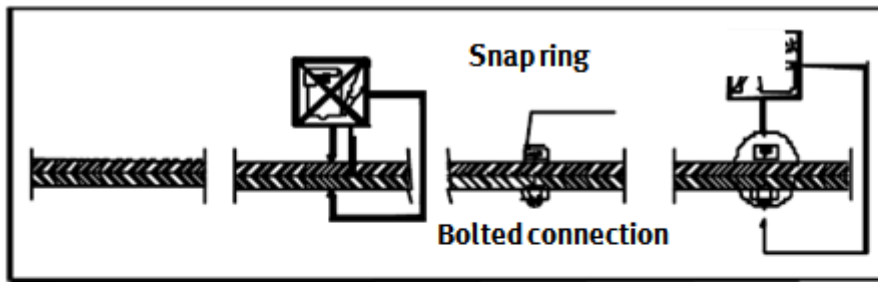
If FESTO converters are installed in standard control cabinets with coated sheet steel, the radiated interference according to category C3 of EMC product standard EN 61800-3 can be adhered to by observing the following measures:

- All metal housing parts and mounting plates in the control cabinet must be connected to each other and to the cabinet frame as extensively as possible and in a highly conductive manner. Extensive metal connections or connections by means of wide grounding straps suitable for high frequency are optimal.
- Cabinet covers such as doors, side plates, back walls, roof plates and bottom plates must also be connected to the cabinet frame in a highly conductive manner, ideally by means of wide grounding straps suitable for high frequency.
- All screw connections on painted or anodised metal parts must either have special contact discs, which penetrate the non-conducting surface and thus establish conductive metal contact, or the non-conducting surface between the parts to be connected must be removed before the installation to ensure an extensive metal connection.
- For EMC reasons, ventilation openings should be kept as small as possible. However, adequate cabinet ventilation requires certain minimum cross sections because of the laws of flow mechanics, so a reasonable compromise must be found. Therefore, ventilation grilles with typical opening cross sections of approx. 190 mm² per hole are used for FESTO cabinet devices.

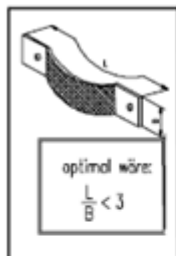


EMV flat belt
Contact housing part

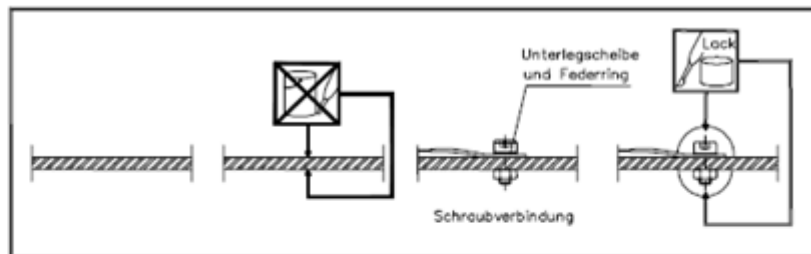
Fig. 3-8: Connection of doors, side walls, back walls, roof plates and bottom plates to the cabinet frame



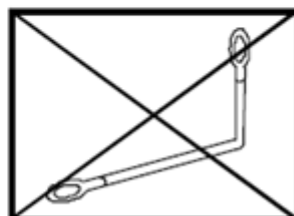
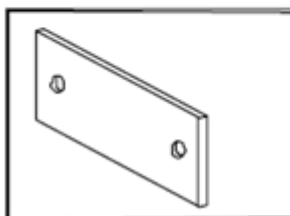
Screw connection of metal parts



Großflächig leitende Befestigung niederinduktiv (daher Rechteck-besser als Rundleiter)



Connection of ribbon cable



Yellow/green potential compensation

Connection potential compensation

Fig. 3-9: Other ground connections

The FESTO converters and FESTO cabinet components already adhere to the radiated interference limits of category C3 according to EMC product standard EN 61800-3 as delivered from the factory. A prerequisite for this is that the devices are operated with closed cabinet doors.

3.3 The frequency converter as a low-frequency interference source (network feedback)

If FESTO converters are connected to a network with purely sinusoidal voltage (generator, transformer), non-sinusoidal network currents flow because of the nonlinear characteristic of the components in the network-side rectifier circuits. These currents distort the voltage at the network connection point PCC (point of common coupling). This low-frequency, conducted interference with the network voltage is called network feedback.

3.3.1 Measures for reducing the low-frequency interference emission (network feedback)

The network feedback of FESTO converters essentially depends on the circuit of the network-side rectifier. Therefore, the selection or configuration of the rectifier can influence the magnitude of the network feedback. 6-pulse rectifiers, which are used in the converters CMMP-AS (three-phase), have the greatest network feedback.

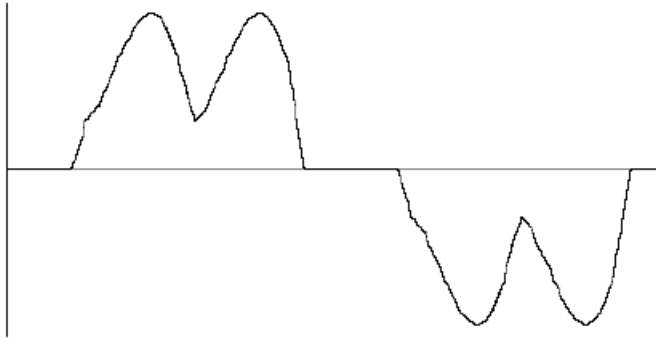


Fig. 3-10: Typical network current for 6-pulse rectifiers

The network feedback is significantly reduced by the use of line harmonics filters in the three-phase converters CMMP-AS.

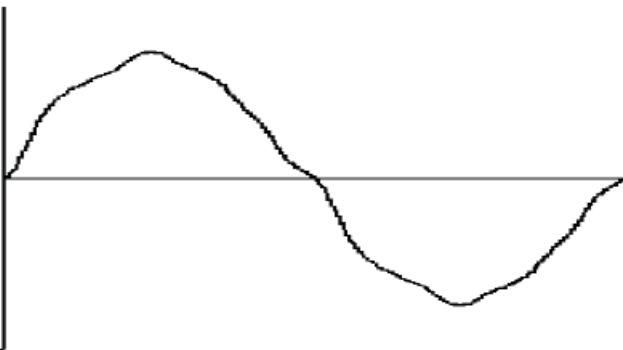


Fig. 3-11: Typical network current for 6-pulse rectifiers with line harmonics filters

Active rectifiers, which are used in the converters CMMS and the converters CMMP-AS single-phase, cause the lowest network feedback. Here, the network current and network voltage are nearly sinusoidal.

3.4 The frequency converter as an interference sink

3.4.1 Influencing mechanisms

The interference produced by the interference sources can be coupled into the interference sinks along different coupling paths. A distinction is made between galvanic, capacitive, inductive and electromagnetic interference coupling.

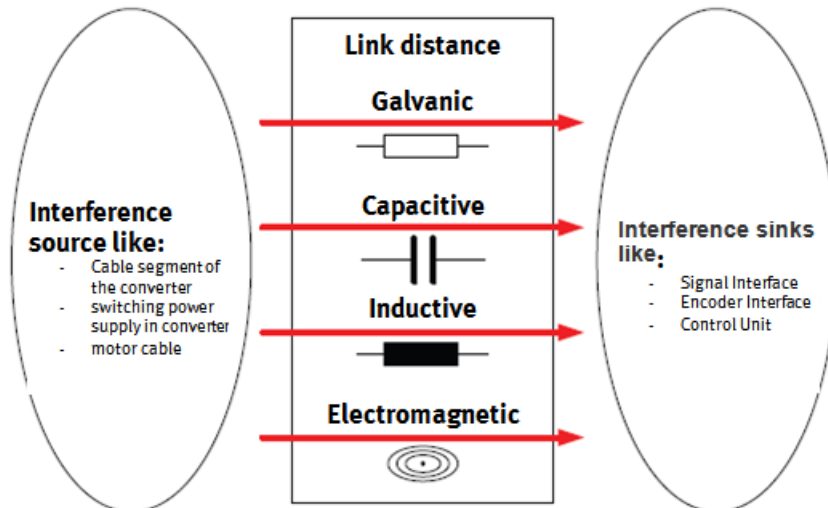


Fig. 3-12: Illustration of the possible coupling paths between interference sources and interference sinks
Galvanic coupling

Galvanic coupling occurs when several circuits jointly use a conductor, e.g., a common ground cable or a common ground connection. At impedance Z of the common conductor, current I_1 of module 1 produces a voltage drop ΔU_1 , by which the voltage changes at the terminals of module 2. Conversely, at impedance Z of the common conductor, current I_2 of module 2 produces a voltage drop ΔU_2 , by which the voltage changes at the terminals of module 1.

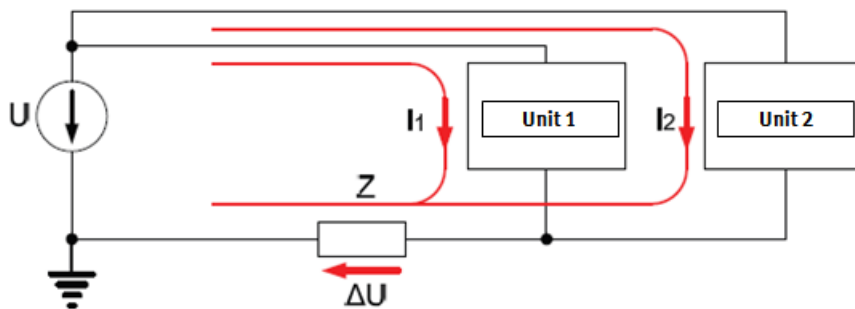


Fig. 3-13: Galvanic coupling of two circuits via the impedance of a commonly used conductor

If for example voltage source U is a 24-V power supply unit that supplies two modules with direct voltage, module 1 is a switched-mode power supply having a periodic, pulse-shaped current consumption, and module 2 is a sensitive interface module for analogue signal transmission, then module 1 acts as an interference source. Module 1 interferes with the supply voltage at the terminals of the interface module acting as an interference sink by means of the galvanic coupling, i.e., by means of voltage drop ΔU at the common impedance Z . This interference can negatively influence the quality of the analogue signal transmission.

Measures to reduce galvanic coupling

- Keep the length of the commonly used conductor as short as possible.
- Use large conductor cross sections if the common impedance is largely resistive.
- Use a separate feed conductor and return conductor for each circuit.

Capacitive coupling

Capacitive coupling occurs between mutually insulated conductors that are at different potential. Because of the potential difference, there is an electric field between the conductors, which is described by the capacitance C_k . The magnitude of the capacitance C_k depends on the geometry and the distance of the conductors that are at different potential.

The following figure shows an interference source, which couples an interference current I_s into the interference sink by means of capacitive coupling. Interference current I_s produces a voltage drop at the impedance Z_i of the interference sink and therefore an interference voltage.

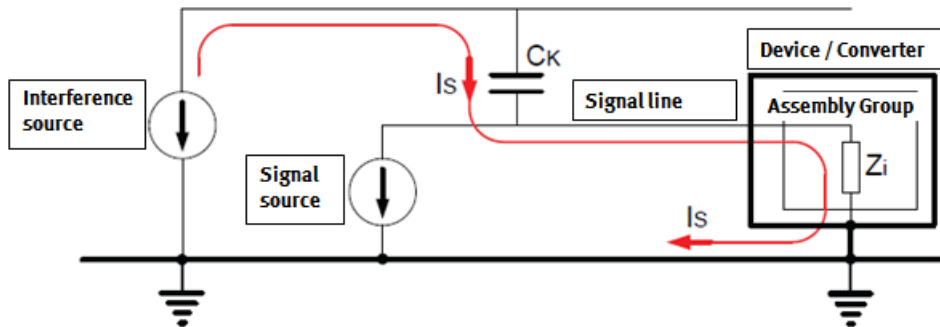


Fig. 3-14: Capacitive coupling of an interference current into a signal line

If for example a motor cable and an unshielded signal line are routed parallel to each other on a cable rack at a small distance over a long length, a very large coupling capacitance C_k results due to the small distance. The motor-side inverter of the frequency converter acting as an interference source couples a pulse-shaped interference current into the signal line via the capacitance C_k with each switching edge. If this interference current flows into the control unit of the converter via the digital inputs, for example, even small interference pulses with a duration of a few microseconds and an amplitude of a few volts can interfere with the digital control of the converter performed by microprocessors and lead to a malfunction of the converter.

Measures to reduce capacitive coupling

- Keep the distance between the interfering line and the line interfered with as large as possible.
- Keep the length of the parallel line routing as short as possible.
- Use shielded signal lines.

The most effective measure is **consistent separation of power cables and signal lines in combination with shielding of the signal lines**. The interference current I_s is now coupled into the shield and flows to ground via the shield and the housing of the device or converter without interfering with the internal circuits.

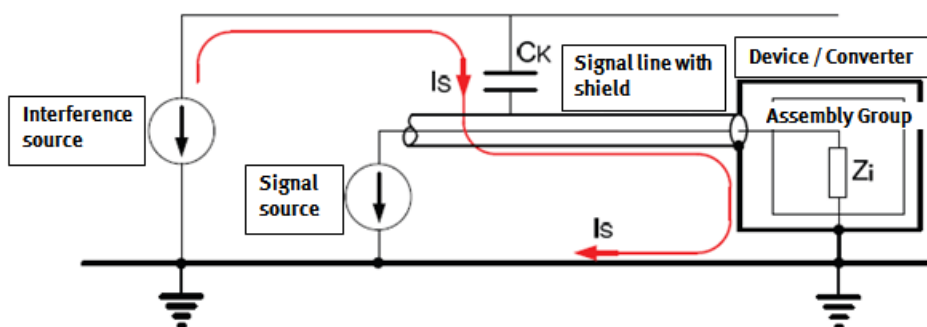


Fig. 3-15: Reduction of the interference coupling by using a shielded signal line

A prerequisite for optimal effectiveness of the shield is extensive, low-inductance shield attachment.

- For **digital** signal lines, the shield must always be extensively attached at both ends – i.e., to the transmitter and to the receiver.
- For **analogue** signal lines, low-frequency interference can result due to attachment of the shield at both ends (ground loops). In this case, the shield must be attached only at one end to the converter.

FESTO converters are designed with appropriate shield attachment options:

Shield clamps are attached to each FESTO device for optimal shield connection of the signal lines.

In addition, the shields can be fastened using cable ties.

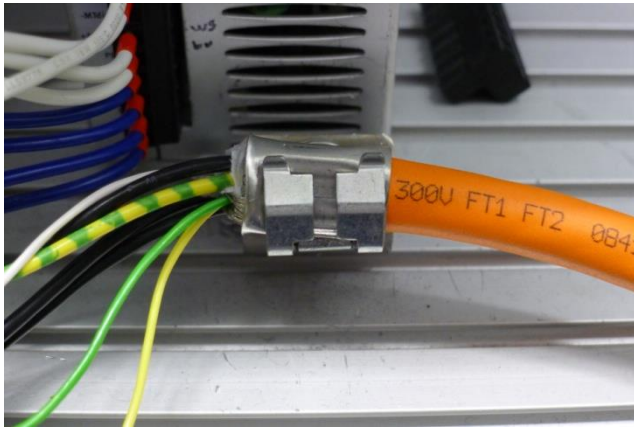


Fig. 3-16: Shield attachment options of FESTO converters

From an EMC perspective, intermediate terminals should be avoided wherever possible, because each shield interruption decreases the shield effectiveness. If intermediate terminals are absolutely unavoidable in a particular case, the shields of the signal lines must be well attached to clamping rails immediately before and after the intermediate terminals. The clamping rails must be extensively connected to the cabinet housing at both ends in a highly conductive manner.

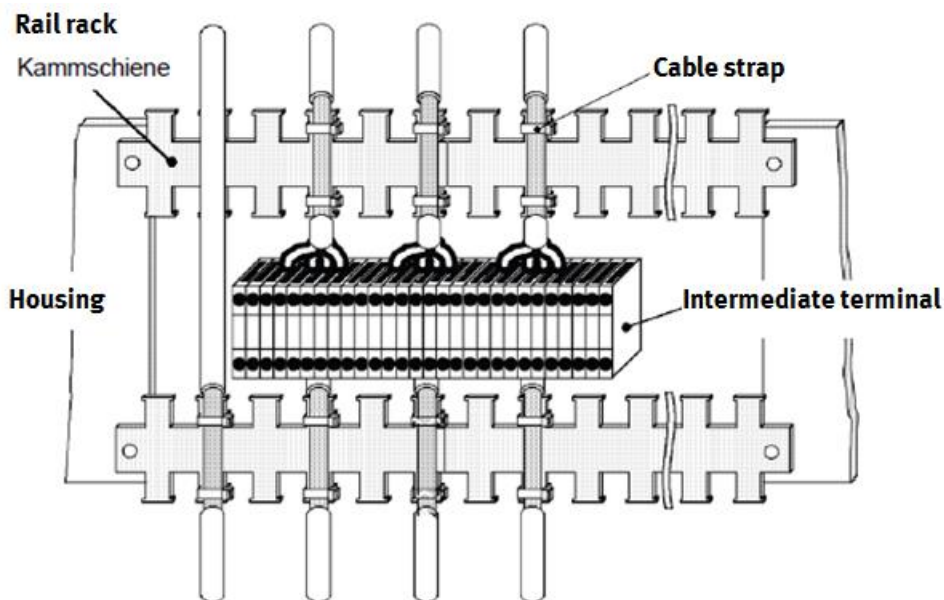


Fig. 3-17: Shield connection of the signal lines in the control cabinet when intermediate terminals are used

Inductive coupling

Inductive coupling occurs between circuits or conductor loops through which current flows. If an alternating current flows in a conductor loop, the alternating current produces an alternating magnetic field. The alternating magnetic field passes through the other conductor loop and induces a voltage there. The magnitude of the inductive coupling is described by the mutual inductance M_k and depends on the geometry and the distance of the conductor loops.

The following figure shows a circuit fed by an interference source. The circuit induces an interference voltage U_s in a signal circuit by means of a magnetic interference field B_s . The interference voltage U_s drives an interference current I_s , which produces a voltage drop at the impedance Z_i of the interference sink and therefore interference.

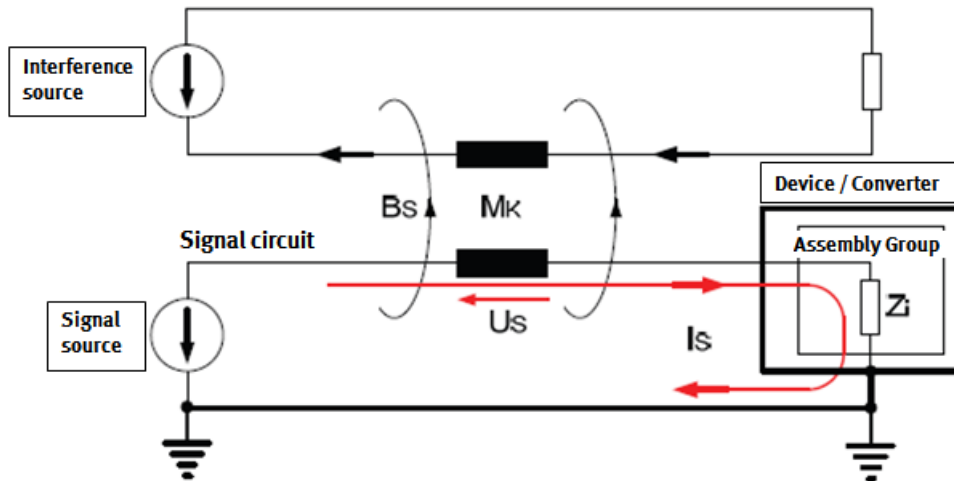


Fig. 3-18: Inductive coupling of an interference voltage into a signal circuit

If for example the interference source is a braking resistor connected to the intermediate circuit of the converter, a high, pulsed current flows to the braking resistor during the braking operation. Because of its magnitude and its high current rise rate di/dt , this pulsed current induces a pulsed interference voltage in the signal circuit, which results in an interference current. If this interference current flows into the interface module of the converter, e.g., through the digital inputs, malfunctions such as sporadic interference switch-offs can be triggered.

Measures to reduce inductive coupling

- Keep the distance between the conductor loops as large as possible.
- Keep the area of the conductor loops as small as possible, i.e., route the feed conductor and return conductor parallel to each other as closely to each other as possible or, for a signal line, use twisted lines.
- Use shielded signal lines. The shield must be attached at both ends.

Electromagnetic coupling (radiation coupling)

Electromagnetic coupling or radiation coupling is interference coupling by means of an emitted electromagnetic field. Typical interference sources are:

- Mobile radio devices
- Mobile phones
- Devices that operate with spark gaps

(spark plugs, welding devices, contactors and switches during the opening of the switch contacts)

Measures to reduce electromagnetic coupling

The electromagnetic fields are in the high-frequency range. Therefore, the shielding measures for reducing radiated interference coupling listed below must be designed in such a way that they are also effective at high frequencies:

- Use metal control cabinets whose individual parts (cabinet frame, walls, doors, etc.) are connected to each other in a highly conductive manner.
- For devices and modules, use metal housings that are connected to each other and to the cabinet frame in a highly conductive manner.
- Use shielded lines having fine-wire braided shields suitable for high frequencies.
- Use ferrite cores (sheath current filters), e.g., in the form of split ferrites, on signal lines, feed lines and return lines

3.5 EMC-compliant construction

The basic principles of the EMC of the frequency converter were described in the preceding section. Interference sources and interference sinks, the various coupling mechanisms, and basic measures for reducing interference emission and interference coupling were discussed. Building on these principal relationships, the following section compiles all the important rules for the EMC-compliant construction of control cabinets and the EMC-compliant installation of power drives.

Finally, the practical application of these rules is illustrated using typical construction examples with FESTO installation devices.

3.5.1 Zone concept within the control cabinet

Interference suppression measures within the control cabinet can be implemented most easily and inexpensively by spatially separating interference sources and interference sinks from each other. This separation must already be considered during the planning of the control cabinet. First, it must be determined whether each device used is a potential interference source or an interference sink.

- Typical interference sources are frequency converters, brake units, switched-mode power supplies and contactor coils.
- Typical interference sinks are automation devices, encoders and sensors, and their evaluation electronics.

Then the entire control cabinet is divided into EMC zones and the devices are assigned to the zones. The following example should explain the zone concept in more detail.

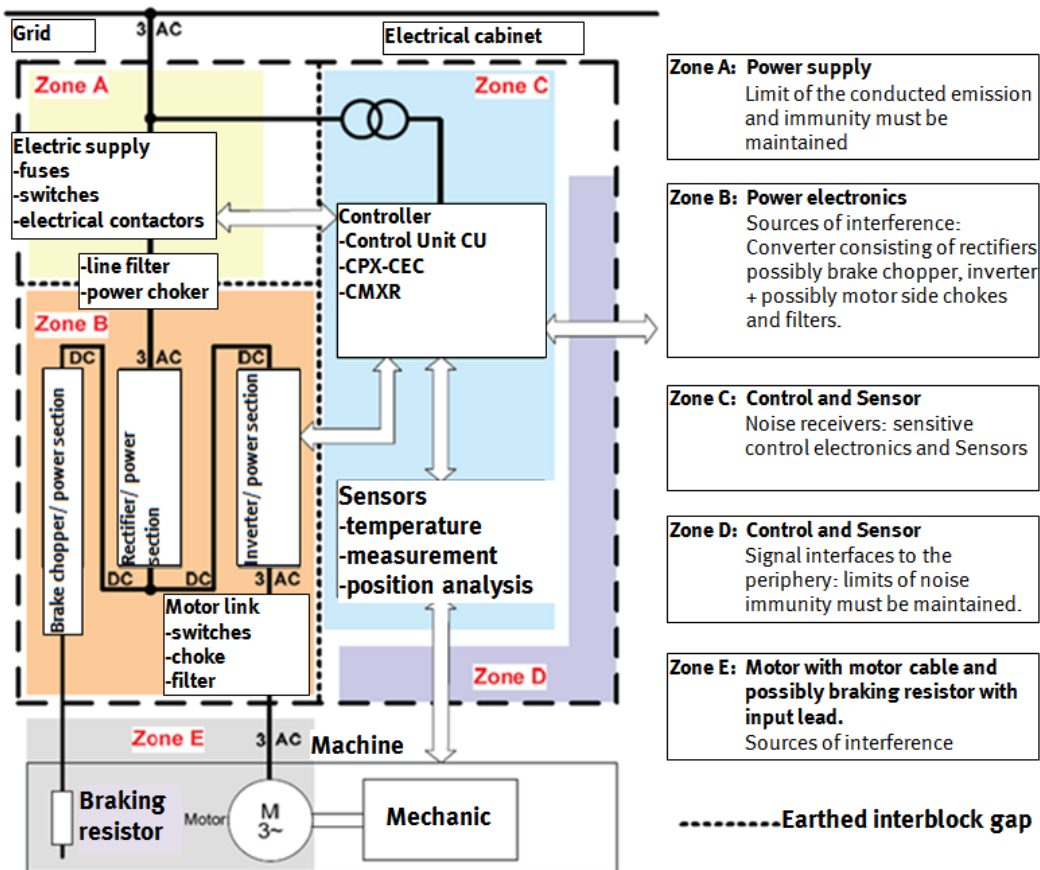
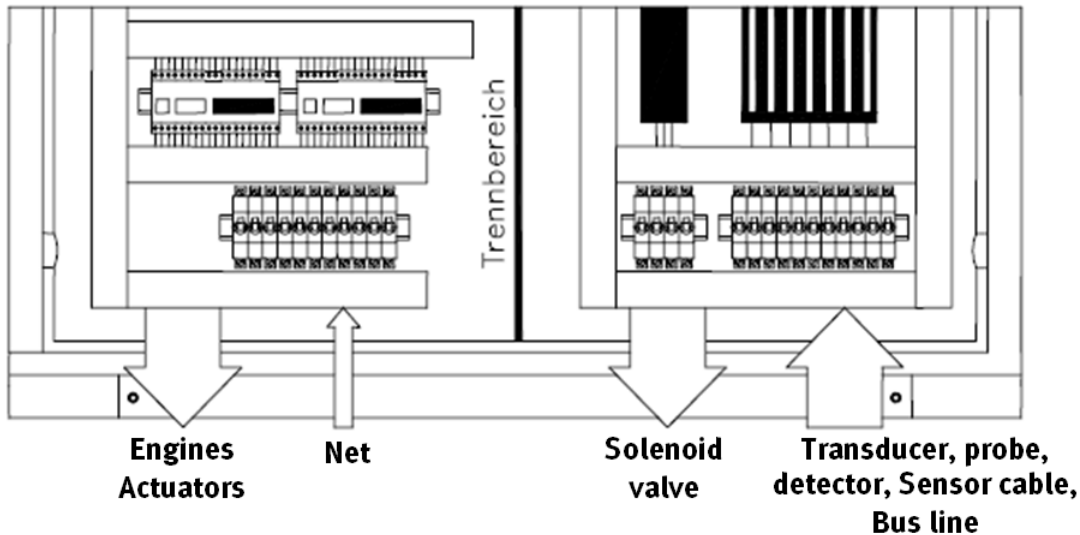


Fig. 3-19: Example of the division of the control cabinet or power drive system into EMC zones



Device- and Clamp order

In each zone, there are specific requirements regarding interference emission and interference immunity. The zones must be electromagnetically decoupled. This decoupling can be achieved, e.g., by means of large spatial distances (approx. 25 cm). However, decoupling by means of separate metal housings or extensive separating plates is better and more compact. Cables within each zone can be unshielded. Cables of different zones must be separated and must not be routed in common cable harnesses or cable ducts. It may be necessary to use filters and/or coupling modules at the interfaces of the zones. Coupling modules with galvanic isolation can effectively prevent the spread of interference among the zones. All communication and signal lines that leave the control cabinet must be shielded. For long analogue signal lines, isolation amplifiers must additionally be used. Adequate contact surfaces that connect the braided shield to the control cabinet ground extensively and with low impedance must be provided for the cable shields. It must be noted here that potential differences regarding the ground potential must not arise between the zones. They must be avoided in order to keep impermissibly high compensating currents away from the cable shields.

3.5.2 Construction of the control cabinet

All metal parts of the control cabinet (side plates, back walls, roof plates and bottom plates) must be connected to the cabinet frame in a highly electrically conductive manner, preferably extensively or by means of a large number of punctiform screw connections, in order to produce a Faraday cage.

The cabinet doors must be connected to the cabinet frame, preferably at the top, middle or bottom, by means of short, wide, fine-wire braided ground straps in a highly conductive manner.

The grounding bus bar and the EMC shield bus bar must be extensively connected to the cabinet frame in a highly conductive manner.

All metal housings of the devices and additional components (e.g., converter chassis, mains filter, control unit, terminal module, sensor module) installed in the cabinet must be extensively connected to the cabinet frame in a highly conductive manner. It is best to install these devices and additional components on a highly conductive bare-metal mounting plate, which in turn must be extensively connected to the cabinet frame and in particular to the grounding bus bar and EMC shield bus bar in a highly conductive manner. For liquid-cooled systems, all metal piping and all metal components of the recooling system must also be connected to the cabinet frame and to the grounding bus bar in a highly conductive manner.

All connections must be permanent. Screw connections on painted or anodised metal parts must have special contact discs, which penetrate the insulating surface and thus establish conductive metal contact, or the insulating surface must be removed at the contact points.

The coils of contactors, relays, solenoid valves and motor holding brakes must be connected to interference suppressors in order to dampen high-frequency emissions during switch-off (RC elements or varistors for coils operated with alternating current and free-wheeling diodes or varistors for coils operated with direct current). The interference suppressors must be connected directly to the coil.

3.5.3 Wiring in the control cabinet

All power cables of the power drive (mains power cables, intermediate circuit cables, connecting cables between converters and associated braking resistors, and motor cables) must be routed with spatial separation from the signal and data transmission lines. The minimum distance should be approx. 25 cm. Alternatively, decoupling can be achieved in the control cabinet by using separating plates connected to the mounting plate in a highly conductive manner.

Filtered mains power cables with low noise, i.e., mains power cables from the mains to the mains filter, must be routed separately from unfiltered power cables with a high noise level (mains power cables between the mains filter and the rectifier, intermediate circuit cables, connecting cables between converters and associated braking resistors, and motor cables).

Signal and data transmission lines and filtered mains power cables must cross unfiltered power cables only at right angles in order to minimise interference coupling.

All cable lengths must be kept as short as possible, and unnecessary cable lengths must be avoided.

All cables must be routed as closely as possible to grounded housing parts such as mounting plates or the cabinet frame. This reduces both the interference emission and the interference coupling.

Signal and data transmission lines and associated potential equalisation lines must always be routed parallel to each other and at the smallest possible distance.

If unshielded single-conductor lines are used within a zone, the feed and return conductors must always be routed parallel to each other at the smallest possible distance or twisted together.

Reserved conductors of signal and data transmission lines must be grounded at both ends in order to achieve an additional shielding effect.

Signal and data transmission lines should be routed only at one location (e.g., from below) in the cabinet.

3.5.4 Cables outside of the control cabinet

All power cables (mains power cables, intermediate circuit cables, connecting cables between converters and associated braking resistors, and motor cables) must be routed with spatial separation from the signal and data transmission lines. The minimum distance should be approx. 25 cm.

The power cable between a converter and a motor must be a shielded cable in order to adhere to categories C2 and C3 according to EN 61800-3 and should be a symmetrical 3-conductor three-phase cable if possible for large power values.

The shielded power cable to the motor must be routed separately from the cables to the motor temperature sensors (PTCs) and to the resolver/encoder, because the latter must be treated as signal lines.

Signal and data transmission lines must be shielded in order to minimise capacitive, inductive and radiation interference coupling.

Especially sensitive signal lines such as setpoint and actual value cables, in particular tachometer, encoder and resolver cables, must be routed without interruption and with optimal shield attachment at both ends.

3.5.5 Cable shields

Shielded cables must be fine-wire braided shields if possible, e.g., cables of type NEBM. Less finely braided shields are not as effective. Foil shields are significantly less effective and therefore unsuitable.

Shields must be extensively connected to the grounded housings in a highly conductive manner at both ends. This is the only way to minimise capacitive, inductive and radiation interference coupling.

Cable shields should be attached directly after the cable enters the cabinet, if possible. For power cables, the EMC shield bus bars must be used. For signal and data transmission lines, the shield attachment options provided in the installation devices and cabinet devices must be used.

If possible, cable shields should not be interrupted by intermediate terminals.

For power cables as well as for signal and data transmission lines, the cable shields should be fastened by means of appropriate EMC shield clamps. The shield clamps must connect the shield to the EMC shield bus bar or to the shield attachment option for signal lines extensively and with low inductance.

Only metal or metallised plug housings should be used at the plug connections of shielded data transmission lines (e.g., CAN bus cables).

3.5.6 Potential equalisation in the control cabinet, in the power drive system and in the installation

Potential is equalised within a control cabinet element in that all metal housings of the devices and additional components (e.g., converter chassis, mains filter, control unit, terminal module, sensor module) installed in the cabinet element are connected extensively to the cabinet frame and the grounding or EMC shield bus bar of the cabinet element in a highly conductive manner by means of a suitable mounting plate. For liquid-cooled systems, this also applies to all metal piping and all metal components of the recooling system.

For large cabinet devices and for the modular cabinet device system, potential is equalised among several cabinet elements by means of a grounding bus bar passing through all cabinet elements. In addition, the frames of the individual cabinet elements must be screwed to each other several times in a highly conductive manner, and contact discs must be used. If very long cabinet rows are installed back to back, the two grounding bus bars of the cabinet assembly must be connected to each other as often as possible.

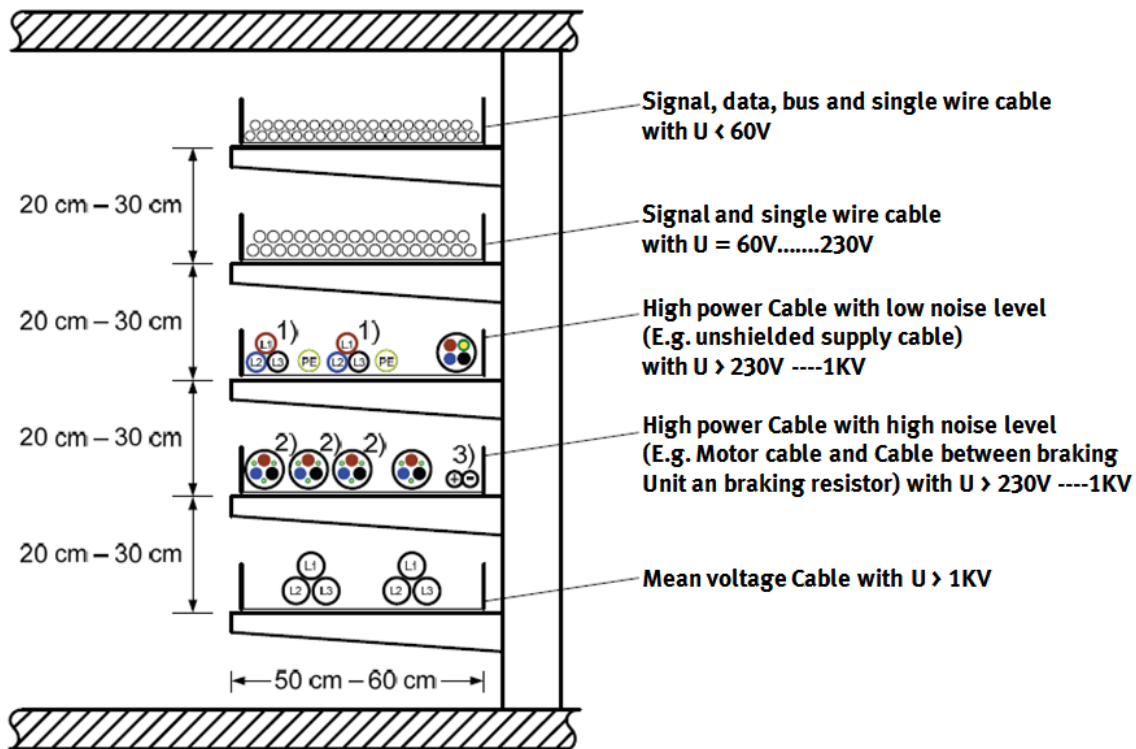
Potential is equalised within the power drive or the system in that all electrical and mechanical power drive components (transformer, converter cabinet, motor, gear unit, machine frame, and piping and recooling system for liquid-cooled systems) are connected to the grounding system. These connections are made with common power grounding cables, which do not need to have any special high-frequency characteristics. In addition to these connections, the inverter – as a source of the high-frequency interference – and all other components of the drive train – motor, gear unit and working machine – must be connected to each other optimally in regard to high frequency. Cables with good high-frequency characteristics must be used for this purpose.

3.5.7 Installation examples

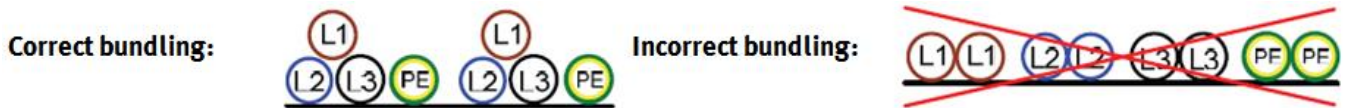
EMC-compliant installation of a control cabinet from FESTO



Fig. 3-20: EMC-compliant construction and installation of a cabinet with installation devices from FESTO
EMC-compliant system-side wiring on cable racks and in cable trays



When wiring three-phase systems using single-conductor lines (e.g., unshielded mains power connecting lines), the three phases L1, L2 and L3 must be symmetrically bundled in order to minimise magnetic stray fields. This also applies especially when several parallel single-conductor lines must be routed per phase of a three-phase system due to high currents. The following diagram illustrates this using the example of a three-phase system having two parallel single-conductor lines per phase:



When wiring direct current cables (intermediate circuit cables or connecting cables between the converters and the associated braking resistors), feed and return conductors must be routed parallel to each other at the smallest possible distance in order to minimise magnetic stray fields.

Checklist for reducing the EMC effects for motor controllers of type CMMx

Please always follow the general guidelines below in order to reduce the EMC effects for motor controllers. In addition, please read and follow the instructions in the hardware manuals for safe and EMC-compliant installation.

- Check the shield connection of the motor cable, especially the connection to the controller (clamping connection). --> Install the end of the motor cable in the clamping connection (spring-force retainer), and use a cable tie if necessary for better contact pressure.
- EMC-compliant operation of the motor "EMMS with terminal connection" is permissible only with the cover closed.
- Check the connections of the encoder and motor cable to the motor and controller:
 - Are the contacts correctly tightened?
 - Are the round plugs correctly screwed?
 - D-sub plug connector correctly screwed?
- Check the grounding between the controller CMMx and the mounting plate and the grounding of the mounting plate in the control cabinet:
 - The connection should be made using a ground strap made of braided wire.
 - Contact surfaces must be free of paint and conductive.
 - Always use star-shaped wiring to the central ground point in the control cabinet.
- Do not use shortened or extended encoder or motor cables.
- If the encoder or motor cables are too long, do not wind them up into a coil, but rather route them loosely.
- If the encoder or motor cables are much too long, route them in different cable ducts made of metal at a safety distance (e.g., 10 cm).
- For plug connector X1, always use shielded cables such as the original cable NEBC-S1G25-K-2.5N-LE26. Unshielded cables act as an antenna and cause interference with the analogue inputs.
- Do not connect the PE and the 24-V GND of the supply voltage of plug connector X9 at the controller or in the immediate vicinity.
- Connect the PE at the controller (X9.7) and the central PE in the control cabinet using a separate cable.
- If you use several protective extra-low voltages, combine the GNDs into a common GND.
- Keep all cables as short as possible, but never shorten pre-assembled cables (e.g., encoder cable), because this can have a negative effect on the EMC.
- The internal filters of the converters are designed for a maximum cable length of
- 15 m for CMMS/D-AS/ST and 25 m for CMMP-AS. For longer cables, external EMC filters must be used. For CMMS-ST and/or CMMS/D-AS, the maximum length is limited to 15 m. The limit is due to the internal design of the controllers. Because of its electronics, the CMMP-AS can correct the voltage drop to the motor encoder over the longer cable length.

