Global Drive
Basic information on controller applications in plants and machinery
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1 Preface

1.1 General information

Our technological world relies ever more on the use of electronic circuits. Frequency inverters, bus systems, measuring sensors etc. are expected to mesh satisfactorily under minimum space requirements. This is possible only if an acceptable degree of electromagnetic compatibility - EMC - is ensured. In this context, it is mainly up to the system designer / equipment manufacturer to ensure the electromagnetic compatibility of system design and wiring. Thorough assessment of the EMC problem requires profound knowledge of the causes and effects of EMC interference. This knowledge allows optimum EMC measures to be derived. This brochure is therefore intended to serve as a guide.

1.2 Cost situation for EMC measures

![Diagram of EMC measures cost development]

Any required EMC measure must be integrated as early as during the design phase. Considering the EMC measures during the design phase results in considerable cost saving. In the commissioning and operating phase these costs rise considerably.
2 EMC - legal foundation

The legal foundation is the EMC Directive and its implementation by the respective EU member states’ existing national law. In Germany, this is the German EMC Act, in force since 1996, and the rules and regulations of its application.

The gist of its central requirement is that the operation of electrical and electronic equipment, systems, or devices must not produce any impermissible mutual interferences.

Within the meaning of the requirements arising from the EMC Directive, there may be varying interpretations at the time of product rating. The EMC behaviour of an electrical or electronic device is essentially determined by

- its interference emissions
- its immunity to interference.

As far as the EMC characteristics of a product are concerned, the manufacturer and / or the party introducing it to the market is always obliged to meet special requirements with respect to information. In their documentation (Operating Instructions), Lenze specify conformity to standards and provide detailed installation instructions.

2.1 EMC product standard for variable-speed electrical drives

EN 61800-3 defines limit values and test procedures for drives and

- covers the electrical drive system from the mains connection to the motor shaft end,
- takes into consideration
  - various distribution channels,
  - various environments (residential / industrial),
  - external connections and internal interfaces.

It defines assessment criteria for the operational behaviour on interference at the external connections and internal interfaces and includes requirements to be met by the immunity to interference in accordance with the environment at the place of use.

2.2 Place of use

The place of use is divided into two so-called environments:

Environment 1
Residential, business, and industrial: Environment that contains residential areas and facilities that are connected directly without adapter transformer to a low-voltage mains that supplies residential buildings.

Environment 1
Industrial: Facilities that are not directly connected to a low-voltage mains supplying residential areas.
2.3 EN 61800-3 requirements on interference emission

EN 61800-3 defines limit values depending on the environments at the place of use.

For the low-frequency range (< 9 kHz), limit values are defined for
- harmonics (EN 61000-3-2/-12)
- voltage fluctuations / flickering (EN 61000-3-3/-11)
- mains voltage commutation notches (EN 60146-1-1)

For the high-frequency range (> 9 kHz), limit values are defined for
- interference voltages (EN 55011 or EN 55022)
- interfering radiations (EN 55011 or EN 55022)

In addition to the functional task of a component, machine or system, EMC measures, too, must be taken into consideration as early as during the planning phase. Only during that stage can EMC measures be integrated with maximum cost efficiency. During the test phase or as late as during operation, the possible measures are drastically reduced, resulting in rising costs (see section 1.2).

The ultimately responsible for adherence to the standards (CE mark) is the party who “introduces a machine or system to the market”. It is therefore essential that the manufacturer or builder of a machine or system takes steps to ensure as early as during component acquisition that EMC measures are considered and information is available as to how to reach compliance with the EMC Directive.

![Interference level](image-url)

**Fig. 2 Requirements for interference emission**
## Interference ranges for frequency inverters

### 3 Interference range of frequency inverters

#### Overview - frequency inverter interference ranges

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Mains current harmonics</th>
<th>Interference emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conducted</td>
<td>Conducted</td>
</tr>
<tr>
<td><strong>Cause</strong></td>
<td>0 ... 2.5 m</td>
<td>150 kHz ... 30 MHz</td>
</tr>
<tr>
<td></td>
<td>Non-sinusoidal mains current</td>
<td>High-speed switching of output stages and switched-mode power supplies. Their electrical connection results in interference injection to the mains input.</td>
</tr>
<tr>
<td><strong>Effect</strong></td>
<td>Increased eff. mains current</td>
<td>Interference injection on the mains side into other consumers on the same mains (electrical connection)</td>
</tr>
<tr>
<td></td>
<td>Additional temperature rise in mains supply transformers</td>
<td>RFI filter on the mains side (internal / external)</td>
</tr>
<tr>
<td><strong>Countermeasures</strong></td>
<td>Mains choke</td>
<td>PFC (Power-Factor-Correction)</td>
</tr>
<tr>
<td></td>
<td>EN 61800-3</td>
<td>EN 55011</td>
</tr>
<tr>
<td>Standards for limit class</td>
<td>EN 55022</td>
<td>EN 55022</td>
</tr>
<tr>
<td>A (industrial)</td>
<td>EN 61000-3-2: Electrical equipment</td>
<td>Optimum shield connection</td>
</tr>
<tr>
<td></td>
<td>Mains current &lt; 16 A or</td>
<td>Short unsheilded wire ends</td>
</tr>
<tr>
<td>Standards for limit class</td>
<td>Input power &lt; 1 kW</td>
<td></td>
</tr>
<tr>
<td>B (residential)</td>
<td>EN 55011</td>
<td></td>
</tr>
</tbody>
</table>

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**Fig. 3** Power unit of the DC bus inverter

- **A** Uncontrolled input rectifier
- **B** DC bus
- **C** Three-phase inverter
- **①** Power-on protection
- **②** DC bus capacitors
4 EMC interference injections

The injection of EMC interference is characterised by different coupling mechanisms. The respective coupling mechanism is the “transmission path” between interference source and potentially susceptible equipment.

There are 4 different coupling mechanisms:

- Conductive coupling
- Capacitive coupling
- Inductive coupling
- Radiant coupling*

* Combination of capacitive and inductive coupling

Fig. 4 EMC: Coupling mechanisms

The degree of intensity of the interference injection may be reduced by various different measures:

At the transmitter
- Shielding
- Filters

At the coupling mechanism
- Shielding
- Topology
- Optical waveguide (electrical isolation)

At the receiver
- Shielding
- Filters
- Circuitry arrangement

Interference source (emitter)

Coupling mechanism (path)

Potentially susceptible equipment (receiver)
4.1 Conductive coupling

Conductive coupling is the result of several power circuits using the same line sections.

Causes
- Frame and earth connections
- Coupling of various power circuits
- Earth loops

Countermeasures
- Short joint reference conductors
- Electrical isolation of the systems (transformer, relays...)

4.2 Capacitive coupling

Capacitive coupling occurs due to the impact of electrical fields on adjacent cables.

Causes
- High-voltage / signal cables
- Switching of inductances
- Parallel cable arrangement

Countermeasures
- Increase distance between cables
- Reduce parallel cable length
- Shield cables
- Reduce rate of voltage rise

4.3 Inductive coupling

Inductive coupling occurs due to the impact of magnetic fields on adjacent cables.

Causes
- High-voltage current switching
- Switching of capacitances
- Parallel cable arrangement

Countermeasures
- Increase distance between cables
- Reduce parallel cable length
- Twist forward and return conductors
- Reduce rate of current rise
5 Shielding

5.1 Shield connection

The quality of shielding is determined by:
- a good shield connection
  - a contact surface as large as possible
- a low resistance:
  - Only use shields with tin-plated or nickel-plated copper braids!
  - Shields of steel braid are not suitable.

5.2 Shielding - what do you need to consider?

- Always connect the shield to the conductive and grounded mounting plate with a surface as large as possible via a conductive clamp.
- Connect the shield directly to the corresponding device shield sheet.
- Do not only connect the shield to the cable rail.
- The unshielded cable ends must be as short as possible.

- Short unshielded cable ends
- Terminals must be separated, minimum distance: 100 mm
- Minimum distance between the shield clamps for control cable and motor cable: 50 mm

Fig. 5 Shielding for frequency inverters
5.3 Motor cables

- If the motor cable must be interrupted by chokes or terminals, the unshielded cable must not be longer than 40 - max. 100 m (depending on the cable cross-section).
- If the motor cable must be interrupted by contactors, switches, or terminals, these must be separated from the other components (with a min. distance of 100 mm).
- In case of cable lengths up to 500 mm a second shield (shield connection) is not required.

![Motor supply cable and Cable gland](image)

5.4 Control cables

- The cables of the analog and digital inputs and outputs must be shielded. If short (up to 200 mm) and unshielded cables are used, they must be twisted.
- In case of the analog cables the shield must only be connected to the controller.
- In unfavorable conditions (very long cable, high interferences) it is possible in case of analog cables to connect one shield end to PE via a capacitor (e.g. 10 nF/250 V) to have a better shielding effect (see sketch).
- In case of digital cables the shield must be connected on both sides.
- The shields of the control cables must have a minimum distance of 50 mm to the shield connections of the motor cables and DC cables.

![Shielding of long, analog control cables](image)
6 Arrangement according to EMC requirements

6.1 Specification for shielded cables for arrangement according to EMC

6.1.1 Motor cable design

- Only use shielded, four-core motor cable (core U, V, W, PE and overall shield).
- Cables with a YCY copper braid have a good shielding effect, cables with SY steel-tape armour are less suitable (high shield resistance).
- The contact ratio of the braid:
  - At least 70% to 80% with overlap angle of 90°.
- **Use low-capacitance cables** to reduce the discharge currents.
  - The values depend on the cable cross-section.
- The rated voltage of the motor cable for inverter operation amounts to \( U_{0}/U = 0.6/1 \text{ kV} \).
- The cables used must comply with the required approvals of the application (e.g. UL).

The EMC safety of the connection for motor temperature monitoring depends on how the shielded connecting cables are laid.

<table>
<thead>
<tr>
<th>EMC safety</th>
<th>Type of laying</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>Motor cable and PTC/thermal contact cable are laid separately</td>
<td>Ideal laying system with very low interference injections. Treat PTC/thermal contact cable like a control cable</td>
</tr>
<tr>
<td>Medium</td>
<td>Motor cable and PTC/thermal contact cable are laid together with separate shields</td>
<td>Laying system is permitted but shows higher interference injections.</td>
</tr>
<tr>
<td>Unfavorable</td>
<td>Motor cable and PTC/thermal contact cable are laid together with a common shield</td>
<td>High-energy interference injections!</td>
</tr>
</tbody>
</table>

6.1.2 Cable design for DC connection and brake resistor

- These DC cables must be designed like the motor cable.
  - Shielding
  - Rated voltage
  - Approval
- Being relatively short, low-capacitance versions are not necessary.

6.1.3 Control cable design

Control cables must be shielded to minimise interferences.
Arrangement according to EMC requirements

6.2 In the control cabinet

6.2.1 Mounting plate characteristics

- Use mounting plates with an electrically conductive surface (zinc-coated or V2A).
- Varnished mounting plates are unsuitable, even if the varnish is removed from the contact surfaces.
- When using several mounting plates, make a conductive connection over a large surface (e.g. using grounding strips).

6.2.2 Mounting of the components

- Connect the controller and RFI filter to the grounded mounting plate with a surface as large as possible.
- No DIN rail mounting!

6.2.3 Correct cable installation

- Control cables and mains cables must be separated from the motor cable.
- Install terminals for the motor cables e.g. at the control cabinet entry with a minimum distance from the other terminals of at least 100 mm.
- The cables must always be installed close to the mounting plate (reference potential), as loose cables act like aerials.
- The cables must be routed in a straight line to the terminals (avoid “tangle of cables”!)
- Use a separate cable duct for mains cables and control cables. Do not mix different cable types in one cable duct.
- Never lay motor cables in parallel with mains cables and control cables.
- Cross the motor cable vertically with mains cables and control cables.
- Twist unshielded cables of the same circuit (go-and-return line) and ensure that the area between go-and-return-line is as small as possible.
- Reduce coupling capacitances and inductances due to unnecessary cable lengths and reserve loops.
- Short-circuit cable ends of unused cables to the reference potential.

6.2.4 Earth connection

- Connect all components (controller, RFI filter, filter, chokes) to a central earthing point (PE rail).
- Set up a star-shape earthing system.
- Comply with the corresponding minimum cable cross-sections.
6.2.5 Installing the cables within the control cabinet

Separation of the “hot” motor cable from control cables, signal cables and mains cables:

- Never install motor and signal cables in parallel. Crossings must be laid at right angles.
- Arrange the conductors of a 24 V power supply unit close together along the whole length so that no loops may occur.

Fig. 7 Cable routing in the control cabinet
6.3 Wiring according to EMC outside the control cabinet

6.3.1 General information

Notes for cable laying outside the control cabinet:
- The longer the cables the greater the space between the cables.
- In case of parallel cable routing of cables with different types of signals it is possible to minimise the interferences by means of a metal barrier or separated cable ducts.

![Cable routing with separator](image1)

![Cable routing with separate cable duct](image2)

6.3.2 Wiring on the mains side

- It is possible to connect the controller, mains choke or RFI filter to the mains via single cores or unshielded cables.
- The cable cross-section must be rated for the assigned fuse protection (EN 0160).

6.3.3 Wiring on the motor side

**Stop!**

The motor cable is highly susceptible to interferences. Hence the following applies:

The motor cable must **not** contain any further cables (e.g. for brake control, separate fans etc.).

One exception is the temperature monitoring cable of the motor.

- Use shielded, low-capacitance motor cables only.
- Shield the cable for temperature monitoring of the motor (PTC or thermal contact) and separate it from the motor cable.
Limiting harmonic currents in the supply mains

Power consumption of a standard inverter

The input circuit of a frequency inverter with DC voltage bus generally consists of an uncontrolled rectifier and the DC bus capacitance made up of electrolytic capacitors.

Non-sinusoidal input currents of frequency inverters are referred to as harmonic currents (mains harmonics) and can "pollute" the supply system and have an impact on other consumers.

European Standard EN 61000-3-2 ensures the quality of public mains systems, specifying limit values to restrict mains loads (background: increasing number of non-linear consumers).

The standard only applies to public mains systems. Mains systems which have their own transformer station as common in industry are not public. The standard does not apply to them.

This affects units (inverters) with an input current (mains current) of up to 16 A or with input powers of up to 1 kW.

If a machine or system consists of several components, the limit values apply to the entire machine or system.
Limiting harmonic currents in the supply mains

The listed measures ensure that inverters with DC voltage bus adhere to the limit values according to EN 61000-3-2. The machine / system manufacturer is responsible for the compliance with the regulations of the machine:

<table>
<thead>
<tr>
<th>Connection voltage</th>
<th>Power [kW]</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/NPE AC 230 V</td>
<td>0.25</td>
<td>Use assigned mains choke</td>
</tr>
<tr>
<td></td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>Use active filter / PFC</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>3/PE AC 230 V</td>
<td>0.55</td>
<td>Use assigned mains choke</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>3/PE AC 400V</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
</tbody>
</table>
8 Compensation equipment

Interactions with compensation equipment
Controllers only consume a very small fundamental reactive power from the AC mains. Therefore compensation is not necessary.

Stop!
Where higher-power machines in old industrial systems are updated with standard inverters, steps must be taken to ensure that the old compensation systems are equipped with chokes or replaced by new ones (with chokes).

The harmonic currents generated by the inverter (specifically 5 and 7) may cause the capacitor currents to assume values that would very quickly destroy the capacitor batteries, leading to a complete compensation breakdown.

Please consult the supplier of the compensation equipment in due time.
9 Equipotential bonding

Potential differences occur in:
- Spatially separate mounting plates within a control cabinet
- Several control cabinets spatially distributed within the system
- Use of decentralised controllers (motec/starttec)
- Components fed from different supplies

Existing potential differences cause a flow of compensating currents which amount up to several amperes for short periods.

The effects of potential differences are as follows:
- Interference of control signals
- Interference of communication systems (error frames)
- Destruction of electronic components (e.g. interfaces)

The following measures are suitable to reduce potential differences:
- Establish equipotential bonding between mounting plates/control cabinets with the help of large-surface large-contact earthing strip.
- Set up supplies with joint reference potential
- Provide large-surface shield contact surfaces
- Provide an electrical isolation (optical or isolating transformer) if above measures do not suffice.
10  Operation with e.l.c.bs (earth-leakage circuit breakers)

**Danger!**

The controllers are internally equipped with a mains rectifier. In the event of a short-circuit to frame, an earth leakage current can block the tripping of AC-sensitive and / or pulse-current sensitive e.l.c.b. and thus cancel the protective function for all equipment operated on this e.l.c.b..

Different protection measures are suitable to protect humans and animals (DIN VDE 0100).

Note the following when using earth-leakage circuit breakers:

- Pulse-current sensitive e.l.c.bs in systems with controllers with single phase mains connection (L1/N)
- Universal-current sensitive e.l.c.bs in systems with controllers with three-phase mains connection (L1/L2/L3)
- E.l.c.bs must only be installed between mains supply and controller.

E.l.c.bs can be activated although not wanted by

- Capacitive leakage currents of the cable shields during operation (especially with long, shielded motor cables),
- Mains connection of several controllers at the same time,
- Use of additional RFI filters.

The intensity of these capacitive earth currents depends on the following factors:

- 1AC- or 3AC frequency inverter, phase failure
- Inverter-internal EMC elements
- Length and type of motor cable
- Mains voltage level
- Switching frequency level
- Winding structure in the motor
- Installed filters on the mains / motor side
- Mains switch make and break characteristics

**Remedies**

- Low-capacitance and short motor cables
- Increase switching frequency (e.g. 16 kHz)
- Switch mains phases simultaneously (e.g. contactor)
- Provide supply via isolating transformer
## Operation with e.l.c.bs

<table>
<thead>
<tr>
<th>Symbol on the e.l.c.b.</th>
<th>E.L.C.B. types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC-sensitive earth-leakage circuit breaker (e.l.c.b., type AC): Not suitable for controllers; no longer used.</td>
</tr>
<tr>
<td></td>
<td>Pulse-current-sensitive earth-leakage circuit breaker (e.l.c.b., type A): Single-phase-supply controllers; commercially available</td>
</tr>
<tr>
<td></td>
<td>Universal-current-sensitive earth-leakage circuit breaker (e.l.c.b., type B): Single-phase and three-phase-supply controllers</td>
</tr>
</tbody>
</table>
11 Leakage current for portable systems

Frequency inverters with internal or external radio interference suppression filters usually feature a leakage current to the PE potential, higher than AC 3.5 mA or DC 10 mA.

This requires solid connection for protection (refer EN 50178/5.2.11.1) and must be specified in the operating documentation.

Where a solid connection is not realistic in the case of a portable consumer although the leakage current to the PE potential is above AC 3.5 mA or DC 10 mA, a suitable countermeasure would be the installation of an additional two-winding transformer (isolating transformer) into the power supply, with the PE conductor being connected to the drive’s PE’s (filter, inverter, motor, shields) and also to one pole of the secondary winding of the isolating transformer.

For 3-phase-supplied units, select a suitable isolating transformer with secondary star connection, with the star point being connected to the PE conductor.

Fig. 12 Installation of a two-winding transformer (isolating transformer)