EMC and adjustable speed drives
Outline

- EMC and EMI
- Legislation and standards
- EMC phenomena
- EMC requirements
- Coupling mechanisms
- EMC correct installation techniques
-
EMI - Electromagnetic interference

Radiated interference

Conducted interference
EMI - Electromagnetic interference

- Radiated
- Radiated followed by conducted
- Conducted
- Conducted followed by radiated
EMI - Electromagnetic interference

Definition

EMI is the degradation of the performance of an equipment caused by an electromagnetic disturbance.
EMC - Electromagnetic compatibility

Definition

EMC is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable disturbances in that environment.

- Limited emissions
- Specified immunity
EMC - Electromagnetic compatibility

Limited emissions

Level

Immunity margin

Compatibility gap

Emission margin

Specified immunity

Drives Division
Legislation and standards

- EMC Directive 89/336/EEC
- Australia C-tick
- Marine approvals GL, DNV, RINA etc
- Other Directives xx/xx/EEC
- UL
- CSA
EMC legislation and standards

Legal basis

In the European Union the legal basis is the **EMC Directive (89/336/EEC)**

EMC Directive *does not* specify exact requirements for emission and immunity!

but requires (for products delivered ready for use to end user)

- the use of generic EMC standards or EMC product standards
- verification of conformity
- product documentation
- CE mark
The EMC Directive requirements

**EMC directive 89/336/EEC**

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### Standards

- **Conducted emission**: EN55011 (0,15-30MHz)
- **Radiated emission**: EN55011 (30 -1000MHz)
- **Conducted RF-CM**: EN61000-4-6 (0,15-80MHz)
- **Radiated EM-field**: EN61000-4-3 (80 –1000MHz)
- **Burst**: EN61000-4-4 (5/50nS)
- **Surge**: EN61000-4-5 (1/2/50uS)
- **ESD**: EN61000-4-2 (1.2/5nS)
- **Harmonics**: EN61000-3-2/12
- **Harmonic distortion**: EN61000-2-2/4
- **Commutation notches, Voltage changes, fluctuations, unbalance, flicker, ...**: EN61800-3 EN61000-6-X
EN61800-3 - Division in categories

Recall the compatibility gap concept

Residential areas

Industrial areas

Level

Immunity margin

Compatibility gap

Emission margin

Level

Immunity margin

Compatibility gap

Emission margin
EN61800-3 - Division in categories

EMC Product Standard
EN61800-3

Residential Areas
(First environment)
Connected directly to low-voltage network

Category C1
Layman installs
Ex.: Household appliance

Category 2
Professional installs
Ex.: Lifts, HVAC

Industrial Areas
(Second environment)
Own transformer substation

Category 3
General industry

Category 4
Heavy industry or IT-networks
First Environment - Categories C1 and C2
Residential and commercial areas
Connected directly to low-voltage power supply network

C1: The units are installed and used by layman.
Ex.: Household appliance

C2: No plug or movable equipment.
The units are installed and used by professionals. (Persons having the necessary EMC skills)
Ex.: Lifts and HVAC installations
Second Environment - Categories C3 and C4

Industrial areas (or other than first environment)
The costumer is not directly connected to low-voltage power supply network and has his own transformer substation.

**C3:**
For industrial areas.

**C4:**
Technical reasons in some applications means that C3 requirements can’t be met.
Ex.:
IT-networks in complex systems
Current above 400A
Voltage above 1000V
**EMC Product Standard requires**

- **Conducted emission** \(\text{EN55011 (0,15-30MHz)}\)
- **Radiated emission** \(\text{EN55011 (30 -1000MHz)}\)
- **ESD** \(\text{EN61000-4-2 (1.2/5nS)}\)
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- **Conducted RF-CM** \(\text{EN61000-4-6 (0,15-80MHz)}\)
- **Harmonics** \(\text{EN61000-3-2/12}\)
- **Voltage fluctuation** \(\text{EN61000-3-3/11}\)
- **Commutation notches** \(\text{EN60146-1-1}\)
- **Harmonic distortion** \(\text{EN61000-2-2/4}\)
- **Commutation notches** \(\text{EN60146-1-1}\)
- **Voltage changes, dips** \(\text{EN61000-3-3/11}\)
- **Voltage unbalance** \(\text{EN61000-2-2/4}\)
The frequencies we use
The noise frequencies we create

- 50/60Hz supply
- Harmonics
- SMPS and harmonics
- Microprocessor and harmonics

dB

0

50/60Hz supply

Harmonics

SMPS and harmonics

Microprocessor and harmonics

MHz
Immunity - Phenomena

**ESD** is
- low energy
- high voltage
- very high frequency pulses (1.2/5ns)

Simulates discharge for instance from a human

**Radiated Field immunity**
The radiated immunity test ensures the equipment’s immunity against external radiated high frequency interferences.

Simulates various sources like walkie-talkies, FM-radio, other electronic equipment, etc.
Immunity – Phenomena

Burst transient
- Low energy
- Medium frequency
- Repetitive pulses

Simulates the effect of fast transients from switches, relay contacts, etc.

Surge
- Medium to high energy
- Low frequency

Simulates the effect of lightning strike

HF conducted immunity
- Low energy
- Medium to high frequency

Simulates radiated noise coupled to conductors connected to equipment
Danfoss Drives and immunity

Conducted emission EN55011 (0.15-30MHz)

Radiated emission EN55011 (30-1000MHz)

ESD EN61000-4-2 (1.2/5nS)

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Burst EN61000-4-4 (5/50nS)

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Conducted RF-CM EN61000-4-6 (0.15-80MHz)

Harmonics EN61000-3-2/12

Voltage fluctuation EN61000-3-3/11

Commutation notches EN60146-1-1

Harmonic distortion EN61000-2-2/4

Commutation notches EN60146-1-1

Voltage changes, dips EN61000-3-3/11

Voltage unbalance EN61000-2-2/4
EN61800-3 – Immunity requirements

**Basic immunity**

**Residential Areas**  
(First environment)  
Connected directly to low-voltage network

**Category C1**

**Category 2**

**Increased immunity**

**Industrial Areas**  
(Second environment)  
Own transformer substation

**Category 3**

**Category 4**
Danfoss Drives and immunity

Our products met the immunity levels according to **Industrial Environment**

It is our experience that these high requirements are needed.

And that for some phenomena (Ex.: Burst, Surge and more) Danfoss Drives specify even higher test levels to achieve a high quality product.
## Danfoss Drives and emission

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Danfoss Drives and emission

Req. depend on Category.
Danfoss Drives offers build in optional EMI filters.

Danfoss Drives ASD’s have typically build in suppression of harmonics

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EN61800-3 – Emission requirements

EMC Product Standard EN61800-3

Residential Areas
(First environment)
Connected directly to low-voltage network

Category C1
EN55011, Class B1

Category 2
EN55011, Class A1

Industrial Areas
(Second environment)
Own transformer substation

Category 3
EN55011, Class A2

Category 4
No specific req. except for EMC PIAN
Conducted emission limits

EN55011 conducted emission limits

- Class B
- Class A, Gr.1
- Class A, Gr.2
- Class A, Gr.2, I>100A

Average [dBuV] vs. Frequency [MHz]
Radiated emission limits

Radiated emission limits for ASD

- First env.+Cat. C1
- Second env.
- Cat. C2
- Cat. C3

[dB µV/m]

Frequency [MHz]
Complying with standards and requirements

We develop our ASD’s for compliance with the relevant standards and based on our knowledge of the actual requirements...

...but...

This is a necessary but not sufficient condition...

Everything can be ruined by a bad installation!

It is not enough to have a good frequency converter. It has to be installed correct to achieve EMC!
Interference coupling

Interference

Coupling
Interference coupling mechanisms

- Galvanic (conductive) coupling
- Electric/capacitive coupling
- Magnetic/inductive coupling
- Electromagnetic coupling
Galvanic/conductive coupling

The typical paths are:
- power lines (AC or DC)
- signal lines
- ground connections

If contact between the source and the victim circuits can not be avoided, filters should be installed. Use correct grounding technique.
Electric/capacitive coupling

Capacitive coupling requires a return path for the capacitive current.

The noise source is a time varying voltage. The coupling is made through a parasitic capacitance between two conductors.

The victim circuit typically has a high impedance.

Use shielded cables and/or separate cables.
Magnetic/inductive coupling

The inductive coupling does not require any connection between the two circuits.

The noise source is a time varying current $dI/dt$ causing a magnetic field that induces a disturbing voltage in the victim circuit through the mutual inductance of the two circuits.

The victim circuit typically has a low impedance.

Use shielded cables and separate cables.
Electromagnetic coupling

Requires a distance between the source and victim circuits that is longer than the wavelength of the noise signal.

The noise source radiates electromagnetic energy through an antenna. The victim circuit receives the disturbance through an receiving antenna.

Use shielding and shielded cables.
Installation techniques
Start by making an EMC plan

- List components, equipments and areas
- Divide into potential noise sources or potential sensitive equipment
- Classify the cables
- Set requirements for and select the equipment
- Separate potential noise sources from potential sensitive equipment
- Control interfaces between noise sources and sensitive equipment
- Route cables according to the classification
Making an EMC plan

Example

Potential
noisy

Potential
sensitive

EMI filter

Separation and
shielded cables

Separation and
noise
suppression

Separate supply and
EMI filter

Galvanic signal
isolation.
Shielded cables

Separation and
shielded cables

AsD

Contactors
and Relais

Control
Unit
PLC

Sensors

Aux.
equipment

Power Switch

Panel

Line EMI
filter

Fuse or
Circuit
Breaker

Communication

Communication

Analogue signals

M

Encoder

Property of Danfoss Drives A/S

Drives Division
Cable classes - based on the IEC 61000-5-2:1997

**Class 1**: Cables carrying very sensitive signals: milivolt-level analogue transducer signals, radio receiver antenna, high-speed digital communication (Ethernet). Analogue (Cl. 1A) and digital (Cl. 1B) in separate bundles.

**Class 2**: Slightly sensitive analogue signals (4-20 mA, 0-10V, or signals below 1 MHz), low-speed digital signals (RS232, RS485), digital (on/off) signals.

**Class 3**: Cables carrying slightly interfering signals: AC power (<1kV), DC power (24 V), power to equipment with RFI/EMI filters, control circuits with resistive or suppressed inductive loads, direct-on-line (DOL) induction motors.

**Class 4**: Cables carrying strongly interfering signals: motor cables, DC-link load sharing, unsuppressed inductive loads, DC motors and sliprings, transmitter antenna cable.

**Class 5** and **6**: MV and HV.
Separation of classified cables

- Category 1 cable
  - 150mm
  - 450mm
- Category 2 cable
  - 450mm
  - 600mm
- Category 3 cable
  - 300mm
  - 450mm
- Category 4 cable
  - 150mm
How do shielded cables work?

The shielded cables consist of one or more conductors surrounded by a conductive shield. The inner conductors are coupled with the shield through the mutual inductance which results in very good coupling factor (for example for RG58 50 ohm coaxial cables $k=0.999$).

A shielded cable can be imagined as a transformer where the primary winding consists of the inner conductors and the secondary is the shield.
Transfer impedance

The performance of a shielded cable is indicated by the transfer impedance $Z_t$.

The transfer impedance relates a current on one surface of the shield to the voltage drop generated by this current on the opposite surface of the shield.

$$Z_T = \frac{U_2}{I_1 \cdot L}$$
Typical transfer impedance values of shielded motor cables

- Aluminium foil with copper drain wire
- Twisted copper wires or steel wire armoured cable
- Single layer braided copper wire - with various percentages of screen coverage
- Dual layer braided copper wire
- Dual layer braided copper wire with high permeable middle layer
- Cable runs in rigid copper or steel conduit
- Lead cable with 1.1 mm wall thickness - full coverage
Transfer impedance with 2cm pigtail

\[ Z_t = \frac{V_{\text{shield}}}{I_{\text{shield}}} \]

1 meter RG58 shielded cable
Self-inductance of the shield: 
\[ L_{\text{shield}} = 1[\mu H] \]
Reactance at 50 MHz: 
\[ X_L = 2\pi fL \approx 314[\Omega] \]
Coupling factor: 
\[ k \approx 0.999 \]
Transfer impedance of 1 meter cable: 
\[ Z_{t-50MHz} = X_L \cdot (1 - k) = 314 \cdot (1 - 0.999) = 0.3[\Omega] \]

2cm pigtail
Self-inductance of the pigtail: 
\[ L_{\text{pig}} = 20[n H] \]
Reactance at 50 MHz: 
\[ X_L = 2\pi fL \approx 6.2[\Omega] \]
Coupling factor: 
\[ k \approx 0.3 \]
Transfer impedance of 2cm pigtail: 
\[ Z_{t-50MHz} = X_L \cdot (1 - k) = 6.2 \cdot (1 - 0.3) = 4.4[\Omega] \]
Shielded control and communication cables

Control cables and serial communication cables should normally be grounded at both ends.

Oops! Never terminate screen through pigtail.

Earth potential between PLC and VLT: Disconnect cables and measure voltage with voltmeter to check. Use equalizing cable or make sure units are bolted together.

50/60 Hz ground loop: Use current clamp meter to check. => Ground one end through 100 nF capacitor with short leads. NB! Use screened twisted pair cable for serial communication.

Potential equalizing currents in serial communication cable screen between two VLT drives: => Connect one end of screen to terminal 61. (RC link – VLT5000). Remember “correct” pigtail installation!
Correct installation of a circuit breaker on the motor cable

Bad!
Due to pig-tail:
* Radiated noise.
* Noise current finds an alt. return path for instance via comm.

GOOD!
Noise is conducted to ground through panel frame.

Source: DD-DS3 – Preben Holm
Installation within cabinet
(from VLT Design Guide)
Grounding/Earthing

Why?

1. For safety reasons
   Safety grounding reduces voltage differences between exposed conductors that might become energized. Safety grounding requires properly sized and located conductors.

2. For interference reasons
   Interference grounding reduces voltage differences that might cause noise emission or susceptibility problems. Grounding to reduce interference is completely different from routing to reduce interference.
Explanation of poor grounding

All ground connections have some impedance. The connection of an equipment to two grounding points with some (how much?) distance between them creates a ground loop. The connection of two equipments grounded at two different grounding points with a potential difference between them creates also a ground loop. The ground conductor needs a sufficient cross-section in order to minimize its impedance.
General installation rules

- Make an EMC plan for the installation and purchase
- Separate potential noise sources from potential sensitive equipment
- Use RFI filters on line for both ASD and aux. equipment like PLC’s
- Use shielded motor, brake, loadsharing cables. Connect in both ends
- Use shielded cables for control lines, comm. and sensor cables
- Avoid pigtails at cable screen. Use EMC glands or cable brackets
- Separate control and power cables by min. 200mm
- Use separate ducts for power and signal cables
- Ground the ASD to panel back plate via mounting brackets
- Use equalising ground connections between equipment and/or panels
- Consider the use of galvanic signal isolator in complex installations
- Use galvanic isolation between encoder/resolver and motor
- Use noise suppression filters on contactors and relais
- Be careful when using one 24V power supply in complex installations