EMI Filter Safety

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> Application with high EMI noise over the standard limits

You need a filter solution!
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Filter

- Basic requirements
  - Voltage DC/AC / no. of phases
  - Current, inrush / leakage current
  - Attenuation: dB @ kHz, sym./asym.
  - Dimensions, weight, connection
  - Safety approvals

- Additional requirements
  - High voltage tests
  - Leakage currents
  - Inrush / overcurrents (e.g. SCCR)
  - Environment: temperature, humidity, vibration
  - Durability (MTBF)
  - Service: CAD and simulation data

Filter data sheet
Filter high voltage tests

> Standard requirements

<table>
<thead>
<tr>
<th>Standard</th>
<th>Rated voltage</th>
<th>L – L</th>
<th>L - PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60939-2</td>
<td>250 VAC</td>
<td>1075 VDC</td>
<td>1500 VAC / 2250 VDC</td>
</tr>
<tr>
<td>UL 1283, CSA 22.2 no. 8</td>
<td>250 VAC</td>
<td>1000 VAC / 1414 VDC</td>
<td>1500 VAC / 2121 VDC</td>
</tr>
<tr>
<td>IEC 60939-2</td>
<td>480 VAC</td>
<td>2064 VDC</td>
<td>2000 VAC / 3000 VDC</td>
</tr>
<tr>
<td>UL 1283, CSA 22.2 no. 8</td>
<td>480 VAC</td>
<td>2000 VDC</td>
<td>2031 VAC / 2872 VDC</td>
</tr>
</tbody>
</table>

> AC: 50/60Hz, 60 sec.
> Test source min. 500 VA

> Attention:
repetition of the voltage proof test may damage the filter!
Filter high voltage tests

- Filter tests with AC voltage cause leakage current through capacitors
  - Example: $1 \mu F \times 1500V \times 60Hz = 560mA \times (840 VA)$

- Do HV tests on filters with DC

\[
I = 2\pi f \times U \times C
\]
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Filter high voltage tests

> Voltage ramp-up time
> Too fast ramp-up time cause errors because of capacitor charging

\[ I = C \frac{\Delta V}{\Delta t} \] (without internal and series resistance)

> Example:
  > 3 phase filter tested
  > 3000 VDC test L – PE
  > ramp-up 5 sec. max. current 17mA
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High voltage tests on equipment with EMI filter

> Do HV tests with DC

> Be aware of the charge currents of the capacitors

> Not too fast voltage ramp-up time

> Don’t do repetition of HV test too many times

> Some application standards allow to disconnect the filter for HV tests

> Example: IEC / UL 60950-1 (IT Equipment)

> Test voltage AC 50/60Hz, or DC equal, 60 sec.

> NOTE 2 Where there are capacitors across the insulation under test (for example, radio-frequency filter capacitors), it is recommended that d.c. test voltages are used.

> NOTE 3 Components providing a d.c. path in parallel with the insulation to be tested, such as discharge resistors for filter capacitors and voltage limiting devices, should be disconnected.
Leakage Currents

> Leakage currents, are currents that under normal operation **not** returns through the neutral or line conductor.

> **Direct coupling** through capacitors e.g. Y-capacitors in mains filter wired from line to ground

> to calculate \[ I = 2\pi \times f \times U \times C \]

> **Capacitive coupling** from line to ground e.g. cable shielded or long cables to chassis

> Capacity often unknown

> Higher frequencies generate high leakage currents

> Long shielded cable = high capacity
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Filter leakage currents

> In EMC filters, capacitors from all conductors are wired to ground
> Current is continually flowing through each of these Y-capacitors, and the amount depends on the size of the capacitor, grid voltage and the frequency

Example

> Most filter manufacturers specify the maximum expected leakage current so that it is easier to select the most suitable filter
Leakage currents on filters data sheets

**Technical Data**
- Rated Current: 6 - 1100 A
- Rated Voltage: 480/520 VAC, 50/60 Hz
- Approval for: 6 - 1100 A @ Ta 40 (75) °C / 520 VAC; 50 Hz
- Overload Current: 1.5 x Ir
- Leakage Current: industrial < 5 mA (440 V / 50 Hz)
- Dielectric Strength: 480 VAC; 2.25 kVDC between L-L; 3 kVDC between L-PE

**Leakage current under normal condition acc. IEC60950-5.2.5**

**Variants**

<table>
<thead>
<tr>
<th>Rated Current @ Ta 40°C (75°C) [A]</th>
<th>Characteristic</th>
<th>Rated Voltage [VAC]</th>
<th>Tripped Power Dissipation [W]</th>
<th>Leakage Current [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (5)</td>
<td>Excellent attenuation</td>
<td>480</td>
<td>5.38</td>
<td>40</td>
</tr>
<tr>
<td>16 (10)</td>
<td>Excellent attenuation</td>
<td>480</td>
<td>8.83</td>
<td>40</td>
</tr>
<tr>
<td>16 (Pending)</td>
<td>High voltage filter</td>
<td>520</td>
<td>8.83</td>
<td>26</td>
</tr>
<tr>
<td>16 (10)</td>
<td>Excellent attenuation</td>
<td>-</td>
<td>8.83</td>
<td>40</td>
</tr>
<tr>
<td>25 (15)</td>
<td>Excellent attenuation</td>
<td>-</td>
<td>8.25</td>
<td>156</td>
</tr>
<tr>
<td>25 (14)</td>
<td>High attenuation</td>
<td>-</td>
<td>9.86</td>
<td>156</td>
</tr>
</tbody>
</table>

**Worst case leakage current acc. to IEC60950 - Annex G4 (situation with two interrupted lines)**
Leakage current in frequency inverters

> In inverter the associated harmonics of the switching frequency can have very large amplitudes at higher frequencies

> These frequencies are on the motor cables and the motor

> the motor cables with their grounded shields act like a capacitor to ground

> Current is then diverted to earth through this capacitance

> The same currents are flowing to ground inside the inverter and motor
Leakage currents in frequency inverter system

Leakage currents in frequency inverters arise through internal interference-suppression measures and all parasitic capacitances in the inverter and motor cables.

> Leakage currents through capacitors

> Leakage currents parasitic capacity
Transient leakage currents

> Transient leakage currents can arise when the system is turned on or off

> Depending on the phase angle, turning the system on, can result in steeply rising voltage spikes as a result of the fast voltage increase

> These fast voltage spikes generate a transient leakage current to ground through the filter capacitors
System leakage currents

> Mains frequency leakage currents of the EMI filter are known by the capacity to ground

> Overall capacity of an inverter system are mostly not known

> Leakage currents might occur over a wide frequency range

> RCD shuts down operation when leakage currents are too high

> RCD shuts down when system is first turned on or off (Residual-Current Device)

> What to do?
Leakage current measurement

> It is recommended to measure the leakage current for every newly installed machine

> The simplest method for doing so is to measure the current on the ground conductor with a clip-on ammeter

> Most clip-on ammeters display only 50-Hz current!
Leakage current measurement

> Most clip-on ammeters display only 50-Hz current, and thus a better way to measure the value is with a leakage-current analysis system.

50Hz leakage current
> Leakage current in higher frequency ranges (9 mA @ 6 kHz) can be larger than at 50 Hz (6 mA @ 50 Hz)!
Practical example
> 2 different filters for a motor drive
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> 2 different filters for a motor drive

**FMAC ECO (single stage)**

- 3 x 0.57 mH
- 3.3 μF = max. 240mA

**FMBC ECO (double stage)**

- 6 x 0.9 mH
- 47 nF = max. 4mA

![Filter Diagrams](image_url)
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Big Y-capacitors to ground

⇒ cheap, compact, good attenuation but high leakage currents!

Replacement of the Y-capacitors with an additional choke

⇒ expensive, bigger, good attenuation and small leakage currents

FMAC ECO (single stage)

FMBC ECO (double stage)
Reducing leakage currents

> Placing the frequency **inverter close to the motor**
  ⇒ shorter shielded cables = lower capacity = lower leakage current

> **Output filter** (sinewave filter) on the drive output
  ⇒ It effectively attenuates leakage currents above 1 kHz by reducing the slew rate of the motor voltage

> **Central filter** at the grid input instead of a filter for each inverter
  ⇒ saves money and space but also reduces the leakage current

> **Power-line chokes**
  ⇒ reduces the current's ripple factor along with harmonics and thus provides for smaller leakage currents
Reducing leakage currents

> **4-conductor filter** with a neutral instead of a 3-conductor filter

⇒ Y-capacitors are connected between the phase conductors and the neutral conductor

3 conductor filter FMAC

![3 conductor filter FMAC](image)

8 Y-capacitors to PE

⇒ high leakage current

4 conductor filter FMBD

![4 conductor filter FMBD](image)

1 Y-capacitors to PE

⇒ small leakage current
Reducing leakage currents

> Separate circuits in RCD protected / non protected areas
> Separate filtered and unfiltered cables
> Starting up the system / frequency inverter in steps
> Overvoltage protection to protect against voltage spikes
> A RCD with delayed response characteristics
> A differential RCM (residual current measuring device)
> Low leakage-currents filters
  > Medical filters
  > 3 phase industrial filters with low leakage currents
Thank you for your attention