Electromagnetism is just electricity

Converters are particularly concerned with EMC:

• **Conducted disturbances** (Mainly by large converters)
  - For the converter itself (self immunity)
  - For the environment (common mode disturbances)

• **Radiated disturbances** (even by small converters)
  - Near fields couplings
  - Far field radiation (mainly for radio receivers)
Beware of unreasonable EMC Standards!

Conducted emission limits of EMC standards for large equipment (inverters, speed drives, arc welders, lifts…) are really too high:

115 dB\(_{\mu V}\) into 9 kHz = 126 dB\(_{\mu V}\) into 120 kHz equivalent to 40 mA into 50 Ω

While the limit corresponding to the radiated emission according to Class A + 10 dB from 30 MHz to 230 MHz is smaller than 30 μA (in common mode for any cable)!
Poorly filtered 300kVA inverter conducted spectrum

**Quasi-Peak measurement**

- ITE Q-P Class A + 10 dB
- EN 50091-2 & EN 62040-2

**Average measurement**

- ITE Average Class A + 10 dB
- EN 50091-2 & EN 62040-2
Beware of 2 kHz to 150 kHz band!

Inverter currents in time & frequency domain (currently, no CISPR limit apply)

Suggested specification for immunity testing: IEC 61000-4-16
Let’s specify modified EMC Standards!

Conducted emission limits for ITER Facility
A switch-Mode Converter at low frequency introduces a **negative incremental impedance**

\[ Z_{IN} = \frac{\Delta V}{\Delta I} \]  
(for P = constant, when U decreases, I increases).

**Risks:**
- No start.
- Start but wrong output voltage.
- Output voltage instability.
- Destruction of the converter.

**Solutions:**
- Add a large (larger) capacitor at the DC/DC converter input.
- Reduce the source impedance (example: several pairs in //).
- Reduce the converter bandwidth.
Let’s read and uphold data-sheets!

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</tbody>
</table>

* typical values at $T_A = 25°C$

Gate Drive Optocoupler HCPL 3120 Technical Data

Diode overvoltage on the inverter IGBT 200A CM Mitsubishi 24A

Oscillation: 35 MHz
Slope: 33 kV/µs
EMC on-site mitigation

- Addition of high $\mu_r$ ferrite toroids on unshielded cables
- Direct connection of the braid of all shielded cables to chassis ground
- Connection of all unused pairs to chassis ground
- Addition of equipotential bonding between cabinets
Maximal CM current over internal cables

Sensitive current clamp: \( Z_t = 12 \, \Omega \) (5 to 230 MHz)

EMC recommendation:
- \( I_{CM} \) on IGBT control cable: < 5 A peak-to-peak
- \( I_{CM} \) on any internal cable: < 2 A peak-to-peak

Comfortable EMC margin: \( 0.2 \times \) those values
DC/DC Input to output common mode

1 mA < $I_{CM\,typ.}$ < 100 mA

$Z_{CM}$

Chassis Ground

"Green wire"

$I_{CM}$

Switching $T$

F ≈ 5 to 50 MHz
Switching inverters and motor drives are noisy sources in common mode.

Principle schematics of a H-Bridge (here a Single-Phase Bridge)
3 cases of input-output common mode

1. No disturbance out of the frame
   - No CM noise through electronic circuits
   - EMC filter easy to optimise

2. No disturbance out of the frame
   - CM current through electronics
   - EMC filter more difficult to optimise
   (due to resonant frequencies)

3. EM radiation out of the frame
   - EMC filter impossible to optimise
   (due to \( I_{CM}' \))
   - Shield or filter the output cable...
EMC overview of a large UPS

EMC Filers on the same metal plate

Limit the stray caps and the loops areas

Impedances to limit (metal plate)

Trafoless UPS

PFC filter

Inrush current limiter

PFC

Battery charger

Neutral arm

Inverter

Impedances to limit (metal plate)
Will you find the errors of this assembly?

Capacitors: $3 \times 2.2 \mu F$ (Mains side)

Capacitors: $3 \times 2.2 \mu F$ (Internal side)
Cabling effects

With extra but poorly wired capacitors:

+ 12 dB degradation

Filter without extra capacitors
(initial reference)

With better wired capacitors:

- 19 dB below reference

Cabling effect > 30 dB

Better wiring (still perfectible)
Re-lightning of the opposite MOS or IGBT \( V_{GS} \) via the Miller capacitance.

**Causes:**
- \( V_{DC\ bus} \geq 100 \, \text{V} \) (400 V here).
- Driver with zero voltage blocking.
- Too long gate trace (within 5 cm).

**Effect:**
- Radiated emission (here \( \approx 200 \, \text{MHz} \)).

**Fixes:**
- Addition of a push-pull near the gate.
- Negative voltage blocking.
- Control with a pulse transformer.
Electrical Fast Transient in Burst (EFT/B)

Characteristics:
- polarity: positive/negative
- output type: coaxial, 50 Ω
- d.c. blocking capacitor: (10 ± 2) nF
- repetition frequency: 5 kHz or 100 kHz ±20 % asynchronous
- relation to a.c. mains: (15 ± 3) ms at 5 kHz
- burst duration: (0,75 ± 0,15) ms at 100 kHz
- burst period: (300 ± 60) ms
- wave shape of the pulse rise time $t_r = (5 ± 1,5) \text{ ns}$
- into 50 Ω load
- pulse width $t_w = (50 ± 15) \text{ ns}$
- peak voltage = ±10 %

IEC 61000-4-4 Immunity Test
Power converters may radiate in excess
(Both large and small cabinets and attached cables)

Keep good VHF contacts between cubicles
Selection of a differential probe

To measure voltages on an H-bridge ($V_{GS}$ or blocking overvoltage), use a differential probe with at least:

- Bandwidth $\geq 100$ MHz
- CMRR $\geq 50$ dB @ 1 MHz

Suggested models:

- 4233 or 4234 (Probe Master) or
- SI-9110 (Sapphire Instruments)

To measure peak overvoltage, trigger the oscilloscope in "normal" mode on the signal peak.
Example of Home–Made Voltage Probe

1500 Ohm Probe (150 kHz to 30 MHz)
Example of Home–Made Current Probe

\[ Z_t = 10 \, \Omega \quad (+1/-2 \, \text{dB from } 3 \, \text{MHz to } 300 \, \text{MHz}) \]
Let’s check Home-Made Probes

**Frequency response of a home-made 1500 Ω Voltage Probe**

Nominal insertion loss = 36 dB
+ 0 / -1 dB from 150 kHz to 30 MHz

**Frequency response of a home-made 10 Ω Current Probe**

Nominal Transfer Impedance = 20 dBΩ
In-band Output SWVR ≤ 1.5
Nominal primary circuit load = 5 Ω
Examples of Home-Made probes

ΔB/Δt passive probe

ΔV/Δt - 1 pF probe
(50 mV / V/ns up to 1 GHz)

BNC Shunt
for current injection
(for Zt of Coaxial cable assessment)