Coupling modes

Véronique Beauvois, Ir.
2018-2019
General problem in EMC = a trilogy

Source (disturbing)

- lightning
- electrostatic discharges
- motors, converters
- etc.

Victim (disturbed)

- receivers
- sensors
- amplifiers
- μC
- etc.

Parameters
- Amplitude
- Spectrum

Coupling modes
- conducted (I / U)
- radiated (cables, slot, shielding defect, …)

Propagation

Perturbations

Couplage
General solution in EMC
= a trilogy

Source (disturbing)

To act on the source
(not always possible)

Propagation
Coupling mode

To reduce the efficiency
of the coupling mode
= frequently only solution

Victim (disturbed)

To act on the victim
(increasing immunity –
reducing susceptibility)

or different combined solutions

Remark: reciprocity (to improve emission frequently improve also immunity)
1st step: to identify the disturbing elements

\[ \downarrow \]

**Protections**

- for inter-system
- for **intra**-system

= source & victim inside the same system
To identify the disturbing elements, the coupling paths, ...
To add elements/components to reduce some effects
The coupling modes between source and victim could be classified according to:

- **Common mode**
- **Differential mode**

**Differential mode** (DM) (or symmetrical): current is on one conductor in one direction and in phase opposition on the second conductor (e.g. power supply, RS-485, CAN, USB).
Common Mode (CM) (or asymmetrical or longitudinal) : current on both conductors in the same direction.

The EM disturbances are weakly coupled in DM as conductors are nearby. On the other hand, in CM, current could be induced by an external field.
How to measure CM and DM?
With a current clamp

CM

DM
**Coupling modes**

Conversion between *DM* and *CM*

Related to the parasitic impedances of different values

Origin? When 2 conductors have a different impedance regarding earth (parasitic capacitors)

If $Z_A = Z_B$, there is no voltage accross $R_L$ due to $I_{CM}$

If $Z_A \neq Z_B$, $V_{\text{charge}(CM)} = I_{CM} \cdot (Z_A - Z_B)$
A. Common impedance coupling (conducted coupling) = common conductor

Considering a conductor AB, impedance $Z(f) \neq 0$:

\[ V_{AB} = Z \cdot i \]

Solutions:
- to decrease $Z$ (coupling)
- to decrease $i_p$ (source)
A. Common impedance coupling (conducted coupling)  
= common conductor
A. Common impedance coupling (conducted coupling) = common conductor

Problème

Entrée système B = (V_{in} + V), où \( V = -L \times dI_L/dt \)

Solution
B. Inductive Coupling

The circulation of a current in a conductor creates a magnetic field, which could couple with a nearby circuit, and induced a voltage.

Solutions:
• source: to decrease dB/dt
• victim: to decrease S or modify orientation
  (\textbf{n} and \textbf{B} perpendicular, \textbf{B} // loop)
• coupling: to increase distance or add a magnetic screen
Coupling modes

B. Inductive Coupling

External disturbance

To reduce S loop
B. Inductive Coupling

Inductive diaphony

$\Delta i_s > B > i_p$

$V = L_2 \frac{d i_2}{dt} + M \frac{d i_1}{dt}$
**Coupling modes**

**B. Inductive Coupling**

\[ V_N = - M \times \frac{dI_L}{dt} \]
C. Capacitive Coupling

dU/dt > E electric field could couple with a nearby conductor and generate a voltage

Solutions:
• source: to reduce dU/dt
• coupling: to increase distance
C. Capacitive Coupling

Capacitive diaphony
C. Capacitive Coupling

\[ V = C_C \times \frac{dV_L}{dt} \times \left( \frac{Z_{in}}{R_S} \right) \]

Impedance of victim circuit to ground
Electric coupling *increases* with $Z_{IN}$ growing whereas magnetic coupling *decreases*.

For the same reason, magnetic coupling is related to circuits with low input impedance as electric coupling to high input impedance.
Coupling modes

Relationship distance - M and C

![Graph showing the relationship between distance (D) and capacitance (C) or inductance (M) per centimeter. The graph includes labels for mutual capacitance (capacité mutuelle) and mutual inductance (inductance mutuelle).]
Coupling modes

D. Radiated Coupling

\{ 
  - H-field (field to loop)
  - E-field (field to conductor)
\}
D. Radiated Coupling

1. Electromagnetic field of short electric dipole

Conductor length \( l \) with a current \( I_0 \)

\( l \ll \lambda \) of the field

So \( I_0 \) is constant on \( l \)
1. Electromagnetic field of short electric dipole

Electromagnetic fields (in spherical coordinates) is evaluated at an observation point P at a distance $r$ from the origin:

$$E_r = \frac{Z_0 I_0 l \cos \theta}{2\pi r^2} \left(1 + \frac{1}{jkr}\right) \exp(-jkr)$$

$$E_{\theta} = \frac{jZ_0 k I_0 l \sin \theta}{4\pi r} \left(1 + \frac{1}{jkr} - \frac{1}{(kr)^2}\right) \exp(-jkr)$$

$$H_{\phi} = \frac{jk I_0 l \sin \theta}{4\pi r} \left(1 + \frac{1}{jkr}\right) \exp(-jkr)$$

où

$$k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c}$$

$$Z_0 = \sqrt{\mu/\varepsilon}$$
1. Electromagnetic field of short electric dipole

We have to consider 3 cases:
- \( r >> \frac{\lambda}{2\pi} \) or \( kr >> 1 \)  
  \textit{far-field}
- \( r << \frac{\lambda}{2\pi} \) or \( kr << 1 \)  
  \textit{near-field}
- \( r \approx \frac{\lambda}{2\pi} \) or \( kr \approx 1 \)  
  \textit{intermediate zone}
1. Electromagnetic field of short electric dipole

Far-field

For $\theta=0^\circ$, no electromagnetic wave, 
consider $\theta=90^\circ$ (maximum of radiation):

$$E_r = 0$$
$$E_\theta = \frac{jZ_0 k I_0}{4\pi r} \exp(-jkr)$$
$$H_\phi = \frac{j k I_0}{4\pi r} \exp(-jkr)$$

Characteristic Impedance

$$Z_w = \frac{|E_\theta|}{|H_\phi|} = Z_0 = \sqrt{\frac{\mu}{\varepsilon}}$$

Dans le vide,

$$Z_0 = 120\pi \approx 377 \, \Omega$$
Near-field

\[
E_r = \frac{Z_0}{2\pi k} \left( \frac{I_o l \cos \theta}{r^3} \right) \exp(-jkr)
\]

\[
E_\theta = -\frac{jZ_0}{4\pi k} \left( \frac{I_o l \sin \theta}{r^3} \right) \exp(-jkr)
\]

\[
H_\phi = \frac{1}{4\pi} \left( \frac{I_o l \sin \theta}{r^2} \right) \exp(-jkr)
\]

Characteristic Impedance

\[
Z_w = \left| \frac{E_\theta}{H_\phi} \right| = \frac{Z_0}{kr}
\]
1. Electromagnetic field of short electric dipole
Coupling modes

D. Radiated Coupling
2. Electromagnetic field of magnetic dipole

Consider a loop with \( I_0 \)
2. Electromagnetic field of magnetic dipole

Electromagnetic fields (in spherical coordinates):

\[
H_r = \frac{jk \pi R^2 I_o \cos \theta}{2\pi r^2} \left(1 + \frac{1}{jk r}\right) \exp(-jkr)
\]

\[
H_\theta = -\frac{k^2 \pi R^2 I_o \sin \theta}{4\pi r} \left(1 + \frac{1}{jk r} - \frac{1}{(kr)^2}\right) \exp(-jkr)
\]

\[
E_\phi = \frac{Z_o k^2 \pi R^2 I_o \sin \theta}{4\pi r} \left(1 + \frac{1}{jk r}\right) \exp(-jkr)
\]
2. Electromagnetic field of magnetic dipole

Far-field \((r \gg \lambda/(2\pi))\)

For \(\theta=90^\circ\):

\[
H_r = 0 \\
H_\theta = \frac{-k^2 \pi R^2 I_o}{4\pi} \frac{r}{r} \exp(-jkr) \\
E_\phi = \frac{Z_0 k^2 \pi R^2 I_o}{4\pi} \frac{r}{r} \exp(-jkr)
\]

Characteristic Impedance

\[
Z_w = \left| \frac{E_\phi}{H_\theta} \right| = Z_o = \sqrt{\frac{\mu}{\varepsilon}}
\]
Near-field ($r \ll \lambda/(2\pi)$)

\[ H_r = \frac{1}{2\pi} \frac{\pi R^2 I_0 \cos\theta}{r^3} \exp(-jkr) \]
\[ H_\theta = \frac{1}{4\pi} \frac{\pi R^2 I_0 \sin\theta}{r^3} \exp(-jkr) \]
\[ E_\phi = \frac{Z_o k}{4\pi} \frac{\pi R^2 I_0 \sin\theta}{r^2} \exp(-jkr) \]

Characteristic Impedance

\[ Z_w = \left| \frac{E_\phi}{H_\theta} \right| = Z_o kr \]
2. Electromagnetic field of magnetic dipole

\[ E_\varphi = 2 \pi \cdot 10^{-7} \frac{I \cdot S \cdot f}{r^2} \text{ (V/m)} \]
\[ H_\theta = \frac{1}{4\pi} \cdot \frac{I \cdot S}{r^3} \text{ (A/m)} \]
\[ Z_W = 7.89 \cdot 10^{-6} \cdot f \cdot r \]

\[ E_\varphi = 1.32 \cdot 10^{-14} \frac{I \cdot S \cdot f^2}{r} \text{ (V/m)} \]
\[ H_\theta = \frac{E_\varphi}{377} \text{ (A/m)} \]
\[ Z_W = 377 \Omega \]
D. Radiated Coupling
Wave impedance of electromagnetic field

E/H is called wave impedance. It is an important parameter as it determines the coupling efficiency of this wave with a structure, and the efficiency of a shielding structure.

In far-field \((r > > \lambda/2\pi)\), plane wave, E and H are decreasing in the same proportion with distance.
Z is a constant and in air \(377\Omega\).

In near-field \((r < < \lambda/2\pi)\), Z is determined by the characteristics of the source.
D. Radiated Coupling

$E \propto 1/r^3$, $H \propto 1/r^2$

le champ électrique prédomine

l'impédance du champ proche peut se situer n'importe où dans cette région

onde plane
$Z_0 = 377 \Omega$

$H \propto 1/r^3$, $E \propto 1/r^2$

le champ magnétique prédomine

zone de transition

champ proche

champ lointain

distance de la source, normalisée à $\lambda/2\pi$
D. Radiated Coupling
Far-field – near-field

Rayleigh criterion

This criterion is related to the radiating diagram of an antenna, too large to be considered as a punctual source. To consider a far-field condition as acceptable, it is needed that the phase shift of the components of the radiated field from the 2 ends of the antenna is small, regarding $\lambda$.
We have a criterion related to $\lambda$ and maximum dimension $D$ of antenna:

\[ d \ggg 2D^2/\lambda \]
Disturbances and Power Quality

Véronique Beauvois, Ir.
2018-2019
An electromagnetic phenomenon susceptible to degrade the performances of an apparatus or system.
• frequency: L.F. / H.F.
• conducted / radiated
• narrowband / broadband
• duration (t): permanent, repetitive, transient, random
• common mode/differential mode
Types of disturbances - Classification

Frequency: L.F. / H.F.

- $0 \leq f \leq \ldots 1$ MHz
- conducted

- $f > 30$ MHz
- radiated
Types of disturbances - Classification

Conducted Voltage/current

Radiated Electric/Magnetic fields
Types of disturbances - Classification

Narrowband (disturbance bandwidth < receiver’s one)
Broadband (disturbance bandwidth > receiver’s one)
Common Mode – Differential Mode
3-phase systems

\[ v_a(t) = \sqrt{2}V \cos(\omega t + \phi_a) \]
\[ v_b(t) = \sqrt{2}V \cos(\omega t + \phi_a - \frac{2\pi}{3}) \]
\[ = \sqrt{2}V \cos(\omega (t - \frac{T}{3}) + \phi_u) \]
\[ v_c(t) = \sqrt{2}V \cos(\omega t + \phi_a - \frac{4\pi}{3}) \]
\[ = \sqrt{2}V \cos(\omega (t - \frac{2T}{3}) + \phi_u) \]

Parameters:
- frequency (50 Hz)
- amplitude (V)
- waveshape (sinusoidal)
- symmetry (phase shift 120°)
1. Frequency – Deviation

Frequency variations are very small (less than 1 %) in the European network (mesh). Consequently, very few problems for electronic equipment.

In a small isolated network (e.g. island or emergency power system), the situation is different. Some process need a very precise control of speed and frequency variation could disturb.
2. Amplitude

2.1 Voltage dips and short interruptions
Voltage dips could be related to short-circuit in the network or at the customer premises (defaults, atmospheric problems, …).
In this case only drop of voltages more than 10 % are considered (otherwise they are voltage fluctuations).
Definition of voltage dip [EN 50160] : quick reduction of power supply at a value between 90 % and 1 % of the nominal voltage, followed by a recovering very soon. Duration from 10 ms to 1 min., by definition.
Short interruptions [EN 50160] : reduction of power supply under 1 % of the nominal voltage. Short : less than 3 minutes.
Consequences : some equipment could stop, if the depth and duration are over certain limits (according to the sensitivity of the load).
2. **Amplitude**

2.2 Voltage fluctuations / Flicker

In some installations, quick variations of power (produced or consumed) could be observed (welding, wind turbines, arc furnaces, air conditioning, …). This could lead to voltage variations. Flicker [EN 50160]: visible change in brightness of a lamp due to rapid fluctuations in the voltage of the power supply. The voltage drop is generated over the source impedance of the grid by the changing load current of an equipment (frequent starting of an elevator motor, air conditioning systems, arc furnaces, welding machines, …). Effects in the band 0.5-25Hz. Major consequences on lamps.

Standards

EN 61000-3-3 (I < 16A)
EN 61000-3-11 (16A < I < 75A)
3. Waveshape

3.1 Harmonics / Interharmonics
Harmonics: components of frequencies which are multiple of fundamental (50Hz) and create a distortion of the sinusoidal waveshape.

Interharmonics: components which are non integer multiples of fundamentals (very rare, arc furnaces, static frequency converters for low speed applications and cycloconverters, e.g. cement crushers). $K.f_m \pm k.f_o$ ($f_m$ is mains frequency and $f_o$ for output frequency).
We have seen that a periodic signal could be represented by a sum of sinus with different amplitudes and phases, with frequency multiple integer of fundamental (frequency f). **Harmonics.**

\[ f(t) = a_0 + \sum_{n=1}^{N} a_n \sin(n \omega t) + \sum_{n=1}^{N} b_n \cos(n \omega t) \]
Harmonics

Origin?
All non linear loads are associated with a non sinusoidal current and generates harmonics

Sources?
inverters, choppers, dc-dc converters
• rectifiers
• speed controllers
• frequency converters
• dimmers
• lighting
• Induction heating systems
• Saturated magnetic circuits
Consequences?

Heating (motors, transformers, cables, …)
Losses (transformers)
Saturation (transformers)
Additional torque components (motors)
Resonance (Q compensation capacitors)
Homopolar components (H3)
Defaults (power electronics, IT, relays, controlers, …)

…
3. Waveshape

3.2 Transient
Overvoltages: related to the release of low voltage apparatus, inductive loads, capacitor banks start (Q compensation) and fuse fusion.

Sinusoidal damped overvoltages: some actions on the medium voltage network as a breaker opening or closing, switches disconnection, … may cause a voltage variation which excites the line with a very short pulse with a short rise time. The consequence is a damped sinus.
3. Waveshape
3.2 Transient
Burst

Types of disturbances

- **Pulse**: 200 µs at 5 kHz, 10 µs at 100 kHz
- **Burst**: 15 ms at 5 kHz, 0.75 ms at 100 kHz, Burst period 300 ms

Frequency range: 0…200MHz…
3. Waveshape
3.2 Transient Surge

4kV

Normalized waveshape
Voltage 1,2/50\,\mu s
Current 8/20\,\mu s

\[ T_1 = 1,2\,\mu s, \quad T_2 = 50\,\mu s \]

0…100MHz…
4. Symmetry / Unbalance

Dissymmetry in the network are very small.

The main problem is the one-phase loading in a 3-phase network, and the repartition of those loads.

Consequences: additional heating and flickering problems.
Types of disturbances

DEFINITION OF POWER QUALITY (PQ)
Power Quality = Voltage Continuity + Voltage Quality

Voltage Continuity
(Reliability of Supply)
- long interruptions

Voltage Quality
- frequency - deviations
- magnitude - deviations
  - dips & short interruptions
  - flicker
- waveform - (inter)harmonics
- symmetry - unbalance
Examples

Véronique Beauvois, Ir.
2018-2019
One of the major effects due to harmonics is the increasing of RMS currents in the mains.

Harmonic 3 in phase
- Sum is not zero
- Sum in neutral: $3 \times I_{phase}$
- Heating
- Destruction risk
- Diameter of cabling should be adapted

(same for 3k multiples)
A. Harmonics – Neutral and cables diameter

Distortion rate

<table>
<thead>
<tr>
<th>Current</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1 225A</td>
<td>81.3 %</td>
</tr>
<tr>
<td>I3 183A</td>
<td>67.6 %</td>
</tr>
<tr>
<td>I5 152A</td>
<td>52.4 %</td>
</tr>
</tbody>
</table>

\[ \text{Iph} = 348A \times 1.55 \times I1 \] (RMS of harmonics)

\[ \text{In} = 3 \times 183A = 549A \times 2.44 \times I1 \]

Phases: 225A > 70mm² with Hn 150mm² (385A)
Neutral > 35mm² with Hn 300mm² (615A)

Based on R.G.I.E.
### B. Eco light

**Maximum RMS current and corresponding values in time window 1:**

| Voltage: | 230.46 Vrms |
| Current: | 0.053 Arms |
| Power: | 6.7 W |
| Powerfactor: | 0.551 |

**Test conditions:**
- EN 61000-3-2:2006
- f=50 Hz
- Phase=1
- Range=0.80 A
- Rated power: 100 W
- Time window cycles=16
- Grouping of harmonics=off

**HARMONIC ANALYSIS: Test FAIL**

<table>
<thead>
<tr>
<th>Hₐ</th>
<th>Maximum Window</th>
<th>EN61000-3-2</th>
<th>Margin in MaxWin</th>
<th>100 to 150%</th>
<th>150 to 200%</th>
<th>Exceeded</th>
<th>100 to 150% Exceeded</th>
<th>150 to 200% Exceeded</th>
<th>Average Value</th>
<th>Exceeded</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>0.0013 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0013 A</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.0316 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0316 A</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.0001 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0001 A</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.0276 A</td>
<td>1</td>
<td>0.0229 A</td>
<td>20.6 %</td>
<td>1</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0276 A</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0.0001 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0001 A</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0.0209 A</td>
<td>1</td>
<td>0.0128 A</td>
<td>63.0 %</td>
<td>1</td>
<td>1</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0209 A</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0.0136 A</td>
<td>1</td>
<td>0.0067 A</td>
<td>100.5 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0136 A</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0.0067 A</td>
<td>1</td>
<td>0.0034 A</td>
<td>144.1 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0067 A</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>0.0001 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0001 A</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0.0069 A</td>
<td>1</td>
<td>0.0024 A</td>
<td>169.8 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0069 A</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0.0069 A</td>
<td>1</td>
<td>0.0020 A</td>
<td>244.3 %</td>
<td>1</td>
<td>1</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0069 A</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0.0061 A</td>
<td>1</td>
<td>0.0017 A</td>
<td>252.7 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0061 A</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>0.0050 A</td>
<td>1</td>
<td>0.0015 A</td>
<td>226.0 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0050 A</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>0.0045 A</td>
<td>1</td>
<td>0.0014 A</td>
<td>231.6 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0045 A</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.0000 A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>n.e.</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0000 A</td>
<td>0</td>
</tr>
</tbody>
</table>
B. Eco light

Power: 6.7 W (limit: 25 W) PASS
Harmonic 2: 37.6 mA < 614 % (limit 61 %) PASS
Harmonic 3: 26.0 mA < 663 % (limit 61 %) PASS
Current flow starts before 90°
Last pulse reached between 90°
Current flow doesn’t stop before 90°
Specimen is class C by Z (P < 25W) if it is lighting equipment

HARMONIC ANALYSIS, Test FN1 in Time window 1 of 1
### C. LED

**Name:** *PBE  
**Department:** Laboratoire CEM  
**Company:** Université de Liège - ACE  
**Serial no.:** Operating modes: EUT ON  
**Test report no:** dimming  
**Device:** 0055  
**Specimen:** B  
**Manufacturer:** AAAN  
**Type:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>230.44 Vrms</td>
<td>THD=0.01 %</td>
</tr>
<tr>
<td>Current</td>
<td>0.066 Arms</td>
<td>0.121 Apk</td>
</tr>
<tr>
<td>Power</td>
<td>5.4 W</td>
<td>P1=5.4 W</td>
</tr>
<tr>
<td>Power factor</td>
<td>0.354</td>
<td>CosPhi1: 0.371</td>
</tr>
</tbody>
</table>

**Test conditions:** EN 61000-3-2:2006, f=50 Hz, Phase=L1, Range=0.80 A, Rated fundamental / pf: 3.0 A, 1.0  
**Time window cycles:** 16, Grouping of harmonics: off

**HARMONIC ANALYSIS: Test FAIL**

- Tobs = entire measurement; POHC: avg=0.00 A, limits=0.01 A; Rated I1/Pf exceeded, changed to 0.06 A/0.354

<table>
<thead>
<tr>
<th>Ha</th>
<th>Maximum</th>
<th>Window</th>
<th>EN61000-3-2 Class C a</th>
<th>Margin in MaxWin</th>
<th>100 to 150%</th>
<th>150 to 200%</th>
<th>100 to 150%</th>
<th>150 to 200%</th>
<th>Value</th>
<th>Exceeded</th>
<th>Average</th>
<th>P A S F A I L</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>0.0071 A</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0071 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0631 A</td>
<td>1</td>
<td>0.0013 A</td>
<td>796.2 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0631 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0113 A</td>
<td>1</td>
<td>0.0067 A</td>
<td>51.4 %</td>
<td>0</td>
<td>1</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0113 A</td>
<td>1</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0012 A</td>
<td>1</td>
<td>0.0067 A</td>
<td>-51.0 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0012 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0006 A</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0006 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0031 A</td>
<td>1</td>
<td>0.0063 A</td>
<td>-43.3 %</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0031 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0024 A</td>
<td>1</td>
<td>0.0064 A</td>
<td>...</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0024 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.0025 A</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>0</td>
<td>0</td>
<td>n.e.</td>
<td>n.e.</td>
<td>0.0025 A</td>
<td>0</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
D. Generators – Renewable Energy

Figure 4. Wind speed series

Figure 5. Disturbing current