Harmonics and transformers…
Harmonic component filter
Harmonic components: electrical network polluters.

LV and MV networks are becoming increasingly polluted by current and voltage harmonics. Harmonics are generated by non-linear loads, which are more and more frequently found in today's networks. These loads include frequency changers, constant current regulators, induction furnaces, UPSs, energy-saving lighting, discharge lamps, etc.

There are several basic methods of reducing the impact of harmonics, including:
- placing polluting loads on the upstream network,
- grouping polluting loads together,
- separating energy sources,
- using transformers with specifically designed vector groups,
- fitting equipment with inductances,
- using an appropriate earthing system.

These current and voltage harmonics can put transformers under significant stress, and may even damage them.

Solutions proposed by Schneider Electric

Schneider Electric proposes 2 solutions to this phenomenon, depending on the type and magnitude of the harmonics encountered. The two solutions may be combined if necessary:
- oversizing the transformer at the design stage,
- installing filtering systems to protect equipment.

Oversizing the transformer

Transformers must be oversized thermally to compensate for the additional specific losses caused by harmonic currents. Harmonisation documents HD 428 and HD538 recommend power reduction coefficients for oil-immersed distribution transformers and dry-type transformers in networks polluted by current harmonics. These coefficients are calculated according to the rates and orders of the current harmonics encountered.
The following graph, taken from a draft of the IEEE 519 Application Guide (1996), shows the recommended derating rate for a transformer supplying electronic loads:

![Graph showing recommended derating rate for a transformer supplying electronic loads.](image)

- Standard UTE C15-112 suggests a transformer derating factor based on the type of harmonic current encountered:

\[
k = \frac{1}{\sqrt{1 + 0.1 \sum_{h=2}^{16} h^2 T_h^2}}
\]

\[
T_h = \frac{l_h}{l_1}
\]

Typical values:
- «Rectangular» current (spectrum in 1/h(*)): \( k = 0.86 \)
- Frequency converter type current (THD ≥ 50%): \( k = 0.80 \)

(*) in fact, as is the case with all rectifiers (three-phase rectifiers, induction furnaces, etc.) the current signal closely resembles a rectangle.

- Standard ANSI C57.110 recommends a derating factor known as the « K factor », which is obtained as follows:

\[
K = \frac{\sum_{h=2}^{m} I_h^2 h^2}{\sum_{h=1}^{m} I_h^2} = \left( \frac{I_{\text{rms}}}{I_{\text{eff}}} \right)^2 h^2
\]

The K-factor, which is more restrictive, is widely used in North America.

In the following example, a « K-factor » of 13 is obtained:

<table>
<thead>
<tr>
<th>H-order harmonic</th>
<th>Harmonic current ( I_h ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h )</td>
<td>( I_h )</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>23</td>
<td>5</td>
</tr>
</tbody>
</table>

Note that a transformer sized according to this « K-factor » will be 30 to 60% more expensive depending on its rated capacity, which may vary from 15 to 500kVA.

Oversizing is only possible if the harmonic pollution level is established and given to the manufacturer before the transformer is designed.
As a guideline, for a Special Losses ratio of 10% compared with Ohmic Losses, the derating factor of power as a function of the factor Kn, to allow for harmonics, is given in the table below:

<table>
<thead>
<tr>
<th>Value of factor K</th>
<th>K4</th>
<th>K9</th>
<th>K13</th>
<th>K20</th>
<th>K30</th>
<th>K40</th>
<th>K50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Derating factor</td>
<td>0.886</td>
<td>0.761</td>
<td>0.692</td>
<td>0.606</td>
<td>0.524</td>
<td>0.469</td>
<td>0.428</td>
</tr>
</tbody>
</table>

- Do not forget that there is another preventive solution that can feasibly be used with transformers: it consists in using transformers with special vector groups, which effectively do away with some harmonic orders.

Hence:
- a "Dy" vector group stops 5th and 7th order harmonics,
- a "Dy" vector group stops 3rd order harmonics (the harmonics circulate in each phase and return via the neutral point of the transformer).
- a "Dz" vector group stops 5th order harmonics, which return via the magnetic core.

A "Dy" transformer prevents 5th and 7th order harmonics from spreading to the upstream network.

**Filtering harmonics**

In applications using power electronic components and UPSs, 2 phases of the alternative network are, from a dielectric point of view, very briefly short-circuited at each switchover. As a result, the MV and LV waveforms are distorted, harmonics appear at the switching points, and the dv/dt values at these points are very high. The presence of these voltage harmonics at the switching points puts the transformer under significant dielectric stress.

These recurring switching points (with an oscillation frequency of approximately 10 kHz) may lead to premature ageing of the transformer, or to internal resonance if the natural frequencies of the transformer windings are in line with the oscillations of the switching points.

If the preventive measures mentioned in the introduction above prove inadequate, the polluted equipment should be fitted with a filtering mechanism.

Three types of filter can be used, depending on the type of application originally causing the harmonics:
- the passive filter,
- the active filter,
- the hybrid filter.
The passive filter:

Typical applications:

- industrial installations containing a number of harmonic component generators, the overall power of which exceeds 200 kVA (speed changers, UPSs, rectifiers, etc.),
- installations requiring reactive energy compensation,
- reduction of the voltage distortion rate to protect sensitive receivers,
- reduction of the current distortion rate to prevent overloads.

Operating principle:

A loop circuit (LC) is tuned to each harmonic frequency and, at the same time, to the harmonic component generator. This branch circuit absorbs the harmonics and prevents them from circulating in the power supply.

Passive filter operating principle

The passive filter is usually tuned to a harmonic order similar to that which needs to be eliminated. Several branches of filters can be used at the same time if the distortion rate needs to be significantly reduced over several orders.

The active filter:

Typical applications:

- tertiary installations containing a number of harmonic component generators, the overall power of which does not exceed 200 kVA (speed changers, UPSs, office equipment, etc.),
- reduction of the current distortion rate to prevent overloads.
Operating principle:

The active filter consists of a power electronics system, which is installed in series with or parallel to the non-linear load. Its purpose is to compensate for either the stress caused by harmonics, or the harmonic currents generated by the load. The figure below shows an example of an active filter compensating for the harmonic current: $i_{har} = -i_{act}$

The active filter injects anti-phase harmonics into the load supply to cancel existing harmonics. As a result, the loop current is sinusoidal.

The hybrid filter:

Typical applications:

- industrial installations containing a number of harmonic component generators, the overall power of which exceeds 200 kVA (speed changers, UPSs, rectifiers, etc.),
- installations requiring reactive energy compensation,
- reduction of the voltage distortion rate to protect sensitive receivers,
- reduction of the current distortion rate to prevent overloads,
- compliance with strict harmonic emission requirements.

Operating principle:

The above two types of filter can be combined in the same equipment to produce a hybrid filter: see figure below.

This new filtering solution has all the advantages of existing solutions, and is appropriate for a wide range of powers and performance levels.
Filter selection criteria and guidelines:

- The **passive filter** both compensates for reactive energy and has significant current filtering capacity. The equipment in which the filter is installed must be sufficiently stable, with very little load fluctuation. If the reactive power supply is significant, the passive filter should be turned off during low load periods. Existing compensation batteries should be taken into consideration when studying the possibility of installing a passive filter, as they may subsequently have to be removed.

- The **active filter** filters harmonics over a wide frequency band. It is suitable for all loads. However, its harmonic power is limited.

- The **hybrid filter** combines the best attributes of both passive and active filters.

These criteria can be used to establish filter selection guidelines, according to the application in question:

<table>
<thead>
<tr>
<th>Application type</th>
<th>Passive filter</th>
<th>Active filter</th>
<th>hybrid filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office building (computing, air</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>conditioning, lighting, lifts)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper, cardboard, plastics industries</td>
<td>■ ■ ■</td>
<td></td>
<td>■ ■</td>
</tr>
<tr>
<td>(conveyor systems, coilers, uncoilers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water treatment industry</td>
<td>■ ■ ■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>(pumping, agitating)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling (lifting, elevators)</td>
<td>■ ■ ■</td>
<td></td>
<td>■</td>
</tr>
</tbody>
</table>

**Key:**

- **■ ■ ■** - Totally suitable
- ■ ■ - Totally suitable technically, but not cost-effective
- ■ - Satisfactory

Whichever solution you choose, you should discuss your choice carefully with your Schneider Electric representative before ordering any equipment, to avoid potentially disastrous on-site complications.