An overview of the impacts of compact fluorescent lamps implementation

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Abstract

European Union (EU) is continually promoting energy efficiency among electricity consumers. One of the latest EU activities that influence us all is to limit the use of traditional incandescent lamps by replacing them gradually with compact fluorescent lamps (CFL). By looking only on energy efficiency, the purpose seems to fulfill the target. On the same time it raises new questions so far not asked about lighting. These questions are higher harmonics, reactive power and neutral conductor current. In this paper common CFLs and their impact are investigated theoretically and supported with laboratory test results.

Keywords
CFL, harmonics, reactive power, neutral current

Introduction

In long term the energy consumption is growing and old generating units will drop off step by step. Therefore we constantly need new power plants or try to enhance our consumption. CFLs consume less energy with same luminous efficiency and last longer than usual bulbs, but their current curve is definitely not perfect sinusoid and it may be detrimental for power quality if they are used together in great numbers. So far the influence to the grid is ignored because the power of one lamp is marginal. Also the widespread use of CFLs may implicate significant reactive power and problems with higher harmonics in a grid. [1]

Higher harmonics, which CFLs generate to a grid and thereby affect the power quality, are the main issue using CFLs. Secondly what’s important is the generated reactive power which definitely needs to be investigated.

1 Theoretical background

1.1 Requirements for higher harmonics in electricity grid

Current Total Harmonic Distortion (THD) of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the currents of all harmonic components $I_n$ to the current of the fundamental frequency $I_1$.

$$THD = \sqrt{\sum_{k=2}^{50} \left(\frac{I_n}{I_1}\right)^2}$$ (1)

Some of the CFLs may have the THD over 100 %, but their active power use is not so significant compared to other harmonics generating devices. Therefore their quality requirements are not so precisely regulated. The current THD limit to the CFLs with electronic ballasts is 20 % according to IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electrotechnical Commission).

Harmonics generated by customer’s appliances must not cause voltage rise in the connection point. [14] In this article current THD value which should not be exceeded when implementing CFLs has estimated on 5 %. Fixing limits may become important before using numerous harmonics emitting devices together.

1.2 Ratio of grid voltage harmonics and CFLs current harmonics

Studies have showed that current THD which CFLs emit increases as supply harmonics level increases. The ratio is not linear and it is particularly true in case of CFLs with electronic ballast. [2, 3, 4]

In field studies the influence of power grid’s higher harmonics to the CLS harmonics generation has not been notable. It is specially because there are not yet many grids with high harmonics penetration level. The problem may occur with the rising use of CFLs with electronic ballast and other harmonics emitting devices.

1.3 CFLs influence on harmonics level

Power Factor (PF) is defined as the ratio of the sum of all real power components $P$ to the sum of all apparent power components $S$ in the circuit. PF is dimensionless number between 0 and 1 and is here calculated with equation 2

$$PF = \frac{P}{S}$$ (2)

Implementation of CFLs brings up a problem with higher harmonics. Penetration of higher harmonics rises as number of installed CFLs increase.

Concrete example of increasing harmonics is a field study [4] where were installed 2500 CFLs. All harmonics increased, but not over the limit fixed for
single harmonics. However the current THD 12.7 % crossed optimal 5 % level highly. 5 % THD was reached already at 920 lamps.

Other analysis [1] was done where all bulbs were replaced with CFLs in one household. After the replacement CFLs constituted to 26.3 % of overall load and PF fell down to 0.65 and voltage distortion rose up to 4.4 %. All those figures were within limits, only the current THD increased to unacceptable 23.5 %.

1.4 Reactive power of CFLs

\[ \text{Cos } \varphi = \frac{P_1}{S_1} \]  

(3)

Considering losses in the transferring of reactive power in transformers and power lines it should be minimized. However the reactive power is inherent phenomenon of CFLs.

If the cos \( \varphi \) of the CFLs is usually about 0.9 the PF may be very different. Average PF is around 0.5-0.6 which means that lamp generates much more reactive power to the grid than it consumes active power.

For example in one test [5] thousand 60 W incandescent lamps were replaced with 7 W CFLs. The reactive power increased from 0 to 8848 var.

1.5 Neutral conductor current

In electrical schemes lamps are usually balanced with neutral and phases. In symmetrical situation with electronically ballasted CFLs triple harmonics (3rd, 9th, 15th etc) may aggregate and cause the overload in neutral conductor. In the worst case the neutral current may exceed phase current \( \sqrt{3} \) times. [6]

Harmonics from single phase appliances spread over all three phases. The neutral current is equal to sum of currents from all three phase. In the case of symmetrical CFL load triple harmonics are in phase and are added arithmetically in neutral. Other harmonics cancel each other out. [7]

1.6 Losses caused by CFLs

Distribution transformers are affected in two ways. First, the eddy current losses increase with the square of the harmonic number. The second effect concerns the triple harmonics (3rd, 9th, 15th etc), which circulate in the delta winding of the transformer and may damage it due to increased thermal losses. [8]

In one experiment [9] results showed 33 % active loss increase when incandescent lamps where replaced with CFLs. Values of different losses are given in Table 1.

Transformer losses \( P_T \) are divided into no load losses \( P_{NL} \) and load losses \( P_{LL} \) as [10]:

\[ P_T = P_{NL} + P_{LL} \]  

(4)

\( P_{NL} \) are the losses due to the voltage excitation of the core. \( P_{LL} \) is expressed as [11, 12]:

\[ P_{LL} = \Gamma \overline{R} + P_{EC} + P_{OSL}, \]  

(5)

where

\( \Gamma \overline{R} \) losses due to load current and DC winding resistance, \( W \);

\( P_{EC} \) winding eddy current losses, \( W \);

\( P_{OSL} \) other stray losses are due to losses in structures other than windings, \( W \).

Table 1. Losses in transformer [9]

<table>
<thead>
<tr>
<th>Measured value, W</th>
<th>CFLs</th>
<th>Incandescent lamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_T )</td>
<td>20.8</td>
<td>15.6</td>
</tr>
<tr>
<td>( P_{NL} )</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>( P_{LL} )</td>
<td>13.1</td>
<td>7.9</td>
</tr>
<tr>
<td>( P_{EC} )</td>
<td>4.1</td>
<td>1.5</td>
</tr>
<tr>
<td>( P_{OSL} )</td>
<td>3.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Also the temperature of transformer was measured in the case [9]. In the case of common bulbs the transformer’s maximum temperature was 59.8 °C, but after the replacement the temperature was 67.6 °C. It makes impressive near 12 % growth.

2 Laboratory tests

All tests were done with two types of lamps which are sold in ordinary supermarkets. Lamps were divided in two:

- Set 1 – Osram brand lamps with price about 5 €;
- Set 2 – lamps without producer’s label and with price about 2 €.

Set 2 had poorer characteristics. With the same active power difference in reactive power consumption was 10 % and in apparent power 6.7 % accordingly. Other values of measured parameters are given in Table 2.

Table 2. Measured parameters of CFLs.

<table>
<thead>
<tr>
<th></th>
<th>Set 1</th>
<th>Set 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cos ( \varphi )</td>
<td>0.892</td>
<td>0.921</td>
</tr>
<tr>
<td>PF</td>
<td>0.607</td>
<td>0.569</td>
</tr>
<tr>
<td>Reactive power, var</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Current THD, %</td>
<td>104</td>
<td>120</td>
</tr>
</tbody>
</table>

Set 2 had much higher harmonics content than set 1. The obvious differences were in all single harmonics up to 25th. It is clearly seen from Fig.1.
2.1 Adding the CFLs

Motive of this test was to see how power consumption changes when quantity of lamps were changed in scheme. Values were taken at points when 2, 4, 6, 8 and 10 lamps were in installed.

Fig. 2 shows apparent power, reactive power and active power values in situations of different number of CFLs in scheme. All power components rose linearly when lamps were added. No compensation was discovered.

2.2 Adding an active load

Goal of this experiment was to reach 5 % current THD level by adding active load to scheme. Number of CFLs in the scheme was constantly 10 and their aggregated active load 140 W.

Achieving the goal needed additional active load 280 more than CFLs own aggregated load. At beginning current THD decreased rapidly when load was added, but before achieving the fixed 5 % goal it slows down. Whole curve is shown in Fig.3.

2.3 Three phase test

The idea of this test was to investigate the current neutral conductor. In this case CFLs were installed symmetrically in three phases. Test started with 2 lamps for one phase, then 3 and finally 4.

Results were almost the worst theoretically can be. With different number of lamps the neutral current was always 70 % higher than phase current.
This kind of difference in currents and aggregation of harmonics in neutral conductor makes grid engineering much more complicated compared to the case of incandescent bulbs. Placing all the CLFs symmetrically between phases the current in neutral conductor may raise unreasonably high. Installing all lamps in one phase makes the harmonics go up.

**Conclusion**

Higher harmonics cause energy losses, overheating of appliances, overvoltage, vibration and mechanical stress. Reactive power reduces overall power capacity of electricity transmission. High neutral current may cause malfunction of sensitive load.

Harmonics are inherent phenomenon of using CFLs, because average price level lamp generates current with 110 % THD. Great amount active power next to them hides the harmonics.

Average \( \cos \phi \) of the CFL is about 0.9 and PF 0.5...0.6 which means that remarkable reactive power is consumed even though the \( \cos \phi \) is high. So in the case of CFLs it should be considered that the reactive power generation is not clarified only by \( \cos \phi \).

Lighting units are most commonly divided symmetrically between phases. If there is a great number of CFLs the triple harmonics aggregate and may cause high current in neutral conductor.

**References**