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The voltage distortion in low-voltage networks caused by compact fluorescent lamps with electronic gear

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Abstract

Commonly used compact fluorescent lamps (CFLs) with electronic gear are characterized by extremely distorted current, with total harmonic distortion (THD) usually exceeding 100%. That is why they cause a significant voltage distortion in electrical installations. The principal goal of this research was to determine their maximum permissible share in the total load installed for commercial customers, at which voltage distortion is still acceptable (according to international standards). An analysis regarding a low-voltage electrical installation of a hotel, representing a typical commercial customer, showed that maximum permissible share should not exceed 10%. As this maximum permissible share could restrict the installment of the intended quantity of CFLs, the costs of two possible solutions for this problem – the use of filters or a new generation of CFLs with a high power factor – are compared.

Keywords: Compact fluorescent lamps; Harmonics; Power quality; Voltage distortion

1. Introduction

A few decades ago the idea of using efficacious and long-aged fluorescent lamps in those applications that were traditionally the province of inefficacious and short-aged incandescent lamps has resulted in the development of compact fluorescent lamps (CFLs). Compact fluorescent lamps with conventional caps (compatible CFLs) were primarily intended for residential and commercial customers. Lasting much longer and consuming much less energy than incandescent lamps with comparable luminous output, they represented promising new lamp types. As a part of their energy-saving strategy, many power utilities were promoting the use of CFLs, even offering to partially support the reduction of their relatively high purchase prices. Economic analyses presented in [1,2] also showed an obvious advantage of the use of compact fluorescent lamps compared with incandescent ones.

The basic problem arising from a possible mass application of CFLs is the problem of network voltage distortion, occurring due to their distorted currents, containing a high level of harmonic components even at pure sine wave supply voltage. A large number of papers were published dealing with the behaviour of CFLs under various exploitation conditions, i.e., under various voltage distortions and different root mean square (rms) values of the network voltage. A survey of selected papers is given in Section 4. On the contrary, a small number of analyses were published dealing with the influence of CFLs on power networks.

In [3] an analysis of a medium-voltage network of 13.8 kV with three different feeders, each with a load of 10 MV A, was made. The results showed that 3000–4000 residential customers in a 10 MV A feeder, all of them having two or three CFLs per home, would cause voltage distortion with THD greater than 5%, which is less than the planning level of 6.5%, typical for the utilities, as stated in IEC/TR3 61000-

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3-6 [4]. During the last few years, international standards were adopted for harmonic current emission (IEC 61000-3-2 [5]) and for voltage distortion (IEC/TR3 61000-3-6 [4]). In IEC/TR3 61000-3-6 the terms "planning level" and "compatibility level" are introduced and discussed. They relate to the individual harmonics, as well as to the total harmonic distortion. Based on these standards, it is possible to analyze the harmonic distortion in a network caused by CFLs. The most important question is to determine the maximum permissible share of CFLs which will be acceptable regarding the voltage distortion. Such an analysis, concerning the low-voltage network (with the greatest harmonic components impact), is presented in this paper. An example of a typical hotel electrical installation was analyzed, where a considerable share of CFLs participates in the total load installed. Other nonlinear loads (TV sets, computers, electronic devices, etc.) have also to be taken into account, since they influence significantly the voltage distortion. They reduce the maximum permissible share of CFLs. Note that hotels can be considered a good representative of commercial customers, which also include offices, department stores, shopping centres, hospitals, etc.

The principles applied in this analysis have a more general significance. They can also be used for an analysis regarding the electrical installation with a large number of smaller loads having highly distorted current. The results concerning the influence of the capacitors and filters on the voltage distortion also have a more general importance.

2. Relevant standards

In general, the voltage-distortion problem (its deviation from pure sine wave function) has risen with the mass use of equipment containing power electronic elements (mainly, input rectifiers). This is why during the last decade a considerable effort was spent to provide, through international standards, some recommendations for allowable harmonic levels. On one hand, the standards protect the customers from the consequences of bad-quality network voltage, by prescribing the maximum permitted values of individual harmonics, as well as of the total harmonic distortion of the supply voltage. IEC/TR3 61000-3-6 [4] contains the allowable levels for low-, medium-, high- and ultrahigh-voltage systems. Since this paper deals with the analysis of low-voltage electrical installations, only the data from IEC/TR361000-3-6 relevant for this voltage level are presented in Table 1.

On the other hand, the standards protect the power utilities (i.e. electric power network), forbidding too high current harmonic components produced by the customers' load. IEC 61000-3-2 [5] provides the maximum allowable values of the harmonic current emission of the equipment with input current not exceeding 16 A per phase. It is obvious that it was particularly difficult to adopt the limits for self-ballasted CFLs with electronic gear, omitted in the 1995 edition of this standard. In the valid 1998 standard, the maximum current levels, expressed in mA per lamp wattage (valid for wattages not exceeding 25 W), were adopted. They are given in Table 2. The third column, showing rms current I_ν of the νth harmonic with respect to rms current I_1 of the fundamental one, was determined on the basis of second column and the assumption that the current fundamental harmonic is equal to the ratio of active power and voltage (voltage of 230 V was adopted).

Note that IEC 61000-3-2 [5] allows somewhat higher limits for the harmonic current emission if some particular requests concerning the current waveform are fulfilled.

Table 2
Harmonic current limits for CFLs according to IEC 61000-3-2 (2001) [5]

Harmonic order ν	Maximum permissible harmonic current per watt (mA/W)	Maximum permissible harmonic current in % of fundamental
3	3.4	78.2
5	1.9	43.7
7	1.0	23
9	0.5	11.5
11	0.35	8.05
13	0.30	6.9
$15 \leq \nu \leq 39$ (odd harmonics only)	$3.85/\nu$	$88.55/\nu$

Table 1
Harmonic voltage limits in LV and MV power systems according to IEC/TR361000-3-6 [4]

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Order ν	Harmonic voltage (%)	Order ν	Harmonic voltage (%)	Order ν	Harmonic voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2	> 21	0.2	10	0.5
19	1.5			12	0.2
23	1.5			>12	0.2
25	1.5				
$\nu > 25$	$0.2 + 1.3 \times (25/\nu)$				

Note: total harmonic distortion (THD) is 8%.