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Power Quality Behavior of Commercial Grade LED Lamps

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Abstract – *The utilization of LED technology in lighting applications has been increasing during the last several years. Parameters like efficiency, reliability, chromatic response and cost are important to consider this technology as a competitive one. LED technology involves power converters so overall Power Quality performance has to be analyzed in terms of emission and susceptibility. This paper reviews the Power Quality behavior of some commercial grade LED lamps and establishes a comparison with the long established incandescent lamp.*

Keywords: *Power Quality, LED Lamp, Flicker, Harmonics*

I. Introduction

LED lamps are semiconductor light sources based on the physical effect of electroluminescence. This technology cannot be considered a new one as it has been widely used in electronic appliances over the last ten years. The color of the light emitted is defined by the energy gap of the semiconductor. From an electrical point of view, LEDs present some advantages over incandescent technology, such as better efficiency figures, longer lifetime, improved robustness, excellent volumetric and gravimetric energy densities and faster switching.

From a Power Quality point of view, it is important to compare this technology with others that are available, widely used and well known, like incandescent, compact fluorescent lamp (CFL) and High-Power High-Intensity Discharge (HID).

CFL technology is also known as compact fluorescent light or energy saving light. The lamps are of the gas-discharge type and the technology can be regarded as the first serious approach to replace the incandescent lamp in the domestic environment. From a design point of view this technology can be considered a type of fluorescent lamp, in spite of the fact that the bulbs can fit into most existing light fixtures widely used for incandescent lamps. The behavior of both types of lamps (incandescent and fluorescent) in terms of flicker emission has been analyzed in the past [1].

The HID lamp also belongs to the family of gas-discharge lamps. By increasing the gas pressure they provide better performance. Their flicker response has also been analyzed in recent papers [2]-[4].

From a Power Quality point of view, an increase in harmonic distortion generates additional transformer losses in windings and hot spots, resulting in increased stress on tbe insulation of the transformer. This stress can reduce the useful life of the entire machine [5]. In addition, harmonic distortion produces extra losses in other components, such as cables and electric motors.

Table 1 presents a concise comparison of incandescent light bulbs, CFL and LED lamps in terms of their basic characteristics.The color rendering index (CRI) is a parameter that can be used to measure the ability of a type of light source to reproduce colors in an accurate way compared with an ideal or natural light source. A CRI value below 60 means that the lamp has a poor chromatic response. If the value is between 80 and 100, the lamp can be considered a good lamp in terms of chromatic response.

TABLE I
COMPARISON BETWEEN INCANDESCENT, CFL AND LED LAMPS

Feature	Inc.	CFL	LED
Relative Watts per bulb	1/10	1/4	1
Relative expected lifespan	40	8.5	1
Relative cost per bulb	15-30	4	1
Color rendering index (CRI)	70-95	15-85	100

(Inc.- Incandescent lamp)

II. LED Drivers and Lamps

There are several approaches for driving LED lamps. All of them include an ac-to-dc converter. In some cases a dc-to-dc converter is also used. The various architectures can be regulated or unregulated.

Fig. 1 shows an inexpensive LED lamp driver including a bridge rectifier plus a capacitor.

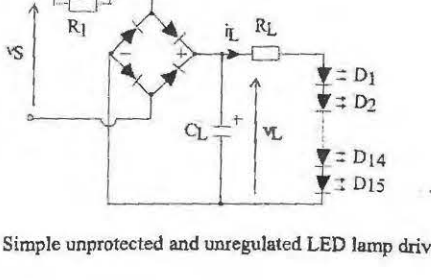

Fig. 1. Simple unprotected and unregulated LED lamp driver

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This approach is unregulated and can be considered suitable to drop the voltage from 230 Vac to the dc voltage required for the LEDs. The capacitor C_1 behaves as a voltage dropping impedance and ensures that the current remains below the maximum value. The current distortion produced by this design includes odd harmonics. Fig. 2 shows another simple unregulated LED lamp driver. I contrast to the driver in Fig. 1, it includes protection against surges and spikes. The resistance R_1 and the capacitor C_1 are used for limiting the current during normal operation.

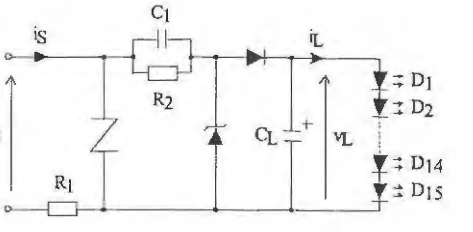

Fig. 2. Simple unregulated LED lamp driver with protection against surges and spikes.

The architecture of the circuits shown in Fig. 1 and Fig. 2 is similar. The difference between the two circuits relates to their behavior against disturbances and inrush currents during transients.

Another inexpensive approach for LED lamp drivers is shown in Fig. 3. This circuit includes an ac-to-dc plus a dc-to-dc converter.

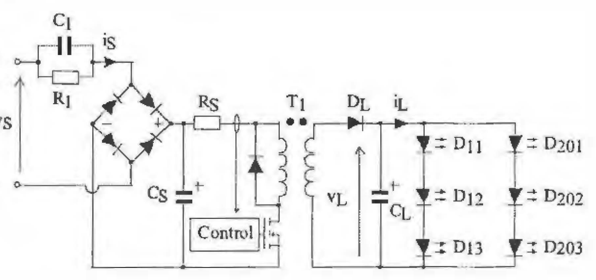

Fig. 3. Simple regulated LED lamp driver with intermediate dc-to-dc converter

III. Power Quality problems

Power Quality from an electromagnetic compatibility (EMC) point of view gives us an idea of the capability of an electrical or electronic system, equipment or device to operate in a specific electromagnetic environment at design levels of achievement without experiencing unacceptable degradation of operational performance.

In this paper we focus on the behavior of LED lamps under flicker and the role they play in the voltage distortion increase of low-voltage (LV) distribution networks.

III.1. Harmonic distortion

Harmonic distortion is one of the main problems associated with Power Quality. It is related with the existence of frequency components added to the main frequency. These components are mainly produced by non-linear loads [6]. The Total Harmonic Distortion (THD) is commonly used to quantify the degree of distortion of a voltage or current waveform. The general expression is defined as:

$$THD = \frac{\sqrt{\sum_{h=0}^{H} X_h^2}}{X_1} \qquad (1)$$

whereX_h is the rms value of harmonic h of the voltage signal or current $x(t)$.

The standard IEC 61000-3-2 [7] assesses and sets the limit for equipment that draws input current up to 16 amps per phase. When the equipment draws current between 16 and 75 amps per phase, it is necessary to use IEC 61000-3-12 [8]. In both cases the harmonics measurement and evaluation methods are governed hy IEC 61000-4-7 [9].

From the point of view of the distribution network, the limit in North America is defined by the standard IEEE 519 [10] that evaluates expression (1) with h varying from 2 to H. The most recent standard IEEE 1459 [11] devoted to power definitions under non-sinusoidal conditions includes the dc component in the numerator, so expression (1) is used. In Europe, the limits for voltage distortion are defined by standard EN 50160 [12].

III.2. Flicker

Flicker can be defined as the effects produced on humans by the variation of the light emitted by lamps that are supplied with a voltage that is modulated in amplitude. The maximum modulation levels are defined by the type of modulation and its frequency. The standard IEC 61000-3-3 [13] defines the maximum flicker emission levels for loads with current consumption less or equal to 16 A. Annex A.2 defines the test conditions for evaluating the flicker emission of equipment whose primary function is the supply and/or regulation of lamps, including LEDs. The evaluation of the P_{st} andP_{lt} has to be done only when the illumination system is capable of producing flicker. That is the case of numerous automatically regulated applications such as those commonly used in discos.

From the point of view of the Distribution System Operator (DSO), the European standard EN 50160 [12] defines the maximum value of the $P_{st}$and P_{lt}. The document establishes a limit of 1 for 95% of the values measured in any one week measurement period. In North America, the reference values are defined by the standard IEEE 1453[14]. This document uses IEC 61000-4-15 [15] as the measurement method and establishes compatibility levels in LV networks for P_{st} and P_{lt} of 1.0 and 0.8 respectively.

The IEC 61000-4-15[15] defines the functional and design specifications for a device intended for flicker measurement. The document provides the information needed for manufacturing the instrument. The main drawback of this document is that the flicker evaluation is related with a 60 W incandescent lamp [1].

A normalized flicker response F_N[1], [2], [4], [16] has been defined in order to carry out a comparison of different commercial grade LED lamps in terms of their flicker response to voltage supply modulations. The parameter F_N is defined as:

$$F_N = \sqrt{\frac{1}{S^2_{opt,rms}} \sum_{h=h_s}^{h_e} (W(hf_0)S_{opt}(hf_0))^2} \qquad (2)$$

where:

- $S_{opt}(f)$ is the frequency spectrum of the instantaneous intensity of light $s_{opt}(t)$.
- $S_{opt,rms}$ is the rms value of the instantaneous intensity of light.
- $W(f)$ is the weighting curve defined by IEC 61000-4-15.

This transfer function represents the human eye response.

IV. Set-Up Facility

The set-up facility is based on a dark-box containing the illumination system under test and a calibrated luxometer. This equipment produces a voltage signal proportional to the intensity of visible light. Fig. 4 summarizes the architecture of the set-up facility.

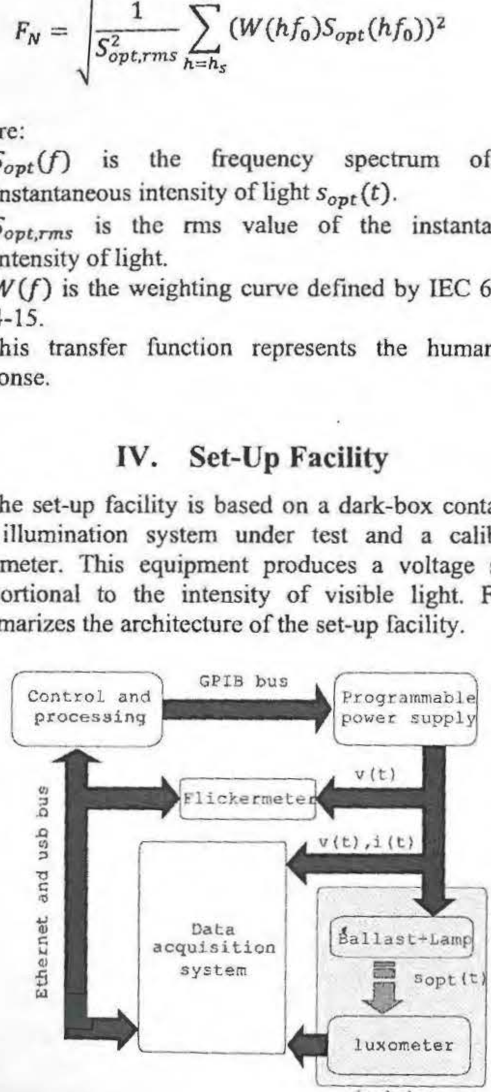

Fig. 4. Architecture of the set-up facility

The methodology applied in order to study the behavior of the LED lamps is summarized in the following steps:

1. Define the voltage waveform (modulation frequency and amplitude) as a function of the P_{st}.
2. Synthesize the voltage waveform defined in point 1 with an arbitrary waveform linear power source [17].
3. Record the voltage $v(t)$, current $i(t)$, flicker P_{st}, and the instantaneous intensity of visible light $s_{opt}(t)$.
4. Compute the instantaneous flicker perception F_N.

Fig. 5 shows the test system with the dark-box, the arbitrary waveform power supply and the data acquisition system.

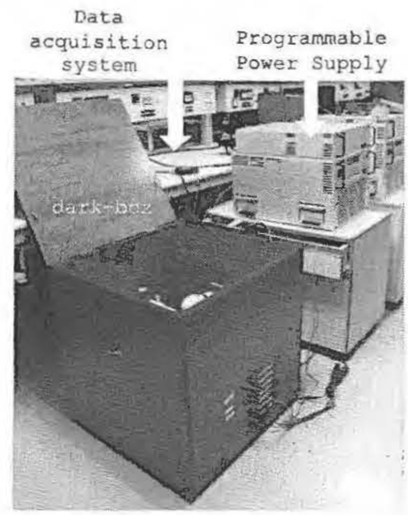

Fig. 5. Set-up facility

V. Results

The evaluation of the behavior of the available commercial technology has been done using ten different lamps. Table II summarizes the basic electrical parameters associated with the consumption for each lamp.

TABLE II
BASIC ELECTRICAL PARAMETERS ASSOCIATED WITH THE LAMPS UNDER TEST

Lamp	Vrms [V]	Irms [A]	S [VA]	P [W]	Q [var]	PF
Inc.	*235.6*	*276.9*	*65.24*	*65.14*	*3.46*	*0.99*
L1	*235.8*	*58.3*	*13.74*	*6.3*	*12.2*	*0.45*
L2	*235.9*	*19.5*	*4.61*	*0.89*	*4.52*	*0.19*
L3	*235.7*	*105.2*	*24.79*	*5.05*	*24.27*	*0.2*
L4	*235.9*	*53.3*	*12.57*	*3.02*	*12.2*	*0.24*
L5	*235.7*	*53.0*	*12.49*	*3.15*	*12.08*	*0.25*
L6	*235.9*	*51.7*	*12.2*	*3.21*	*11.77*	*0.26*
L7	*235.8*	*65.3*	*15.4*	*5.92*	*14.21*	*0.38*
L8	*235.7*	*52.5*	*12.38*	*6.33*	*10.64*	*0.51*
L9	*235.7*	*42.3*	*9.96*	*1.04*	*9.91*	*0.1*
L10	*235.8*	*18.3*	*4.31*	*1.03*	*4.18*	*0.24*

Inc.- Incandescent lamp. *Lx.- LED lamp number x.*

It is important to highlight that none of the ten commercial LED lamps that were analyzed includes a power factor corrector (PFC). Table III shows the normalized instantaneous flicker perception F_N.

The reference value is the F_N produced by a 230 V, 60 W, incandescent lamp. As an example, a CFLor a HID lamp exhibits a normalized F_N that can be up to 300 times larger.

Table IV summarizes the basic harmonic distortion parameters associated with the lamps under test. From the point of view of the harmonic distortion there are important differences in terms of their THDF-i.

TABLE III
NORMALIZED INSTANTANEOUS FLICKER PERCEPTION F_N ASSOCIATED WITH THE LAMPS UNDER TEST

f_m	1			10			20		
ΔV(%)	5	7.5	10	5	7.5	10	5	7.5	10
Inc.(1)	*6.78/1.00*	*10.64/1.00*	*14.54/1.00*	*16.77/1.00*	*26.33/1.00*	*35.99/1.00*	*6.25/1.00*	*9.84/1.00*	*13.45/1.00*
L1	*0.00439*	*0.00246*	*0.00192*	*0.00766*	*0.00395*	*0.00387*	*0.00888*	*0.00642*	*0.00350*
L2	*0.00070*	*0.00043*	*0.00046*	*0.00079*	*0.00070*	*0.00058*	*0.00145*	*0.00109*	*0.00094*
L3	*0.00215*	*0.00193*	*0.00202*	*0.00294*	*0.00283*	*0.00302*	*0.00363*	*0.00402*	*0.00413*
L4	*0.00065*	*0.00057*	*0.00062*	*0.00106*	*0.00110*	*0.00060*	*0.00235*	*0.00201*	*0.00125*
L5	*0.00272*	*0.00286*	*0.00296*	*0.00458*	*0.00443*	*0.00404*	*0.00463*	*0.00370*	*0.00353*
L6	*0.00235*	*0.00388*	*0.00317*	*0.00317*	*0.00323*	*0.00328*	*0.00497*	*0.01123*	*0.00396*
L7	*0.01376*	*0.01018*	*0.00771*	*0.02231*	*0.01401*	*0.00891*	*0.03537*	*0.0196*	*0.01843*
L8	*0.01320*	*0.01026*	*0.00725*	*0.01835*	*0.01379*	*0.00986*	*0.03669*	*0.02242*	*0.01732*
L9	*0.00668*	*0.00749*	*0.00812*	*0.00928*	*0.01029*	*0.01082*	*0.01364*	*0.01412*	*0.01518*
L10	*0.00095*	*0.00131*	*0.00120*	*0.00189*	*0.00167*	*0.00166*	*0.0028*	*0.00222*	*0.00222*

(1) $P_{st}/\frac{F_N}{F_{N(Inc)}}$ *Inc.- Incandescent lamp.*   *Lx.- LED lamp number x.*

TABLE IV
BASIC HARMONIC DISTORTION PARAMETERS ASSOCIATED WITH THE LAMPS UNDER TEST

Lamp	THDF-v [%]	THDF-i [%]	I_3/I_1 [%]	I_5/I_1 [%]	I_7/I_1 [%]	I_9/I_1 [%]
Inc.	*1,9*	*2,3*	*1,5*	*0,5*	*0,2*	*0,2*
L1	*1,8*	*175,9*	*93,9*	*82,9*	*68,5*	*53,2*
L2	*1,9*	*32,6*	*17,1*	*12,9*	*7,6*	*3,1*
L3	*0,9*	*207,2*	*43,0*	*31,0*	*15,4*	*30,9*
L4	*1,8*	*142,6*	*90,2*	*71,3*	*51,4*	*33,1*
L5	*1,5*	*209,5*	*98,8*	*92,7*	*84,6*	*75,1*
L6	*1,8*	*209,4*	*98,0*	*92,7*	*84,3*	*75,8*
L7	*2,3*	*159,4*	*88,3*	*73,1*	*61,7*	*54,4*
L8	*2,0*	*171,5*	*95,3*	*83,6*	*67,6*	*53,3*
L9	*1,8*	*34,9*	*23,2*	*15,5*	*8,7*	*3,0*
L10	*0,8*	*32,4*	*22,6*	*11,6*	*9,7*	*5,2*

Inc.- Incandescent lamp.Lx.- LED lamp number x.

The evaluated commercial LED lamps exhibit a THDF-i that ranges from 32% to 209%.

VI. Conclusion

LED lamps exhibit a lower susceptibility to flicker distortion than lamps utilizing other illumination techniques. However, the current distortion is extremely high compared with other technologies. This distortion is not important in small-scale installations because of the low consumption demanded by these lamps but it must be taken into account if LED lamps are to be widely installed. It is important to highlight that almost all the commercial LED lamps analyzed do not include any PFC module. This is also an important drawback that needs to be improved in future designs. In addition, most commercial models do not include any element for overvoltage protection. This element increases the cost of the lamp but it is important in order to maintain acceptable levels of reliability and expected operational life.

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