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Light intensity variation (flicker) and harmonic emission related to LED lamps

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ABSTRACT

This paper discusses two power-quality aspects of LED lamps: harmonics and flicker. Measurements have been performed of 24 different LED lamps: the harmonic current spectrum and light intensity variations have been measured. To enable an objective comparison, the light intensity variations were measured for all the lamps when exposed to the same voltage magnitude variations. Results show a large variety in harmonic emission between different LED lamps indicating that different technologies or different components are being used within the LED lamps. Moreover the results show a large variety in light intensity variations when different LED lamps are subjected to the same voltage fluctuations. A clear correlation was found between harmonic emission and sensitivity to voltage magnitude variations. Lamps with low light intensity variations are also the ones with the highest harmonic current emission. No clear relation between active power or price and sensitivity to voltage magnitude variations was found.

1. Introduction

Lighting accounts for 19% of electricity consumption worldwide and 14% in the European Union [1]. An agreement to phase out incandescent lamps by 2012 was made among the member states of the European Union in 2009. Similar regulations aimed at phasing our incandescent lamps are in place in other countries as well (e.g. Canada in 2015, Brazil in 2015, and China in 2016). According to UK data [2], 55% of the lamps used in domestic installations in 2014 were compact fluorescent lamps (CFLs) or light emitting diode (LED) lamps; 40% were halogen. LED lamps offer a reduction in the energy use with savings of 75–80% in terms of energy consumption compared to incandescent lamps [3].

The large scale introduction of LED lamps impacts two important power-quality disturbances: harmonic distortion and light flicker. Harmonic distortion of LED lamps will be higher than of incandescent lamps, which draw a close-to-sinusoidal current when fed by a sinusoidal voltage waveform. It has been shown in Refs. [4–6] that LED lamps currently on the market show a large variety of harmonic emission and displacement power factor. The concern of especially network operators is that large quantities of these lamps will impact the grid in a negative way, for example in the form of low power factor and high levels of current harmonics. There is to date no harmonic emission limit that applies to low active power LED lamps (below 25 W); neither is there any limit on the power factor. However there are ongoing discussions in standardization groups to introduce such limits. The concern is that even though the absolute value of the emission from one lamp might be low, lamps are likely to be installed in large quantities and the combined emission resulting from the lamps might be significant. Papers indicating this significant emission are usually based on simulations [7,8]. However, there are studies based on field measurements [9,10], and laboratory measurements [11–13], showing that the impact of the distortion from individual lamps on the distortion of a complete installation is limited in a mixed load installation. A comparison of a large number of studies presented in Ref. [14] came to the same conclusion.

Light flicker can have a number of causes; best documented is light flicker with incandescent lamps due to variations in voltage magnitude in the frequency range between about 0.5 Hz (also known as "voltage flicker") and 25 Hz. The flickermeter and the flicker severity index, used in standards to quantify variations in voltage magnitude, are based on the behaviour of a standard 60 W incandescent lamp [15]. With the introduction of LED lamps, there are strong arguments for the flickermeter standard and the definition of flicker severity to be reevaluated and updated [16]; however there are also arguments for keeping the definition [17]. All incandescent lamps, of the same nominal luminous flux and voltage,

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show very similar variations in light intensity for the same variation in voltage magnitude. This is not the case for LED lamps, due to the difference in converter technology, parameter values, etc., used in different LED lamps [18,19]. There are other phenomena, like interharmonics [20,21], causing flicker [22–25], but these are not considered in this paper. In addition, switching power supplies driving LED strings can operate with frequencies from 3 Hz up to 1 kHz. Therefore, some LED lamps produce variations in light intensity (that can be perceived as flicker) even for a constant voltage magnitude while others maintain a constant light intensity. Also this phenomenon is not considered in this paper; none of the LED lamps used produced measurable variation in light intensity under normal operation.

This paper investigates light intensity variations due to variations in voltage magnitude with 24 different LED lamps for domestic use. The variation in light intensity of different LED lamps for the same voltage magnitude variation has been studied. Next to light flicker also the harmonic emission from those LED lamps has been studied. The paper studies any relations between the susceptibility of lamps to voltage magnitude variations and the harmonic distortion of the current waveform taken by the lamp.

The paper is organized in six sections. Section 2 reviews the flicker effect definition. Section 3 describes the measurement and data analysis. The results are presented in Sections 4 and 5, starting with harmonics and power factor and continuing with light intensity variations, including the relation between them and power quality parameters. Section 6 presents a discussion of the results providing some concluding remarks.

2. Flicker effect

Flicker is the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time [26]. One of the sources of light flicker is the variation of the voltage magnitude at time scales less than a few seconds. The variations in voltage magnitude result in variations in light intensity. The response of a human observer to those light intensity variations depends on several parameters, such as amplitude modulation, shape and frequency of those variations; but there are also differences between observers, not being always the same for the same observer. Annoyance, distraction, eye strain, headaches, migraine, and fatigue are the detrimental physiological effects of light flicker on humans. It can even endanger the safety of industrial workers because of interaction with moving machinery. In Ref. [27] there is an extensive reference list on health effects of flicker.

The standardized way of quantifying the severity of voltage magnitude variations, with respect to light flicker, is the IEC flickermeter [15]. It quantifies the amount of light flicker, for an average human observer, that a given voltage magnitude variation will cause for a standard 60 W incandescent lamp. The relation between light flicker and voltage magnitude variations has been deeply studied with compact fluorescent lamps (CFLs) [18,22] but the number of studies remains limited for LED lamps [28]. Most of those studies include recommendations for the development of a new flicker severity index.

Flicker or light flicker is a widely used term; however, the term involves a factor of perception that is unique for each person and highly subjective. This has not been taken into consideration during the experiments described in this paper where the variations in light intensity were measured with the use of an illuminance meter. By comparing light intensity variations, the subjective part (the human response) is removed and an objective comparison becomes possible. In the remainder of this paper, we will study and measure light-intensity variations. The underlying assumption made is that a higher amplitude of light intensity variations at the same frequency will increase the likelihood of observable or annoying light flicker.

3. Measurement and data analysis

3.1. Light intensity variations

There are no standards specifying how to measure the luminous flux modulation [16]. Therefore, a measurement setup appropriate to the aim of the study has been followed in this paper. The tests were carried out at the University of Cordoba using the 3 AC phase ix3000 California Instrument programmable power source, a Hagner illuminance meter and a Yokogawa oscilloscope.

In the IEC 61000-4-15:2010 [15], the normalized flickermeter response is given for both 120 V (50/60 Hz) and 230 V (50/60 Hz) for sinusoidal and rectangular voltage fluctuations. In this paper only rectangular voltage magnitude variations have been measured.

LED lamps commonly found on the market in Spain and Sweden have been exposed to synthetic rectangular voltage magnitude variations generated by the programmable power source. The E-27 lamps range from 2 W to 15 W and are integrated with internal driver. They come from different manufacturers and with different price. A few of the lamps tested were dimmable (LED 1, 2, 12) but no measurement with a dimmer was done.

The technology of the driver differs between them, due to the variety of lamps appearing on the market. A higher sample of 104 LED lamps, from different European countries, has been considered in the harmonic analysis. The results were similar to the harmonic analysis shown here, thus indicating that the LED lamps used within this study are representative for the European market.

The light output from the lamps was measured against a grey background. The distance between the LED lamp under test and the illuminance meter as well as all settings for the instruments were kept constant through the whole data test. This makes it possible to compare between different lamps since any systematic error will be the same for all tests. Variations in luminous flux were recorded for all lamps. With the use of Fourier transform the sinusoidal component of the light intensity variations at the same frequency as the voltage magnitude variation introduced by the programmable voltage source was extracted.

These set of measurements used the frequencies for rectangular voltage magnitude variations considered in Table 2b in IEC 61000-4-15:2010 [15]. Since the incandescent lamp-eye-brain block of the flicker meter was not considered, there was no need for varying the amplitude of the voltage magnitude variation. As it was stated in Ref. [29], “to establish valid comparisons between the devices, it is necessary to fix frequencies and, less important, to fix disturbance levels”. The voltage magnitude variation used was kept constant for all frequencies at 3% of the fundamental voltage (230 V), considerably higher than what is expected in a real grid, but within the range defined in the EN 50160 [30] (<10% nominal voltage). The high amplitude of the modulation was intentionally chosen to make sure that the luminous flux was high enough to be recorded without risking a big influence from the surroundings.

As mentioned before, the aim of the paper was to compare the behaviour of different LED lamps when exposed to the same voltage magnitude variations, and not to see how the individual lamps would behave under real voltage magnitude variations.

3.2. Gain factor

As stated in Section 2, the light flicker has been studied in this paper by measuring the light intensity variation for a given voltage–magnitude variation. To compare the behaviour of differ-