Electric Power Systems Research 164 (2018) 11–19

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Supraharmonics emission from LED lamps: A reduction proposal based on random pulse-width modulation

Joaquín Garrido, Antonio Moreno-Munoz*, Aurora Gil-de-Castro, Victor Pallares-Lopez, Tomás Morales-Leal

Departamento de Ingeniería Electrónica y de Computadores, Universidad de Córdoba, Campus de Rabanales, Edificio Leonardo Da Vinci, E-14071 Córdoba, Spain

ARTICLE INFO

Keywords:
EMC
EMI
RPWM
Harmonics
High-frequency harmonics
LED lamps
Supraharmonics
Power quality

ABSTRACT

There is an outstanding concern from the international standard-setting community about harmonics distortion in the frequency range 2–150 kHz, referred to as supraharmonics. Power electronics has established as a ubiquitous technology, which plays a linchpin role in almost any electrical systems. The classical deterministic pulse-width modulation strategy, entailing at reducing low-frequency harmonics emission (< 2 kHz) in power converters, in a sense, bring them to move at the switching frequency and its multiple, in the kilohertz range. The amplitude of spectral components is the main concern when studying electromagnetic interference from active power factor correction stages, included in state-of-the-art LED drivers. Supraharmonics are nowadays the origin of numerous problems in electrical networks. The standardization bodies are presently updating the compatibility limits in the frequency range from 2 to 150 kHz. Supraharmonics behave differently from (lower frequency) harmonics, as reported in the literature. Fortunately, as will be demonstrated in this paper, it is possible to undertake this issue, from the very beginning, by leveraging technologies like random pulse-width modulation. An experimental system based on digitally controlled LED driver has been set up to evaluate the different methods. The algorithms have been implemented on a compactRIO controller incorporating an FPGA and a real-time processor.

1. Introduction

Worldwide energy consumption has risen 30% in the last 25 years. Increasing energy costs have become a significant concern and are expected to continue to increase in the foreseeable future. Businesses, institutions, and consumers will be searching for more efficient products and solutions. Residential and commercial building electricity consumption accounts for almost 60% of total IEA (International Energy Agency) electricity demand. In Europe, transport and industry are major energy consumers, but buildings account for around 41% of all energy consumption. The Public Lighting Systems in our cities is a basic and vital service for city councils and other public administration. On the one hand, citizens demand high-quality service in accordance with our high development society. On the other hand, a lighting installation is an important energy consumption source. Concretely, lighting is responsible for approximately 15% of the global electricity consumption and about 5% of greenhouse gas emissions [1].

In the quest for sustainability, the light-emitting diode or LED light has entailed an energy revolution, involving energy savings of up to 80% compared to incandescent lamps [2]. The transition to LED light is transforming the lighting industry, which has seen a faster than expected drop-off in the price of this disruptive technology. LED lighting not only delivers high efficiency but a high level of brightness, long lifespan and high reliability. Consequently, LED lamps are used in most applications, both indoors and outdoors. Market forecasts estimate extraordinary and continuous growth of LED market throughout the present decade, with LED becoming the dominant lighting technology in terms of the aggregate number of installed units, with a share reaching almost 70% of the global lighting market in 2020 [3].

Since LED lighting represents an energy-efficient technology, the issue of total power factor (TPF) is unavoidable. But the market expects not only for the higher TPF but also for a better performance from the electromagnetic compatibility (EMC) point of view. With the general adoption of self-commutated power electronic converters (PEC) in these electronic devices, generation of harmonics has been shifted from the hertz to the kilohertz frequency band. These high-frequency components, the so-called 'supraharmonic' (frequency range: 2–150 kHz), are characteristic in the pulse-width modulation (PWM) operation of PEC

* Corresponding author.
E-mail address: amoreno@uco.es (A. Moreno-Munoz).

https://doi.org/10.1016/j.epsr.2018.07.032
Received 30 November 2017; Received in revised form 13 June 2018; Accepted 23 July 2018
0378-7796/

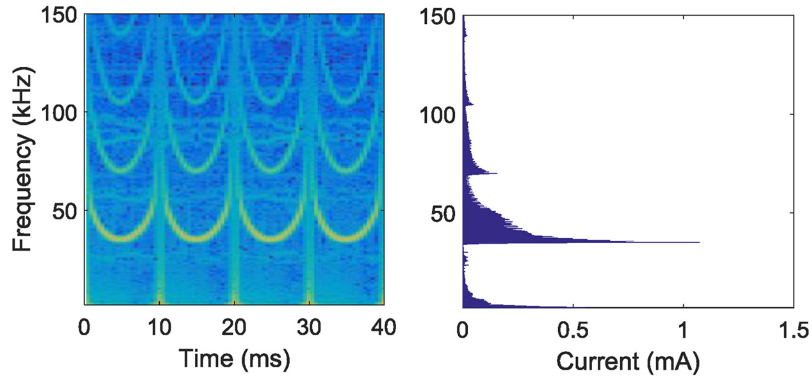

Fig. 1. Group II. STFT (left) and FFT (right) of the current.

employed in the LED driver. The amplitude of spectral components, caused by fixed-frequency PWM, is the main issue when facing electromagnetic interference (EMI).

Supraharmonic behaves differently from (lower frequency) harmonics and interharmonics. An increase in the number of malfunctions and non-intentional equipment behavior due to the presence of supraharmonics has been reported during the last years, for example, with power line communication, brown goods, biomedical devices, smart meter, ground leakage current switches, and overload of electrolytic capacitors [4]. EMC standards had almost forgotten this frequency range until recently, resulting in lack of requirements [5]. However, standards' revisions with new compatibility levels for supraharmonic disturbances are on their way [6].

There are different filtering devices for reduction of these undesirable interferences. There are different filtering devices for reduction of these undesirable interferences. Recently novel passive mitigation technologies like a variable capacitance filter have been proposed [7]. Nevertheless, more circuit board space is needed for them, and obviously cost increases, so avoiding the harmful emission is preferable. As will be illustrated in this paper, among the methodologies to deal with this problem, the random PWM (RPWM) represents an outstanding option. Particularly a new improvement in the Random Pulse Position Modulation (RPPM) will be presented with excellent performance.

The organization of the rest of the paper is as follows. Section 2 is devoted to power quality, mainly in the supraharmonic topic. Section 3 presents a survey of LED drivers. Section 4 addresses the RPWM techniques while Section 5 is devoted to results. And finally, Section 6 contains the conclusions.

2. Power quality in lighting systems review

There is growing concern about the quality of electricity. One of the main reason is because new generation of loads are more sensitive to variations in energy quality than in the past [8]. Power quality is not a new term, however still nowadays there are attempts to deal with it. It is an umbrella concept considering many types of power system disturbances. It indistinctly refers to both current and voltage. While the quality of the current usually characterizes the emission of equipment and installations, the quality of the voltage describes how equipment connected to a certain point in the distribution grid is affected by other equipment emissions. Customer equipment affects the voltage quality, and the latter also affects customers, therefore to find the responsible in a power quality concern is difficult. Both definitions have in common that they are related to the non-sinusoidal waveform of the voltage or current, leading to a distortion. Therefore, this waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.

With the introduction of LED lamps in the market, numerous papers have been written about power quality, considering the possible increase in the voltage distortion in distribution networks due to the widespread use of that technology. The harmonic generation from LED lamps has been deeply studied at a lab level [9,10], and also over real measurements [11,12]. However, there are still not so many papers on studying the supraharmonic emission of LED lamps [13,14].

It has been shown in Refs. [4–6] that LED lamps currently on the market show a large variety of supraharmonic emission. There is no emission limit in that range that applies to LED lamps, so every manufacturer uses their own driver topology. Therefore, it is not possible to use standard supraharmonic models for LED lamps, as nowadays each device appears to be unique. Even worst, in this frequency range, a small change in any electrical component between drivers has a big influence on it.

In Ref. [15] according to measurements over 73 LED lamps for indoor lighting, overall three groups can be observed according to the high frequency emission. From those groups, group II is formed by lamps with a high frequency spectrum mainly characterized by the switching frequency of the driver and its harmonics. Fig. 1 shows a LED lamp from group II. Broadband components are seen from 35 to 55 kHz, as well as recurrent oscillations are seen below 9 kHz. This paper is proposing a new technique to mitigate the switching component of lamps from group II.

The index that characterizes the distortion in the low frequency is the Total Harmonic Distortion (THD), representing the relative signal energy present at nonfundamental frequencies, as defined in IEC 61000-4-7 [16]. In the supraharmonic range, only the 200 Hz grouping method is recommended at IEC 61000-4-7, but no indices are standardized. However, several indices have been proposed to characterize the emission within this range based in time-domain analysis and in the frequency-domain [17].

The displacement power factor (dPF) is the cosine of the angle difference between the fundamental components of the voltage and current (at 50/60 Hz). The TPF, however, includes the harmonic part of the active and apparent power, as appears defined in IEEE 1459-2000 [18]. The TPF is the product of the distortion factor (DF), own to the harmonics presence, and the dPF, where the latter considers only the fundamental of the current and distortion factors in the harmonics.

As nonlinear loads, LED lamps produce highly distorted currents. Depending on the technology used in the rectification stage, the current waveform of the LED driver will be distorted. The different rectifier topologies can be divided into: non-power factor correction (nPFC), with-passive power factor correction (pPFC), and with-active power factor correction (aPFC). The nPFC topologies emit the highest harmonic currents with (Total Harmonic Distortion of the current) THDi values usually significantly higher than 100% and the current fundamental has a capacitive characteristic with TPF lower than 0.7 (Fig. 2).

Topologies based on pPFC have mostly a moderate low frequency current distortion (30–90%) and a power factor higher than 0.7. The