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Power quality performance of energy-efficient low-wattage LED lamps

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ABSTRACT

Light-emitting Diode (LED) lamps are more versatile and energy efficient compared with conventional light sources. This paper investigates two main problems related to power quality, namely, the harmonic generation from LED lamps and the effect of voltage sags on LED lamps. Laboratory tests on various LED lamps are conducted and the electrical characteristics of LED lamps are tapped under different conditions. Frequency domain analysis is then performed to investigate the generated harmonics. Then, voltage sag sensitivity analysis is performed by obtaining signals from a photo sensor, the different parts of a lamp ballast, and input voltage. The analysis includes the effects of varying sag depth and voltage sag duration. The findings are compared with the SEMI F47 standard curve, which predicts the effects of voltage sags on lamp performance. Experimental results show that the LED lamps produce a considerable amount of current harmonics. Moreover, different types of LED lamps were found to produce different levels of current harmonic depending on the ballast configuration. This harmonic distortion can be reduced by combining various types of LED lamps. Voltage sag tests show that all the tested lamps are sensitive to sag depth and sag duration.

1. Introduction

Lighting accounts for approximately 20% of the electricity consumption worldwide. To promote energy conservation, many governments have introduced directives to ban energy-inefficient incandescent light bulbs and replace them with other technologies, such as LEDs [1,2]. LEDs work under a completely different principle from that of compact fluorescent lamps (CFLs). In LED lighting technology, when an electron is recombines with a hole, release energy in the form of light known as photon. Many high brightness LEDs are required to illuminate a large area because all the light is produced at the *p*–*n* junction [3].

In general lighting applications, a compact AC/DC converter should be used in one lighting fixture to supply DC current to high brightness LED chips, which introduce nonlinearity to a system. As nonlinear loads, LED lamps produce highly distorted currents [3]. Although the required active power of a LED lamp is low, a huge number of consumer using LED lamps and CFLs in one location may give rise to significant power quality (PQ) problems [4]. Voltage sag is an important issue among various PQ disturbances. During sag, a sudden 10–90% reduction in nominal voltage occurs; this reduction lasts from 10 ms to 60 s [5]. LED lamps may be extinguished or generate flickering, causing out of order due to sag. Therefore, a good understanding of the LED bulb's harmonic-producing characteristics and sensitivity to voltage sags is necessary.

Numerous studies were conducted on LEDs as an energy-efficient lamp, but most researchers focused on internal ballast circuit design and on enhancing LED performance [6–8]. Several researchers concentrated about distribution of light [9,10]. Only few studies focused on the harmonic emissions of LED lamps [3,11]. As indicated in [3], the widespread use of LEDs and CFLs could increase

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the voltage distortion in distribution networks depending on the characteristics of the network. However, the arithmetic sum of individual harmonics may lead incorrect estimations of current harmonic distortion levels. Therefore, measuring diversity factors to determine the effect of a large number of LED lamps on PQ is necessary. The ratio of the integral vector of current harmonics to the arithmetic sum of current harmonics is called diversity factor [12].

A number of past studies on voltage sag sensitivity of other nonlinear lighting systems have also been carried out, but no research on the voltage sag performance of LED lamps can be found [13–15]. Taekhyun et al. [16] conclude that LED lamps are responsible for flickering. This behavior is similar to the response of CFLs to high-order inter-harmonics. Therefore, LED lamps with internal electronic ballast are expected to not only be sensitive to flickers, but also to transient under voltage events in electric distribution systems.

This paper presents a detailed harmonic and voltage sag analysis of LED lamps. Measurement tests using various available LED lamps are conducted. A total of 35 high brightness LED lamps with different ratings from seven different manufacturers (brands) are observed. The experiment is executed to monitor the current, voltage and light-output waveforms of the LED bulbs and to analyze the lamps in terms of power rating and brand. The test results are compared with the IEC 61000-3-2 harmonic standard and SEMI F47 voltage sag standard.

2. Basic operation of LED lamps and relevant standards

The principle behind the operation of LED bulbs is described in this section. Relevant standards, including harmonic emission limits for LEDs as defined by IEC 61000-3-2 and voltage acceptability limits defined by SEMI F 47, are discussed.

2.1. Operating principle of LED lamps

LEDs require a constant current source from a low-DC voltage source obtained from the AC mains. Use of a converter for voltage and current regulation which is usable to LED cheap is therefore necessary. The boost, flyback, vallyfil, resonant, buck converters are renowned power sources for LEDs [7,17]. Fig. 1 shows a classical block diagram of the LED lamp ballast circuit, which includes an AC line input voltage (typically 220–240 VAC, 50/60 Hz), an electronic interference filter for obstructing unwanted circuit-produced switching signals, a rectifier with a smoothing capacitor, a pulse width modulation-controlled constant current source converter for DC–DC conversion, and an array of high brightness LEDs. The directives that govern the injection of harmonics are not particularly stringent because rated load powers are low [14]. Thus, power factor control circuits may or may not be found in low-wattage LED lamp ballasts. However, introducing an input passive filter, valley-fill circuits, or an integrated circuit-controlled active filtering configuration reduces generated harmonics and improves the power factor.

Under normal operation, the capacitor voltage decays over a half-cycle as [14]

$$\Delta V = \frac{I_0 T_{50}}{2C_{dc}} \tag{1}$$

where ΔV is the decay of voltage across the capacitor, I_0 is the load current, T_{50} is a duration of 50 cycles, and C_{dc} is the DC link capacitance.

The charge of a capacitor is approximately equal to the supply peak voltage plus $\Delta V/2$, which is standard for a constant DC–DC converter. During the N cycle voltage sag, the smoothing capacitor discharges until $2N\Delta V/2$. Depending on the value of minimum voltage prepared by the ballast configuration, the constant current source converter delivers adequate amounts of voltage and current to the lamp up to the capacitor voltage to obtain the intended minimum converter operating value. The time spent to reach the voltage is called hold-up time (T_h), which can be expressed as follows [14]:

$$T_h = \frac{C_{dc}(V_{norm}^2 - V_{min}^2)}{2P} \tag{2}$$

where V_{norm} is the peak nominal voltage, V_{min} is the peak minimum voltage prepared by the ballast configuration, and P is active power.

2.2. Harmonic injection limits for LED lamps

Like any other appliance, LED lamps must also obey with various instructions feasible to the product. Limits for harmonics are classified into the different categories according to load type. All lighting loads are under class C [18,19]. Harmonic emission limits for class C are divided into two subcategories based on active power up to 25 W and above. The lamps with an active input power less than or equal to 25 W should satisfy at least one of the two criteria. In the first criterion, the third harmonic current should not exceed 86% of the fundamental frequency, and the fifth harmonic current should not exceed 61%. This criterion indicates that the current total harmonic distortion (THD_I) should be approximately 105%. The other

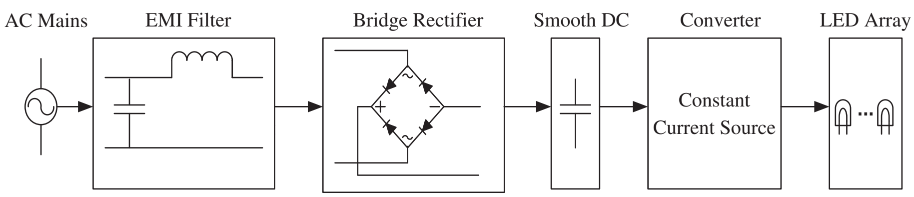

Fig. 1. Basic block diagram of LED lamp internal ballast circuit.