A COMPARATIVE STUDY THE PERCENT FLICKER AND PHOTOMETRIC MEASUREMENT IN THREE-PHASE AND SINGLE-PHASE DRIVERS

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Abstract – **This paper presents the evaluation of a single-phase topology and a three-phase topology. Photometric and flicker characteristics were compared. To validate the results, a single-phase charge-pump driver for power LEDs driving a 22 W luminaire, and a three-phase driver with a switched capacitor was used for power LEDs driving a 216 W luminaire. The obtained results were compared with the actual norms. The three-phase driver is operating within the recommended operating region in Std. 1789-2015, while the single-phase driver is operating outside the recommended region.**

Keywords – **CHROMATICITY, FLICKER, LED DRIVER, PHOTOMETRIC MEASURES.**

I. INTRODUCTION

In recent years, the market for LED lighting has been gaining more attention due to the advantages of this light source when compared to other existing lighting technologies. The LEDs have a high luminous efficacy compared to fluorescent lamps, also they have a high lifetime, approximately 50000 hours [1], which can reduces maintenance costs and energy consumption [2].

The rectifying stage, AC-DC, present in the driver the LEDs, can generate a flicker frequency with twice the frequency of the electrical grid in single-phase converters, while in a three-phase rectification the flicker frequency is six times higher than the frequency of the electrical grid. In Europe, where the grid frequency is 50 Hz the flicker occurs at 100 or 300 Hz. In the Americas where the frequency is 60 Hz, the flicker occurs at 120 or 360 Hz [3].

The flicker phenomenon, which was usually investigated causing photometric depreciation of LEDs, has recently been studied due to evidence of human health risk, such as headaches, malaise [3], [4]. For some people, a low frequency flicker between 3 and 70 Hz can lead to epileptic seizures[5]. The flicker can occur in both visible and invisible modes, but it cannot be perceived when its frequency is above the Critical Flicker Fusion Frequency (CFF), which generally occurs between 60 and 90 Hz [4]. In addition, indirect flicker perception is possible through stroboscopic effects at frequencies of 100 and 120 Hz [6]. Therefore, it is crucial that the drivers attenuates the propagation of current ripple at low frequency to reduce the percentage of flicker that is harmful to human health.

The low-frequency current ripple in the LEDs is the main factor that causes the flicker phenomenon, the current ripple is usually reduced in order to reduce the flicker. The most common method is to use a capacitive filter with electrolytic capacitors. However, this type of capacitor limits the driver lifetime.

Several topologies to reduce flicker are proposed in the literature [7]–[11]. A three-phase topology was proposed in [7] to meet the minimum requirements of Class C of IEC 61000-3-2: 2014, aiming to obtain a high power factor, a low harmonic distortion rate, and a low flicker percentage without using electrolytic capacitor. In [8] it was proposed a three-phase driver with flicker modulation not causing any effects to human health in every range of output power variation. A single-phase topology based on two inverted buck inverters in antiparallel to achieve a high power factor and a low current ripple was proposed in [9]. A single- phase driver was introduced in [10] using a single controller integrated circuit chip to reduce the volume of the driver, however the percentage of flicker obtained is above the value of 10% recommended in IEEE Std 1789-2015 [12]. In [11] it was proposed a three-phase driver with a power factor of up to 0.99, however the percentage of flicker was not evaluated.

Regarding the presented topologies, it is necessary a comparative evaluation between the single-phase and three-phase drivers, taking into account the flicker and photometric characteristics.

This paper presents an analysis of the photometric and flicker characteristics of a 216 W luminaire driven by a three-phase converter proposed in [13] and a 22 W luminaire driven by a single-phase converter proposed in [14]. The luminaires were also powered by a constant DC current source in order to compare the results.

II. PROPOSAL

The converter A proposed in [13], is shown in Figure 1. A three–phase switched capacitor converter that drives a 216 W LED luminaire. This converter features open loop power factor correction (PFC), soft switching and does not use any electrolytic capacitors. The load used are four COB type LED model 10E30JY50WW associated in series (module A), each of these LED has a nominal power of 54 W approximately. The converter A that drives module A in this work is called system A. The COB LEDs are a series of LEDs encapsulated near each other in a single module, giving them a high density of power, reducing their weight and volume, which makes it attractive for public and industrial lighting. Nowadays, COB LEDs in which the luminous efficacy is about 160 lm / W are largely commercialized [15].

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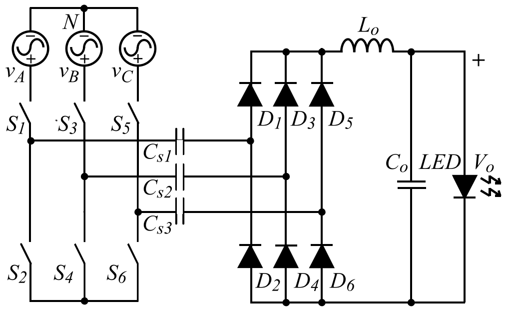

Fig. 1. Schematic circuit of the driver one.

The converter B proposed in [14], is shown in Figure 2. A single-phase charge-pump converter with PFC, with zero voltage switching, dimmable and without using electrolytic capacitor. In this converter, an T8N3528-166-322 LED module was used. This module has a nominal power of approximately 22 W and is composed of fourteen parallel LEDs arrays, each array consists of 23 SMD 3528 20mA LEDs connected in series, resulting in 322 LEDs. The converter B that drives module B in this work is called system B.

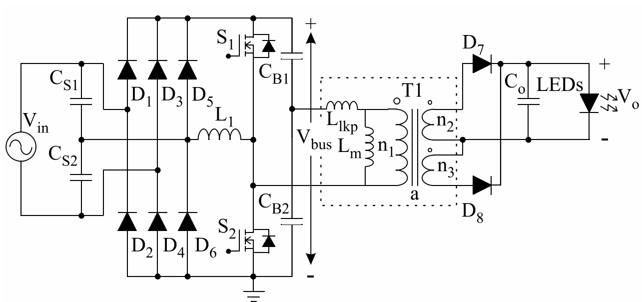

Fig. 2. Schematic circuit of the driver two.

III. METODOLOGY

The luminance variation (flicker) of LEDs was obtained through a BPW21R photodiode. This component has a spectral sensitivity that approaches the sensitivity curve of the human eye [16]. However, the current amplitude resulting from the photodiode is low, making the use of a signal conditioner circuit is mandatory. Figure 3 shows the circuit used for the flicker measurement, where an operational instrumentation amplifier LMC6084 was used to amplify the photodiode signal. To perform flicker measurements, a prototype was developed. It was connected to an MSO5034 350 MHz oscilloscope manufactured by Tektronix. While carrying out the measurements a low pass filter was used, inherent to the equipment.

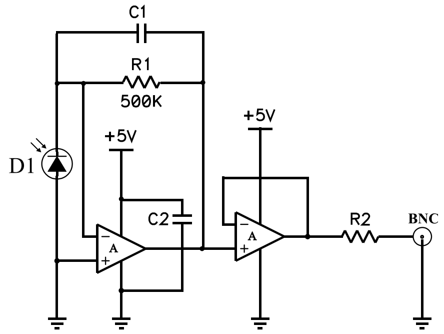

Fig. 3. Schematic circuit used for the flicker measurement.

The photometric measurements of the luminaires were captured using an integrating sphere model ISD - 100HF - V02 manufactured by Gigahertz - Optik which uses the BTS256 - LED Tester sensor that allows measurements inside and outside the sphere. A constant current source model MPL3305M manufactured by Minipa was used to drive the luminaires simulating the ideal features.

The characteristics of modules A and B used by these systems are shown in Table I.

TABLE I

LED Parameters

Module	Nominal Current (A)	Threshold Voltage (V)	LED Resistance (Ω)	Output Voltage (V)	Module power (W)
A	1,75	53.18	4.96	61.86	108.26
B	0,280	69	31,61	78,13	21,88

The driver A drivers four COB LEDs in series, however for photometric analysis two COB LEDs, according to table 1, were used inside the sphere of integration due to the physical arrangement, as shown in Figure 4. The photometric measurements corresponding to the module B were carried out in a single LED with 30º opening angle, through a conical adapter connected to the BTS256 sensor - LED Tester, shown in Figure 5.

Fig. 4. Integrating sphere with BTS256 with cone measuring adapter.

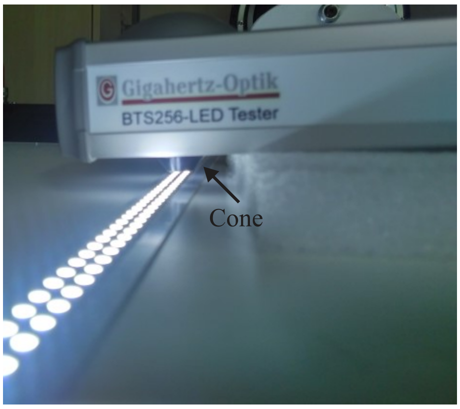

Fig. 5. BTS256 with cone measuring adapter.

For the photometric analysis of the LED luminaires, the luminous flux, the color temperature (CCT), the chromaticity and the color reproduction index (CRI) of the systems A and B, driven by the converters 1 and 2 respectively, were evaluated. The systems were also powered by a DC source, later the results obtained by the DC source and the converters were compared. In addition, the photometric results were compared to the ANSI NEMA standard C78.377-2015 and the flicker results compared to the "Recommended Practices for Modulating Current in High-Brightness LEDs for IEEE's Mitigating Health Risks to Viewers" [17]

IV. EXPERIMENTAL RESULTS

According to [12], the percentual flicker or modulation is obtained from (1) where F_{max} and F_{min} represents the maximum and minimum luminous flux, respectively.

$$Mod_{\%} = \frac{F_{\max} - F_{\min}}{F_{\max} + F_{\min}} \times 100\% \qquad (1)$$

The current ripple is directly related to the flicker, that the higher the current ripple the higher the percentage flicker, being necessary to limit the current ripple in the LED. The percent current ripple in the LED, $\Delta i_{LED\%}$, can be calculated by (2), which I_{max} and I_{min} correspond to the maximum and minimum values of current, respectively.

$$\Delta i_{LED\%} = \frac{I_{\max} - I_{\min}}{I_{med}} \times 100 \qquad (2)$$

For low frequencies, the luminous flux response in the LED can be approximated for the applied direct current, in this way the following relations can be considered:

$$\begin{aligned} F_{\max} &= k \cdot I_{\max} \\ F_{\min} &= k \cdot I_{\min} \end{aligned} \qquad (3)$$

By substituting (3) at (1) percentage flicker is calculated by (4):

$$Mod_{\%} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \times 100\% \qquad (4)$$

Considering the current applied to the purely sinusoidal LEDs, can be calculate the average current through (5)

$$I_{med} = \frac{I_{\max} + I_{\min}}{2} \qquad (5)$$

From (4) and (5) is obtained:

$$Mod_{\%} = \frac{I_{\max} - I_{\min}}{2 \cdot I_{med}} \times 100\% \qquad (6)$$

By substituting (2) at (6) is obtained (7).

$$Mod_{\%} = \frac{\Delta i_{LED\%}}{2} \qquad (7)$$

From (7) it's possible to note that, theoretically, the current percent ripple is twice as high as the flicker percentage. However, this ripple is appropriate for a low current ripple [18], [19].

According by [20], the luminous flux is directly related with the forward current applied in the LED, so that when the LED current increases, the junction temperature rises and reduces luminous flux. Similarly, when the LED current decreases, the junction temperature decreases and the luminous flux increases.

Therefore, because the luminous flux is related to the thermal design of the luminaire, (7) can be rewritten.

$$Mod_{\%} < \frac{\Delta i_{LED\%}}{2} \qquad (8)$$

According to recommended practices at [12], there are low-risk and high-risk regions. It's recommended to operate within the low-risk region. For frequencies smaller than 90 Hz, the percentage flicker should be less than 0.025 times the flicker frequency. For frequencies between 90 and 1250 Hz, the modulation should be less than the product of 0.08 times the frequency of the flicker. It's also noted that for the frequencies of 120 and 360 Hz the acceptable maximum modulation values are approximately 10% and 29%, respectively.

The Figure 6 shows the experimental result of the illuminance variation in the LEDs in the system A converted to voltage values. A maximum voltage value of 1.201 V and a minimum value of 1.093 V were obtained, which resulted in a percentage value of 4.7% modulation, according by (4).

The Figure 7 shows the flicker measurement realized on system B, was obtained a maximum value of 744.4 mV and a minimum value of 466.2 mV, which results in a flicker percentage value of approximately 22.9% according by (4).

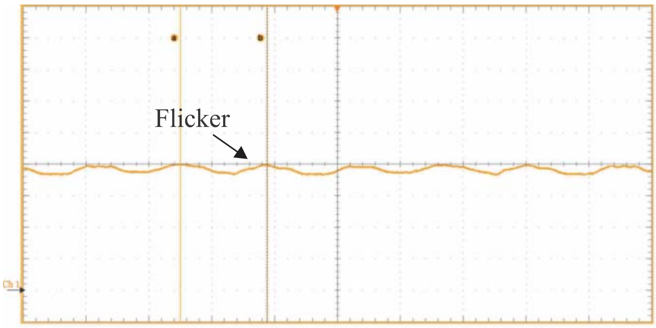

Fig. 6. Voltage ripple proportional to illuminance (Ch1:300mV/div; Base time: 2ms).

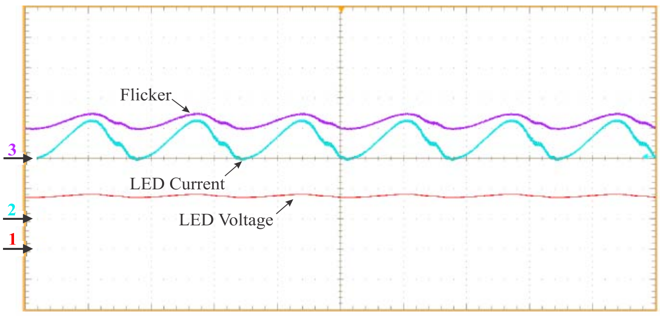

Fig. 7. LED voltage (Ch1); LED current (Ch2); Voltage ripple proportional illuminance (Ch3); (Ch1:40 V/div; Ch2: 100mA/div; Ch3: 500mV/div; Base time: 5ms).

The graph shown in Figure 8 shows the experimental results compared with the operating area recommended by IEEE Std. 1789/2015 [12] and where is located each converter studied in this paper. It can be seen that the percentage of flicker obtained in system A (three-phase) is within the recommended operating area, while in the system B (single-phase) is outside the recommended operating area.

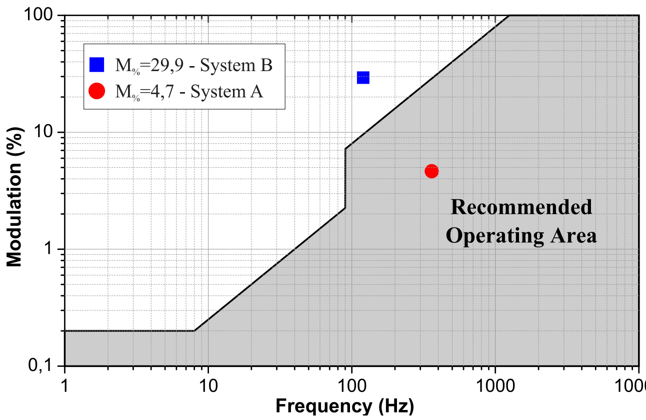

Fig. 8. Graph of the modulation in a function of the flicker frequency.

The table II shows the results obtained from the photometric measurements. The results show that there was a increase of 3.38% in the luminous flux, a deviation of 0.59% in the CCT and a deviation of 0.83% in the CRI when the module A was drive by driver A. For module B there was a reduction of 6.38% in the luminous flux, a deviation of 0.28% in the CCT and a deviation of 0.33% in the CRI when the module B was drive by driver B.

TABLE II
Photometric Results

Electronic Driver / Module	Luminous flux	CCT	"x / y"	CRI	Voltage	Current
Module B / Driver	4.54	6178	0.32 / 0.33	77.9	70.74	0.25962
Module B / Source DC	4.83	6160.6	0.32 / 0.33	77.64	71.4	0.2806
Module A / Driver	3619.3	6181.9	0.32 / 0.32	72.84	61.66	1.772
Module A / Source DC	3493.7	6218.9	0.32 / 0.32	73.45	61.65	1.768

The Figure 9 shows the graph representation of the chromaticity specification of Table I on the diagram chromaticity CIE 1391 obtained from the ANSI NEMA C78.377-2015 standard. The results indicate that the chromaticity coordinates obtained experimentally are in conformity with the standard.

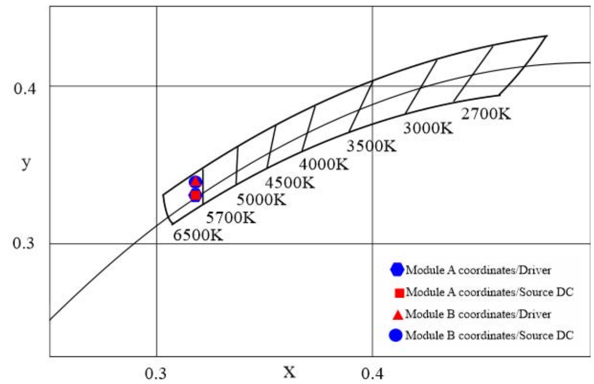

Fig. 9. Graph representation of the chromaticity

V. CONCLUSIONS

This paper presented a comparative study of the photometric and flicker characteristics in a three-phase converter and a single-phase converter. The experimental results obtained were analyzed and compared with the IEEE Std. 1789/2015 and ANIS NEMA C78.377-2015.

The photometric experimental results obtained showed that for module A there was an increase of 3.38% in luminous flux compared when the module was driven by the DC source. For the module B, there was a decrease of 6.38% in luminous flux when the module was driven by the DC source. For both modules, the CCT and the CRI were practically constant when drives by drivers and DC source.

The topology used in the system A (three-phase) obtained a flicker percentage of 4.7%, below the 29% recommended by standard. Therefore, it operates within the recommended operation area, ensuring a low risk to human health. The topology used in the system B (single-phase) obtained a flicker percentage of 22.9%, above the 10% recommended by standard. Therefore, this flicker percentage can be lead to damages to human health.

Therefore, when there is a three-phase electrical grid, which usually occurs in public, commercial and industrial lighting, it is attractive to use three-phase LED drivers, since the percentage of flicker is greater for a three-phase electrical grid compared to the grid single-phase. In addition, the low current ripple is inherent to the three-phase driver due to the power in a balanced three-phase driver with unit power factor being constant.

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