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Analysis of the Voltage Variation Effects in LED Lamps

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Abstract

This work analyzes the effect of the voltage variation in LED lamps at the luminous and power quality behavior of LED lamps which employs different topologies in their drivers. Samples are tested on 18 single-base LED lamps with an integrated control device, GLS LED bulbs, with different wattage between 6W and 18W, 6 flyback topology lamps with input filter, 6 topology lamps input filter and 6 topology lamps buck without Input filter. The methodology of the work consists in applying voltage values different from nominal ones in a step of + 5% and -5% until reaching levels of + 20% and -20%, totaling 22 levels of tension and 396 measurements. Throughout the tests, measurements of power, luminous flux, power factor, harmonic current, total harmonic distortion (THD), color temperature, color reproduction index (CRI) and luminous efficiency were made.

Keywords

Lighting Devices, Power Quality, LED Technology

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1. Introduction

The increase of energy demand caused principally by demographical growth around the world in the last decades has stimulated researchers have been searching for new technologies as more efficient alternatives to reduce the electrical energy consumption impact, thereby improving the lighting quality and end-user safety and reducing environmental impacts. The rapid advancement in semiconductors has brought a new generation of light sources in form of LEDs. LED luminaires have been widely used in commercial lighting systems because of their long lifetime, strong cost-competitiveness, high-energy efficiency and greater design flexibility [1]. Within these new technologies, LEDs are more efficient lighting devices, compared to incandescent and fluorescents lamps, generating almost 80% of energy consumed in light, providing environmental preservation, and presenting more durability by reaching a useful life of 50.000 hours, which is 50 times more durable than incandescent lamps and 6 times more durable than fluorescent lamps [2].

Accordingly to these advantages, LEDs have been growing their acceptation in lightning market diversifying models and types of the different bulb lamps in international markets, by increasing their availability to different projects and consumers. According to the US Department of Energy's Solid-State Lighting Multi-Year Program 2014, LED lighting will capture 74% of market share by 2030, with major growth in all sectors, and will result in 297 TWh of electricity consumption [3]. According to a report entitled LED Lighting Global MarketTrends [4], LED lamps market forecasted to grow 21% to $12.2 Billion in 2018. Because of this reason and considering the need for GLS LED bulbs marketed to present the minimum efficiency requirements,

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safety, and electromagnetic compatibility, its necessary, ameliorate ordinances establishing requirements for energy efficiency and safety to be met by LED lights.

Due to concern about high harmonic distortion levels and an awareness of the decrease in productivity and service life, as well as possible damage to the equipment, energy quality has become a huge preoccupation. One of the most harmonic distortion producers in the power grid is the electronic equipment that, many times through the rectifier part, produces harmonic distortion and other disturbances of energy quality.

The electronic circuits need a continuous power voltage of adequate levels. Some circuits may have this voltage power through the battery. In the case of LED lamps, is necessary the usage of the energy available in the power grid, needing a converter. The electronic converters can be divided into two parts. Rectifiers that realize an AC-DC conversion constitute the first one. The second part is defined as DC-DC converters that provide the current and voltage to safe levels to LED chips. The DC-DC converters have different electronic components that are organized according to the typology used. Within met typologies, Buck and Flyback topologies stand out in GLS LED bulbs.

GLS LED bulbs can be divided into four parts: the first one, responsible for electric energy in light transformation, can be composed by another LED; the second one is composed of lenses and diffusers; the third one is met by a driver and is composed of the electronic circuits responsible for both adequate voltage supply and control of the electric current that fluxes in LED; finally, the fourth one is composed of a base responsible for the contact between the lamp and the electric energy supply circuit [5]. An LED driver with high electrical efficiency is important to achieve higher energy savings [6].

2. DC-DC Converters

Switch-mode DC-DC converters are used to convert the unregulated DC input into a controlled DC output at the desired voltage level. Often the input of DC-DC converters is an unregulated DC voltage, which is obtained by rectifying the line voltage, and therefore it will fluctuate due to changes in the line-voltage magnitude. [7]

2.1. Buck Topology

Assuming an ideal switch, a constant instantaneous input voltage, and a purely resistive load, the basic circuit of Figure 1 shows the Buck converter that produces a lower average output voltage than the DC input voltage. The average output voltage can be calculated in terms of the switch duty ratio as is shown at Eq. 1, where D is the duty ratio.

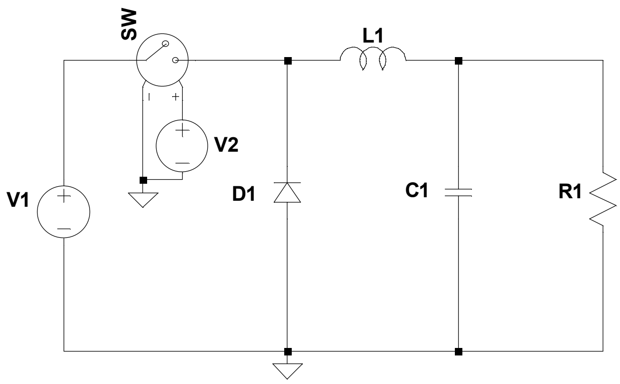

Figure 1. Buck Topology (made with LTspiceXVII).

$$Vout = D.Vin \tag{1}$$

By varying the duty ratio *D* of the switch, *Vout* can be controlled. Another important observation is that the average output voltage varies linearly with the control voltage.

2.2. Flyback Topology

Flyback converter has two inductors working as a transformer that provides electric isolation between the primary side and secondary side. The flyback converter has two modes of operation, to store energy in magnetizing inductance when the switch is on and transfer it to the secondary side when the switch is off.

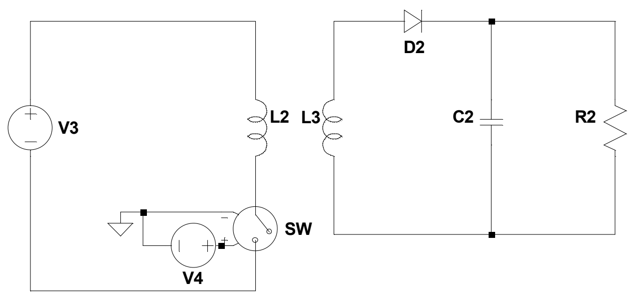

Figure 2. Flyback Topology (made with LTspiceXVII).

3. Power Quality

Due to the requirements to reduce energy and cost of electronic devices, switch mode power supplies have to operate. The total harmonic distortion (THD) is frequently used to define the level of harmonic content in an alternate signal, and it can be calculated as the product of the square root of the sum of all the harmonic components squared divided by the amplitude of the fundamental frequency (Equation 1), where the factors from I2 to IN are amplitudes of the harmonics and I1 the fundamental amplitude. The THD is used to characterize the energy quality of electric energy systems. Distortion factor is a related term, used as a synonym. Therefore, in energy systems, a small THD value means losses reduction.

$$THD\% = \frac{\sqrt{I_2^2+I_3^2+I_4^2+\cdots+I_N^2}}{I_1} \times 100 \qquad (2)$$

The recommended values for PF and harmonic current are presented by the standards IEC 62612-2013 and IEC 61000-3-2, respectively. The values are shown in tables 1 and 2.

Table 1. Values PF according to IEC 62612-2013.

Power	Power Factor
P ≤ 2 w	No requirement
2 w < P ≤ 5 w	≥ 0.4
5 w < P ≤ 25 w	≥ 0.7
P > 25 w	≥ 0.9

Table 2. Values for Harmonic Current according to IEC 61000-3-2.

Harmonic order (h)	Maximum harmonic current permitted (calculated in % compared to fundamental magnitude)
2	2
3	30*(power factor)
5	10
7	7
9	5
11< h≤ 39 (odd only)	3

Due to the requirements to reduce energy and cost of electronic devices, switch mode power supplies have to operate in high frequency in order to use smaller and cheaper magnetics inductors and transformers. Smaller transformer means less inductance and the core can easily go into saturation and make a short circuit, but the high frequency increases the impedance of the magnetic inductance and core saturation is prohibited. High frequency hard switching uncovers a series of problems made by leakage inductance and parasitic elements in the converter. [8]

4. Methodology

In order to analyze LED lamps available on the market, were selected 18 lamps between 8 and 16 W of power and nominal voltage bivolt (127 V or 220 V). Six of the lamps have a driver of Buck topology with an Input filter, six have a control device of Buck topology without an input filter, and six have a control device of Flyback topology with Input filter (Table 3). The lamps submitted voltage variations from -20% of the minimum nominal voltage to +20% of the maximum nominal voltage, totaling 22 voltage levels. In these tests, were carried out measurements of power, luminous flux, power factor, harmonic current, THD, color temperature, CRI, luminous flux, and luminous efficiency.

4.1. Description of the Test Environment

The tests were carried out in the lighting laboratory of Federal Fluminense University-LabLux, accredited by Inmetro in 2005. Its mission is to carry out tests on products in the lighting area, for energy efficiency certification. Opened in October 2002, through agreements between Eletrobrás and Procel, LabLux has the latest equipment, making their participation in the Brazilian labeling program-lighting PBE [9].

4.2. Description of Equipment Used

The power of the lamps tested was taken from an AC voltage adjustable power supply, shown in Figure 3. The tests were carried out in an integrating sphere of Ulbricht, 2m diameter sphere, installed in LabLux (Figure 4), where the photometric characteristics of the lamps studied in this research were measured. A Digital Power Meter Yokogawa WT-210, as illustrated in Figure 5 evaluated the power quality of the tests. The spectrum analysis was performed from the Hass-2000 spectroradiometer (Figure 6) and viewed by the Everfine HaasSuite software version 2.00.604 (Figure 7). For harmonic analysis, waveform, among other features, was measured through the WTViewer software version 8.13, as illustrated in Figure 8.

Figure 3. Power Supply Lisun Group.

Figure 4. Integrating Sphere Ulbricht.

Figure 5. Digital Power Meter Yokogawa WT-210

Figure 6. Spectroradiometer.

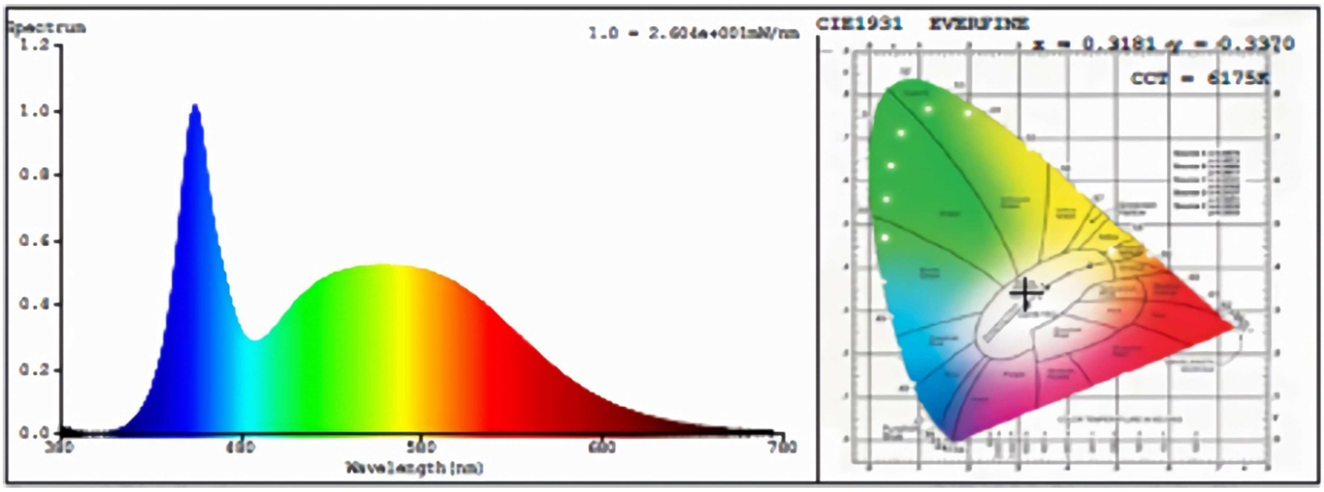

Figure 7. Software Everfine HaasSuite.

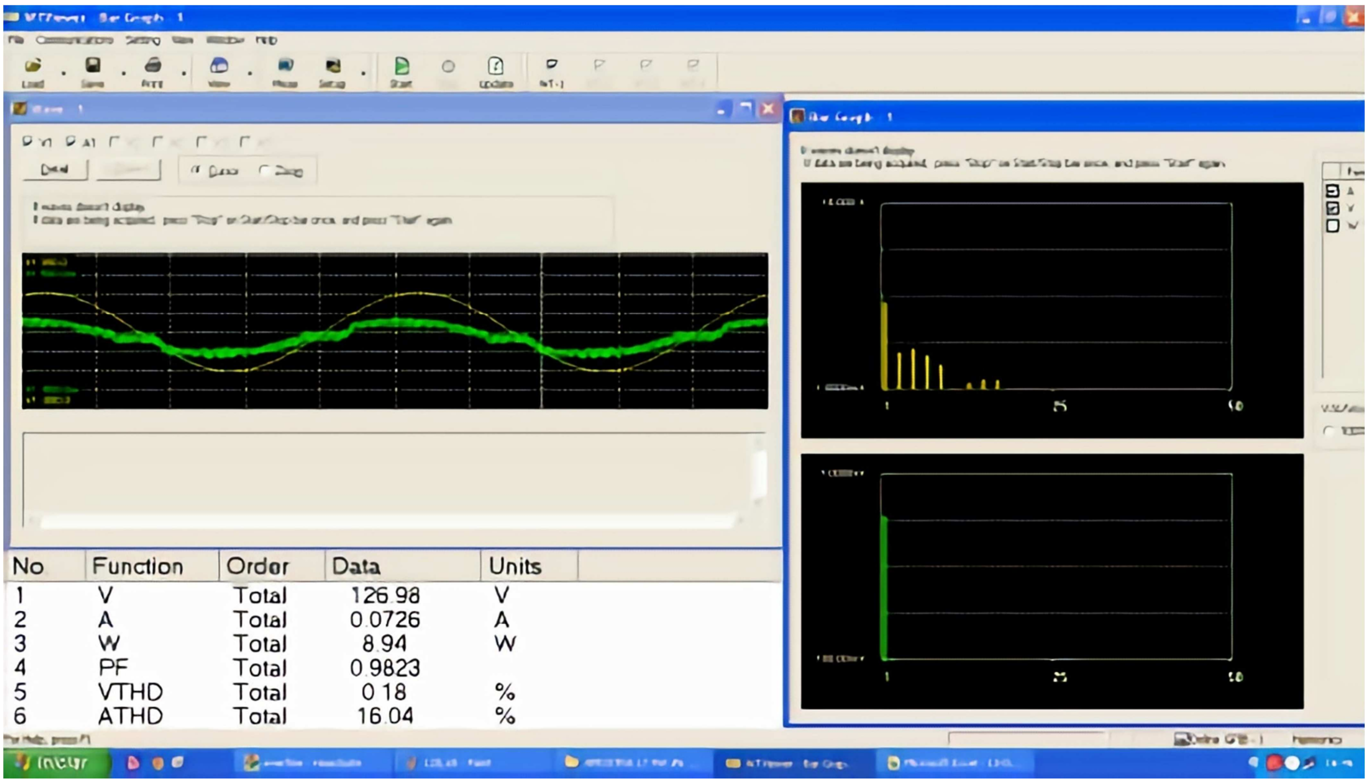

Figure 8. Software WTViewer.

Table 3. Sample Description.

Sample	Power (W)	Topologies
1	8	Fly back with Input filter
2	8	Fly back with Input filter
3	12	Fly back with Input filter
4	12	Fly back with Input filter
5	16	Fly back with Input filter
6	16	Fly back with Input filter
7	9	Buck with Input filter
8	9	Buck with Input filter
9	12	Buck with Input filter
10	12	Buck with Input filter
11	15	Buck with Input filter
12	15	Buck with Input filter
13	9	Buck without Input filter
14	9	Buck without Input filter
15	12	Buck without Input filter
16	12	Buck without Input filter
17	15	Buck without Input filter
18	15	Buck without Input filter

4.3. Routine Testing

The voltage levels used in the tests were defined based on the nominal voltage of the lamps (127V and 220V - Bivolt) and by extrapolating the limits of the PRODIST 8 Module [10], which defines the safe voltage limits to be between 105% and 90% of the nominal voltage. Therefore, the nominal voltage was varied over than 5% and less than 5% until it reaches + 20% and -20% of the nominal voltage. Every sudden change in the parameters presented by the lamps, it is reduced the varying levels from 5% to 2.5%; thus, it was possible to observe the critical point of lamp operation.

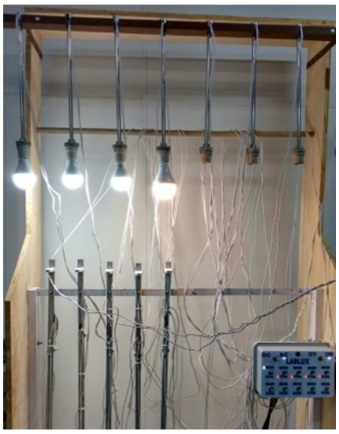

Figure 9. Stabilization of lamps.

As recommended by "Portaria n° 389" of August 25, 2014, the lamps were powered initially at a nominal voltage for 30 minutes, until stabilization was achieved (Figure 9). After stabilization, one at a time, the lamps were positioned inside the integrating sphere. Through the WTViewer software, data regarding the electrical characteristics of the lamps' operation were obtained: potency values, potency factor, current, and harmonic distortion. Then, the Everfine HaasSuite software visualized the spectrum by obtaining the luminous flux, color temperature, and color rendering index (CRI) for each voltage variation. Finally, once the luminous flux data and power were obtained from the measurements, the luminous efficiency was determined as the ratio between these two variables.

5. Analysis Results

The parameters measured in the 18 lamps are arranged in Tables 4, 5 and 6 in a simplified way, where it was calculated as averages of the lamps of the same power for each parameter. The parameters analyzed are Power Measurement, Power Factor (PF), Harmonic Current, Luminous Flux, Luminous Efficacy, Correlated Color Temperature (CCT), Color Rendering Index (CRI) and Total Harmonic Distortion (THD).

Comparing Tables 4, 5 and 6, it is possible to notice among the average of the parameters of the lamps of the same power that some of these parameters, such as the average of the Measured Power, the PF, the Luminous Flux, the Luminous Efficacy, have little variation. On the other hand, the average of the parameters Harmonic Current, CCT, CRI and THD, presented large variation.

Table 4. Average measurements of flyback topology LED driver with Input filter.

Parameters			
Rated Power (W)	**16W**	**12W**	**8W**
Samples	1 e 2	3 e 4	5 e 6
Measured Power (W)	14.73	10.45	7.12
PF	0.94	0.9	0.88
Harmonic Current (mA)	101.7	74.5	51.77
Luminous Flux (lm)	1479.32	1005.75	605.56
Luminous Efficacy (lm/W)	100.43	96.25	85.03
CCT (K)	2713.14	2759.41	2680.95
CRI	81.72	81.85	81.77
THD	18.51	21.8	17.34

During the tests, 396 measurements were carried out on 18 lamps. The six samples of Flyback topology lamps with Input filter presented acceptable data; the average of these data is presented in Table 4, in which the samples were grouped according to the same power. The six samples of Buck topology lamps with Input filter presented reasonable data, and the average of these data is presented in Table 5. The six samples of Buck topology lamps without Input filter obtained unsatisfactory data, due to the high measured level of THD; the average of these data is presented in Table 6.

The behavior of the lamps of the same topology is similar, even of different powers. Therefore, to analyze the effect of the voltage variation of the measured parameters, figures were inserted that show the behavior of the samples 12W lamps topologies Flyback with Input filter, Buck with Input filter and Buck without Input filter respectively, according to the variation of voltage levels.

Analyzing Figure 10 it is possible to notice that the measured power is lower than the nominal power of the lamps and that in the case of lamps with an Input filter, the further the voltage moves away from the nominal value, Increases. When the lamp operates within rated voltage values, the measured power decreases, however, the lamp without Input filter has a different behavior of the samples with Input filter because the measured power is greater. On the measured power, it is possible to conclude that keeping the voltage within the limit of the nominal voltage levels is the most appropriate and that the lamps with Input filter are more effective than those without Input filter.

Table 5. Average measurements of buck topology LED driver with Input filter.

Parameters			
Rated Power (W)	**15W**	**12W**	**9W**
Samples	7 e 8	9 e 10	11 e 12
Measured Power (W)	12.51	10.38	8.95
PF	0.93	0.9	0.92
Harmonic Current (mA)	90.38	75.34	63.21
Luminous Flux (lm)	1249.12	1036.5	877.66
Luminous Efficacy (lm/W)	99.91	99.86	98.08
CCT (K)	6128.58	6250	6075.75
CRI	84.88	84.18	83.65
THD	29.82	22.33	18.39

Table 6. Average measurements of buck topology LED driver without Input filter.

Parameters			
Rated Power (W)	**15W**	**12W**	**9W**
Samples	13 e 14	15 e 16	17 e 18
Measured Power (W)	13.23	11.08	8.87
PF	0.92	0.92	0.92
Harmonic Current (mA)	153.37	138.01	105.96
Luminous Flux (lm)	1198.9	910.05	739.17
Luminous Efficacy (lm/W)	90.69	82.05	83.3
CCT (K)	6026.23	4571.57	6172.55
CRI	78.42	78.54	79.1
THD	138.41	141.2	142.88

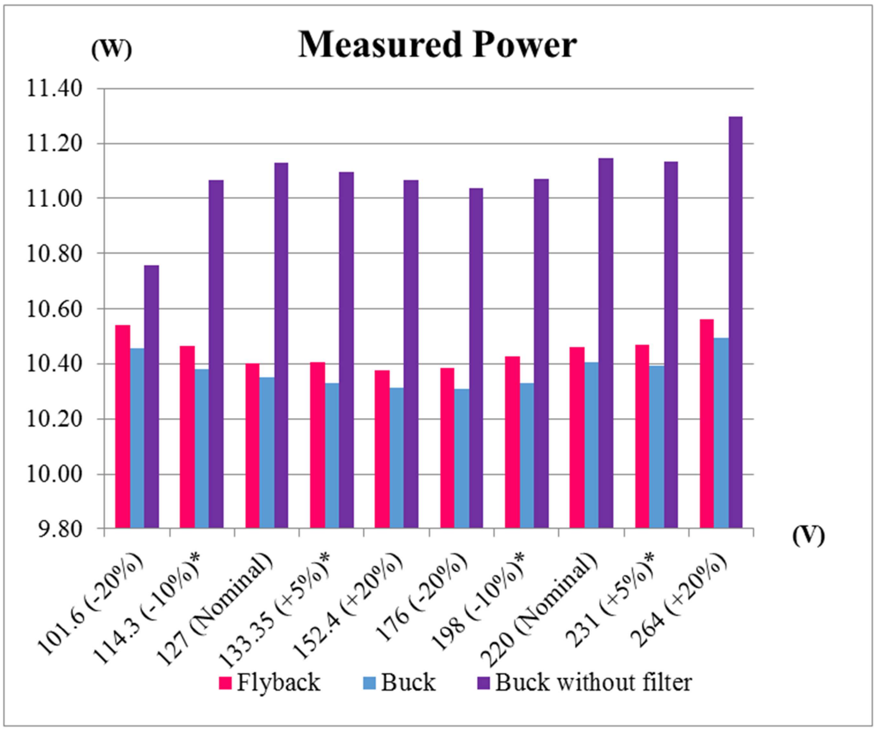

Figure 10. Measured Power behavior of GLS lamps, 12W.

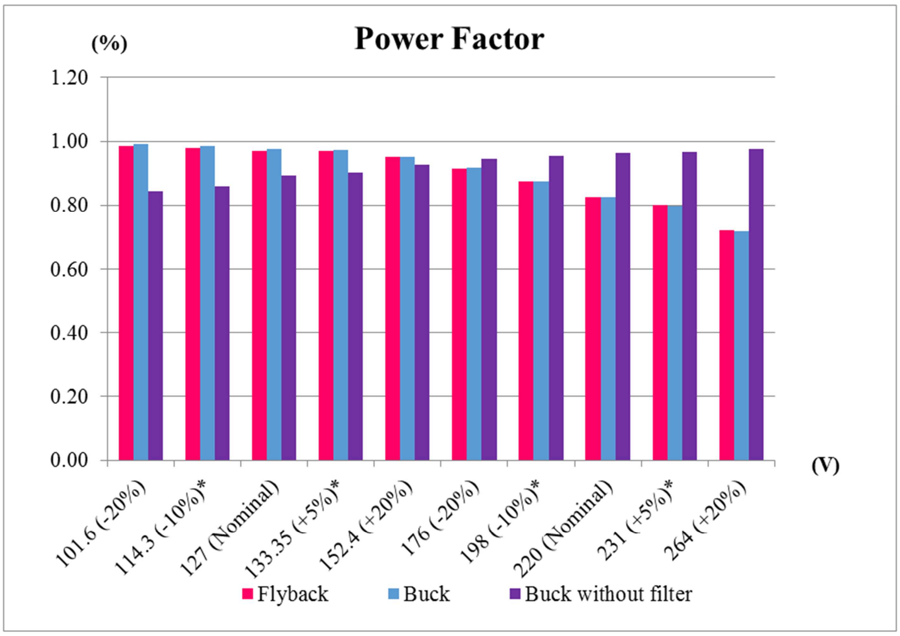

Figure 11. Power factor behavior of GLS lamps, 12W.

According to Figure 11, the power factor of the lamps is decreasing with increasing voltage levels and at the lowest voltage level, the best PF values are measured. The power factor behavior of lamps without Input filter is increasing according to the increase in voltage levels and the best PF values are measured at the highest voltage levels. Considering that the value of the PF indicated for lamps with a power of less than 25W, according to IEC 62612-2013, it is 0.7, It is correct to state that LED lamps with and without filters would operate at the correct PF level even when subjected to unsuitable voltage levels.

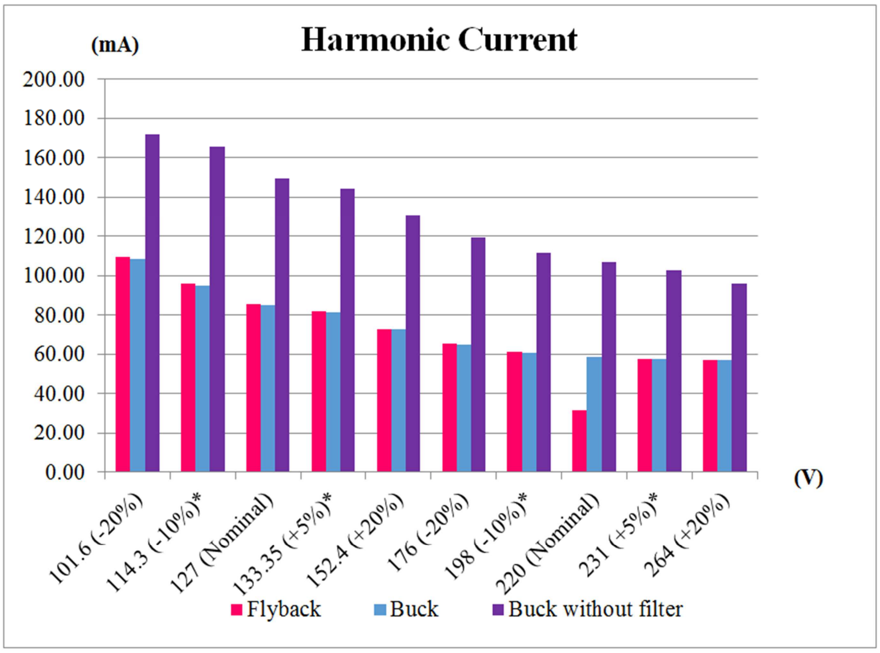

Figure 12. Harmonic current behavior of GLS lamps, 12W.

The behavior of the harmonic current is similar both in lamps that have Input filter and in lamps that do not have a protective surge, both reduce the Harmonic current with increasing voltage. In addition, lamps without Input filter have much higher harmonic current when compared to the levels of lamps with a protective surge. Therefore, lamps with Input filter had a more suitable behavior than lamps without Input filter. According to IEC 61000-3-2, the results are into the limits.

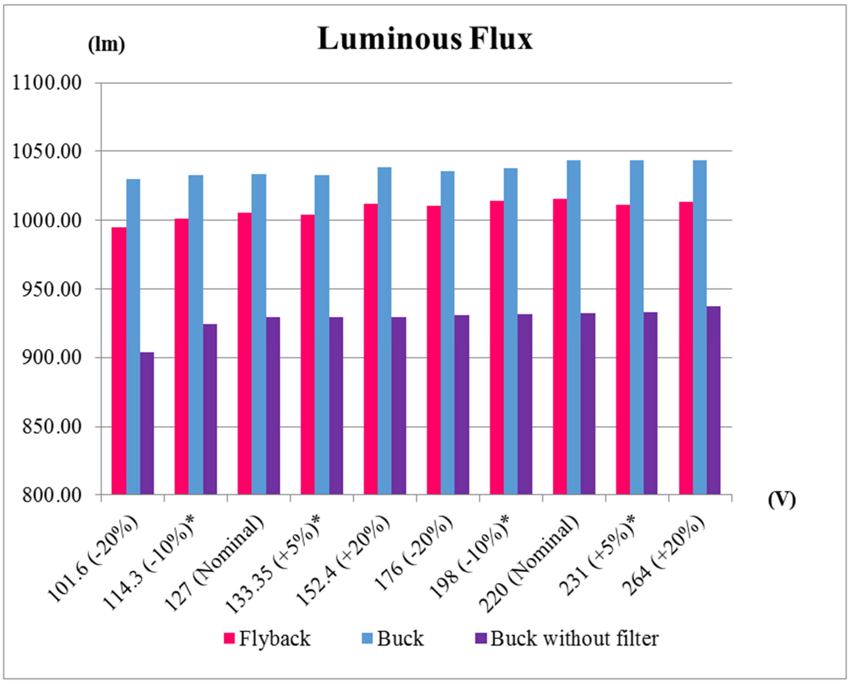

Figure 13. Luminous flux behavior of GLS lamps, 12W.

The luminous flux, according to Figure 13, increases as the voltage level is increased. It is also possible to conclude that lamps without Input filter have lower luminous flux than surge lamps, thus emitting less light.

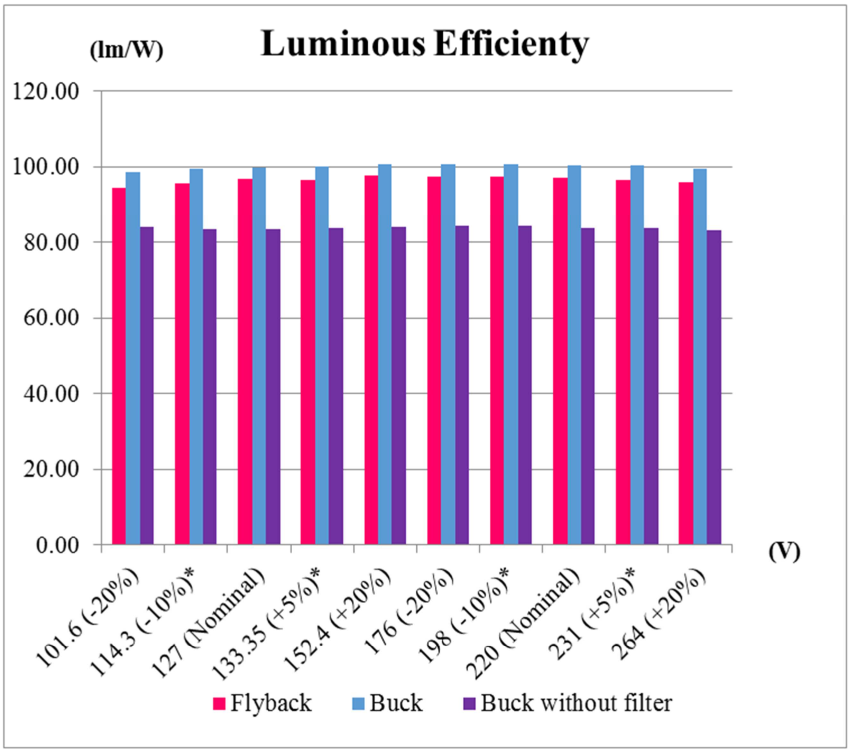

Figure 14. Luminous efficiency behavior of GLS lamps, 12W.

As the luminous flux, the luminous efficacy is smaller in the lamp without an Input filter and behavior of the luminous efficacy of the lamps with Input filter is similar. The greater the luminous efficacy of a lamp, the lower it´s energy consumption. Therefore, Buck lamps without Input filter consume more energy than the flyback and buck topologies with Input filter. Buck topology lamps with the input filter had the best results, consuming less between the nominal voltage values.

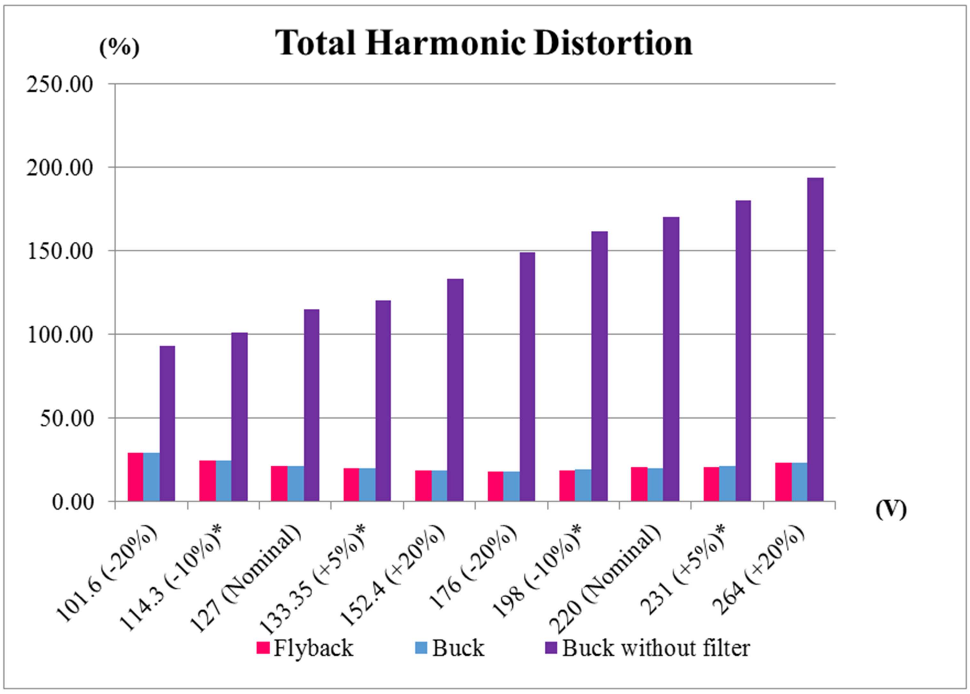

Figure 15. Total Harmonic Distortion behavior of GLS lamps, 12W.

The color temperature and the Color Rendering Index are not showed because it remained constant with the voltage variation.

According to Figure 15 the measured THD in the samples of lamps with Input filter increases when the voltage variation exceeds the nominal maximum and minimum nominal value and reduces within the range of nominal voltage values. On the other hand, the THD values measured in the samples of lamps without Input filter showed an increasing behavior. The higher the voltage levels of the samples of buck topology lamps without Input filter are much higher.

Remembering that the 6 lamps of 12 W whose behaviors are represented from Figure 10 to Figure 15 are of the same power, same model, same manufacturer level, the higher the THD. In addition, the measured THD, have the same technical specifications, except color temperature, and batch number, but have different performances due to their constructive features (such as a LED lamp that has a buck topology driver without an input filter and another that has a flyback topology driver with Input filter.). The distributors and manufacturers on the packaging do not disclose the constructive information of the drivers. It is only possible to discover the difference if the driver circuit is analyzed, as was done in this work. Therefore, thinking from the point of view of the consumer, the buyer is guided by the information contained in the packaging and may be consuming a product that expects to perform but have a lower result.

Figures 16, 17, and 18 show the waveforms of input for Flyback topology lamps with Input filter, Buck topology lamps with Input filter, and Buck topology lamps without Input filter, respectively. All the lamps of the same topology presented standard waveforms; thus, no spectra are present in this text.

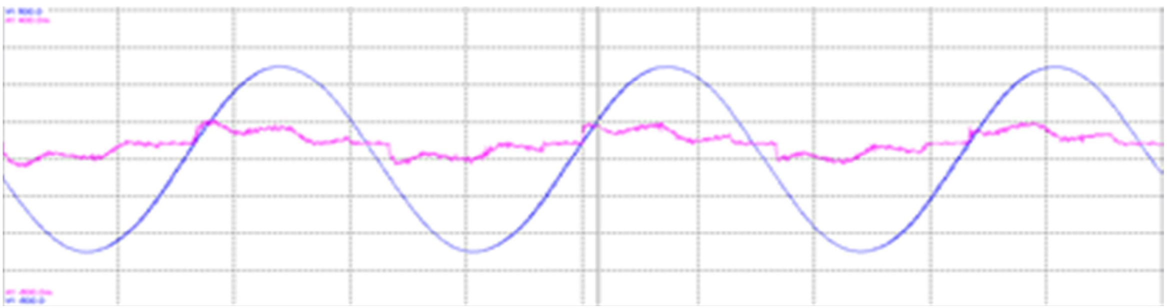

Figure 16. Input waveform of buck topology LED driver with Input filter.

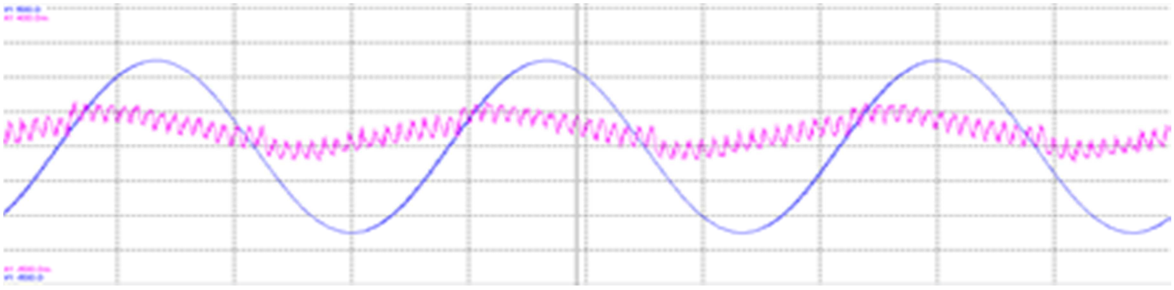

Figure 17. Input waveform of buck topology LED driver without Input filter.

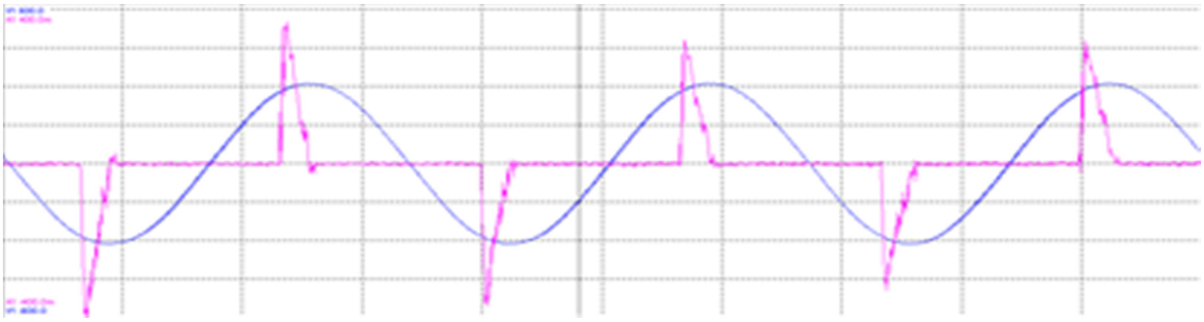

Figure 18. Input waveform of flyback topology LED driver with Input filter.

Figures 19 and 20 represent the harmonic distortion of lamps, which obtained the lowest (THD = 14%) and the highest (THD = 204%) percentage of total harmonic distortion, respectively.

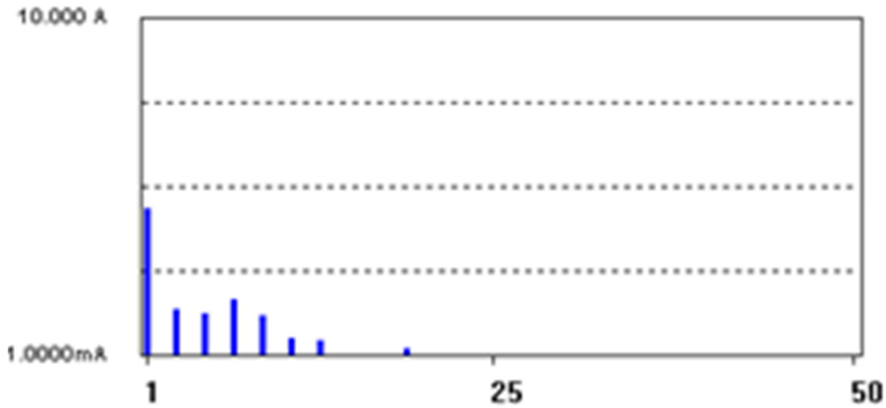

Figure 19. Flyback topology lamp with Input filter (THD = 14%).

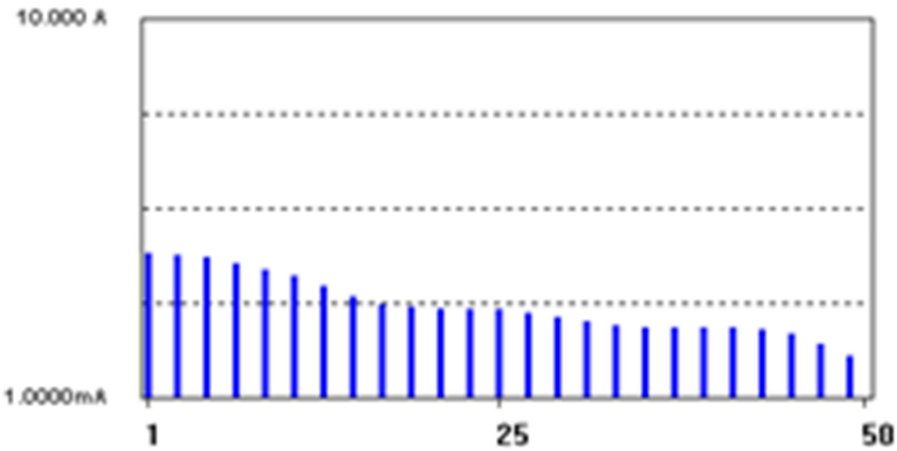

Figure 20. Buck topology lamp without Input filter (THD=204%).

6. Conclusions

The application of voltage levels outside the safe operating boundaries set by the module PRODIST 8 [10] caused the GLS LED lamps to function poorly. When subjected to voltages greater than 220V, the lamps had, in most cases, high levels of THD, up to 204%, and a low power factor, up to 0.69. By applying voltages less than 127V, the sample lamps with Buck and Flyback topologies with Input filter showed an increased THD and power factor. Only the Buck topology lamps without Input filter presented a reduction of the THD and power factor, when compared to nominal voltage levels. According to Inmetro determinations, the sample LED lamps with Buck and Flyback topologies with Input filter showed acceptable behavior between the nominal voltage levels of 127V and 220V. Samples of Buck topology lamps without Input filter had an unsatisfactory behavior, even at normal voltage levels, due to high levels of THD.

Through an analysis of the results, it is possible to conclude that the Buck topology LED lamps with Input filter showed a 14.27% higher efficacy, compared to the performance of Buck topology LED lamps without Input filter. Moreover, Buck topology lamps without Input filter presented harmonic distortion levels up to six times higher, as compared with the Buck topology lamps with Input filter, showing that the application of Input filters in electronic circuits drastically reduces the amount of harmonic distortion injected into the network. Furthermore, from the analysis of the average parameters obtained, it is clear that the samples of Buck topology lamps with Input filter achieved better efficacy when compared to the Flyback topology Input filter; however, samples of the Flyback topology lamps arises with less THD.

These results contribute to the performance analysis of lighting equipment being made available to the market and present an analysis that specifies the lamp power approach in conditions that are different from nominal. In general, consumers do not have information regarding the LED lamp construction technology and are unaware that a massive application of devices produces greater distortion to the distribution system, which may cause power quality problems to the power grid. This work aims to contribute to the LED lighting technology analysis concerning power quality aspects and the adoption of normative benchmarks for approval of LED lamps.

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