Power Quality Analysis of Domestic Lamps Available in the Brazilian Market

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Abstract: - Different economic sectors have attempted to find solutions to mitigate the effect of the global energy crisis. Reducing energy consumption in its various forms is necessary, due to economic and environmental reasons, among others. The rational use of energy is one solution to this problem. It is estimated that 20% of Brazil's residential electricity consumption is spent on lighting. Thus, replacing lamps of high consumption by more efficient light bulbs is one method to reduce energy consumption. This paper presents a comparison of energy efficiency indicators among domestic lighting lamps available in the Brazilian market, specifically, incandescent bulbs, compact fluorescent lamps (CFLs), and light emitting diode lamps (LEDs). Despite this activity (exchange of lamps technology) is widespread in many countries, it is important for researchers to analyze in detail what is being offered in the local market and if the policies and equipment standardization are being met by lighting equipment suppliers. This paper presents and compares results based on an analysis of some power quality criteria (without going into details in rectifier circuits used). This research can be applied to similar products in any country or region, and it can support other researches related to the real impact of new lighting technologies in order to reduce energy consumption in residential buildings (as presented) and others buildings.

Key-Words: - new lighting technologies, energy quality, energy efficiency, lamps, energy measurement

1 Introduction

Buildings account for nearly 40% of global energy consumption, and 40% and 15% of that are consumed, respectively, by heating, ventilation and air conditioning (HVAC) and lighting [1]. In their research, Linhart and Scartezzini [2] comment that in the UK, 16% of the electricity is used in the domestic/commercial sectors. This research presents additional interesting data: In typical non-domestic building, 20-30% of electricity consumption is with artificial lighting (this value is about 30% in office buildings).

It is known that lighting is an important part of the total electricity consumption in countries. For example, according to a report by the Swedish Energy Agency, 23% of the country's total consumption is based on lighting [3]; in Brazil, 20% of electricity is consumed through residential lighting. A report from the U.S. Department of Energy concluded that, in 2010, the lighting consumption reached 18% of the total consumption of electricity [3].

For developing countries, decreasing the energy demand is a necessity; consequently, several measures are being taken to reduce electricity consumption. One solution proposes replacing old equipment with more efficient technology. For example, incandescent bulbs can be replaced by compact fluorescent lamps (CFLs). A interesting research indicates that replacing outdated technology with new and energy-efficient equipment will lead to an estimated energy reduction of approximately 27% in residential buildings and 30% in the commercial sector [3]. An analysis regarding CFLs´ electrical parameters is presented in [4]–[5], and their electromagnetic comparability is presented in [6]. It is important to underline the fact that aspects related to poor power quality effects are been researched, as cited by Rosentino Jr. et al. in [7].

The electricity tariff increase is also one of the reasons for the emergence of new electronic devices with low power consumption. The large-scale use of these electronic devices can cause some harmful effects in energy quality, however, which results in many other problems. The subject of lamps and lighting considering a revision of the characteristics of some lighting equipment technologies (in special lamps) available on the market is presented in Damelincourt [8]. In Brazil, where this work was developed, efficient lighting system projects have begun replacing old projects, a process known as retrofitting. This process is argued in detail in Vahl et al. [9] with regard to the technical, economic, and environmental aspects for project analysis.
As part of the planning process for an efficient and adjusted project, it is important to evaluate the potential consumption of the construction with precision. In this context, Stokes, Rylatt, and Lomas [10] present a proposal for the evaluation of the demand for domestic lighting, and Ryckaert et al. [11] present a criteria for energy-efficient lighting in buildings. Furthermore, Roisin et al. [12] present an analysis of the potential for the energy savings on lighting in office rooms using control .
Some researches related to effect of several LED lamps connected on the same grid, as presented in [13]. This paper presents a performance comparison between conventional lamps used in residences, such as incandescent bulbs, CFLs, and LEDs, considering the indicator of lumens/watt, among other factors.
This article is organized as follows. The section 2 provides a residential conventional lamps technology overview. Section 3 presents the methodology and the description of the tests performed on the samples of lamps. Section 4 is dedicated for the results and the conclusion is showed in item 5.

2 Overview of Incandescent Lamps, Compact Fluorescent Lamps and LED Lamps

This section provides an overview of residential lighting technologies presented on the Brazilian market.
According to the Brazilian Lighting Industry Association (ABILUX) 560 million bulbs were sold in 2011, of which 250 million (44.64%) were incandescent, 200 million (35.71%) of compact fluorescent, 90 million (16.07%) of tubular fluorescent and 20 million (3.57%) of halogen. Considering only the two types most compact lamps used in homes, incandescent would account for 55.56% of the market and CFLs by 44.44%.

2.1 Incandescent Lamps

Incandescent bulbs are inefficient lighting devices because they produce light by the heating of a tungsten filament. On average, this equipment has a luminous efficiency that varies from 10 to 20 lm/W; typically, the lifetime is 1,000 h. This lamp type is considered to have low efficiency because 90% of the energy is consumed by heating [14]. The lifetime of the lamp type can be increased by the addition of halogen gas in the bulb. This addition would increase the lifetime to 4,000 h.
These bulbs are already banned from the market in many countries because of their low efficiency. In the European Union market, for example, this technology has been banned since September 2012 [3]. In Brazil, only incandescent lamps of 25 W or 40 W can be sold, but only until 2015. In 2015, bulbs with an output exceeding 100 W cannot be manufactured, and in 2016, they cannot be sold

2.2 Compact Fluorescent Lamp (CFL)

A lamp of 15 W produces the same amount of light or the same luminous flux as a 60 W incandescent lamp. One of the disadvantages of this lamp type is the fact that the electronic circuit used in the compact fluorescent lamp ballast generates electromagnetic interference and harmonics for the distribution network. Compact fluorescent lamps feature a luminous efficiency between 25 and 118 lm/W and a lifetime of up to 10,000 h. Another important point to underline regards the waste that CFL cause. In Wagner [15], several important environmental topics about this subject are addressed.
Fortes et al [16] present an evaluation of the energy quality of CFLs sold in the Brazilian market, and a special research analyzing CFLs supplied with varying (under/over) voltage power is presented in [17].

2.3 LED Lamps

LEDs were first used in electronic devices, such as a beacon, but they did not present sufficient luminous flux to be used as an environmental lighting source. Their creation in 1907 by Henry Joseph Round occurred when he was conducting experiments in the field of radio communication area and discovered the effect of electroluminescence in diodes. In 1927, the scientist Vladimir Oleg Losev created the first LED that incorporated zinc oxide and silicon carbide, which produces light when passed by an electric current. Unaware of Round´s discovery without knowing the discovery of Round, Losev published reports of his experiment with diodes in a Russian newspaper in 1927. He continued developing his work and publishing until 1930, but the lighting industry of that time was not interested in his discovery. In 1962, the first red light indicator LED with 10 micro candelas was created by researcher Nick Holonyak Jr., who, in the February 1963 issue of Reader's Digest, affirmed that incandescent light was doomed. Other experts were able to increase the LED's efficiency, and for the first time, in 1971, LEDs appeared on the market in shades of green, yellow, and orange. In 1993, the first commercially viable blue LEDs emerged.

Since the LED was invented until the present time, the biggest milestone of its development was the discovery of the white light LED, in 1995, by the Japanese researcher Shuji Nakamura, who determined that it is nothing more than the blue LED with a phosphor layer. This material converts ultraviolet light into white light on a semiconductor, as occurs in the CFLs. Its color temperature can vary between 2,700 K and 6,500 K.

LED bulbs have been increasingly diffuse in the Brazilian market, and they soon will become a reality in all residences in order to replace the current incandescent bulbs and CFLs. Various models of LED bulbs with a built-in control device have been launched in the Brazilian market; these models will be the object of this analysis.

The advantages of using LED lamps in comparison to the CFLs are the durability, energy efficiency, and environmental preservation. The LED lamp has a lifetime of approximately 50,000 h and an efficiency of approximately 200 lumens/W. In contrast, the CFLs offer a lifetime of approximately 8,000 h and an efficiency of 60 lumens/W. In terms of environmental impact, disposal of the LED at the end of its lifetime does not present any risk.

It is important to underline the fact that LED lamps are one of the main features used in Smart Systems - residential, commercial, or industrial. An example of these applications is described for public lighting in [18].

3 Methodology and Test Description

Samples of the lamps were purchased on the market, chosen by a luminous flux equivalent to that which is currently the most widely used in residences. Fifteen different samples were acquired from various manufacturers. Table 1 shows a summary of these samples.

Table 1. Number and Description of the Samples

Sample Number	Model
1	Incandescent 100W 127V
2	Incandescent 60W 127V
3	CFL 3U 15W 220V 6500K
4	CFL ESP 15W 127V 6500K
5	CFL ESP 20W 127V 6500K
6	CFL ESP 25W 127V 6500K
7	LED 6W 100-240V 3000K
8	LED 6W 100-240V 5000K
9	LED 8W 100-240V 3000K
10	LED 8W 100-240V 5000K
11	LED 10W 100-240V 3000K
12	LED 10W 100-240V 5000K
13	LED 9W 110-240V 6400K
14	LED 11W 110-240V 6400K
15	LED 12W 110-240V 3000K

All of the tests were performed in accordance with the Brazilian regulatory standards for incandescent [19], compact fluorescent [20], and LED lamps [21]. It should be noted that the tests were performed in LABLUX/UFF (Fluminense Federal University), which is a laboratory accredited by INMETRO (a federal organization that coordinates the standardization guidelines for this type of equipment).

Electrical and photometric tests were carried out in the laboratory of lighting technique at UFF with controlled temperatures in the range of 25° C ± 1° C and with the voltage controlled at ± 0.5 % during periods of stabilization, reducing the tolerance to ± 0.2 % at the time of the measurements. The total harmonic content of the main voltage must not exceed 3 %. For the life test, the tolerance was ± 2 %, and the voltage total harmonic distortion could not exceed 3 %. The electric power that will supply the lamps in the test LABLUX specifically is through a controlled voltage source by California Instruments Model 300 lix, as shown in Fig 1.

The measurement of luminous intensity was performed with the photometer Everfine Photo-2000J, illustrated in Fig. 2. The tests were carried out on an integrating sphere with a sensor positioned after the bulkhead at a point determined by the sphere's manufacturing design. Fig. 3 illustrates the integrating sphere installed on LABLUX in this study.

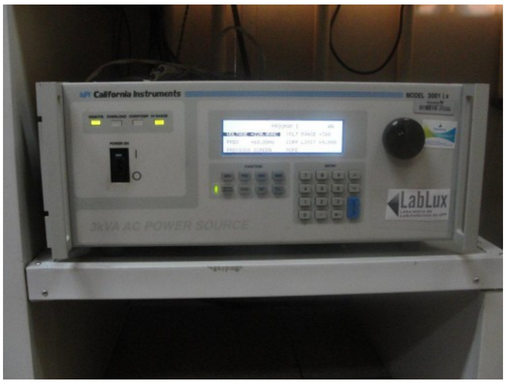

Fig. 1 – Controlled Source California Instruments

Fig. 2 – Photometer

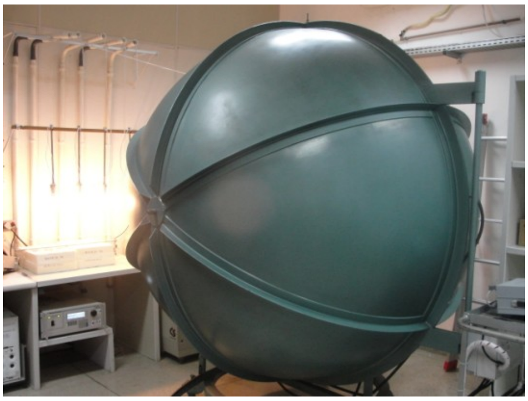

Fig. 3 – Integrating Sphere

The power quality tests were performed by a wattmeter Yokokawa WT-210, illustrated in Fig.4.
The graphs of the current and harmonic spectrum were generated through the software relating to the voltage-controlled source, namely, the California Instruments Model 300lix.
On all of the samples, the same measurements were performed: current, power factor, power, luminous flux, efficiency, and THD (Total Harmonic Distortion).
All of the samples were fed on their particular voltages. Only for the LED lamps were two measurements performed (127 V and 220 V); these measurements were based on the usual voltages in residences in Brazil, because these two specific models can be supplied with voltages ranging between 110-240 V, according to the manufacturer.
All of the lamps were tested before the measurements were taken: the incandescent according to [19], the CFLs as [20] and the LEDs as [22]. The samples were also all stabilized (i.e., after a period of time, they reached the nominal parameters) before measurements were conducted.

Fig. 4 – Quality Energy Analyzer

4 Results

4.1 Results of the Incandescent Lamps Tests

The measurements of incandescent lamps show a very small efficiency, as expected. Table 2 presents the measured results.

4.2 Results of the CFL´s Tests

Compact fluorescent lamps represent a great improvement to increase the light efficient, but they become a major source of current harmonics. They feature an average power factor of 0.63, which is above that permitted by the INMETRO Ordinance, which regulates that powers ≤ 25W are allowed a power factor > 0.5. Table 3 presents these measured results.

Table 2. Incandescent Lamp Measurements

Parameter	**Sample 1**	**Sample 2**
Current (mA)	800	476
Power Factor	1.00	1.00
Power (W)	101.4	60.3
Flux (lm)	1619	819
Efficiency (lm/W)	16	14
THDi (%)	0	0

Table 3. CFL Lamps Measurements

Parameter	Sample 1	Sample 2	Sample 3	Sample 4
Current (mA)	95	172	237	291
Power Factor	0.64	0.65	0.63	0.62
Power (W)	13.3	14.3	19	22.9
Flux (lm)	863	990	1261	1490
Efficiency (lm/W)	65	69	66	65
THDi (%)	100	98	99	102

Figs. 5, 6, 7, and 8 show the harmonic contributions in some samples of CFLs. However, significant problems were observed regarding the energy quality in all of the samples. Figs. 9, 10, 11, and 12 present the harmonic distortion distribution

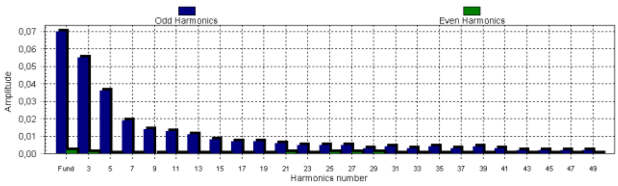

Fig. 5 - Current harmonic spectrum of Sample 3

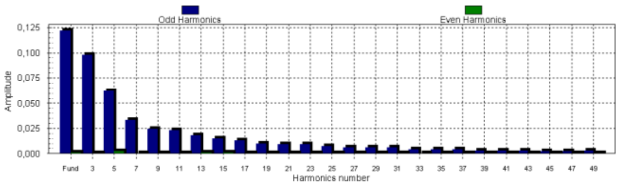

Fig. 6 - Current harmonic spectrum of Sample 4

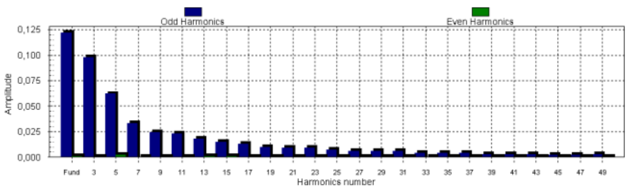

Fig. 7 -Current harmonic spectrum of Sample 5

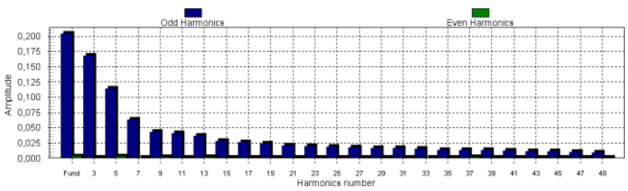

Fig. 8 - Current harmonic spectrum of Sample 6

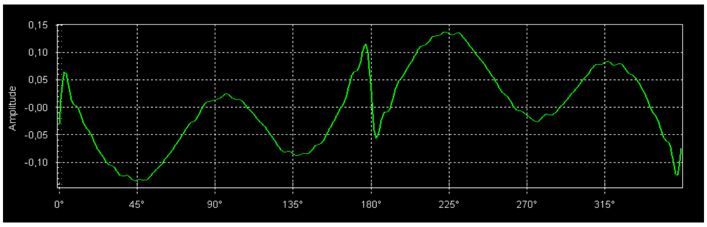
Fig. 9 - Current waveform of sample 3

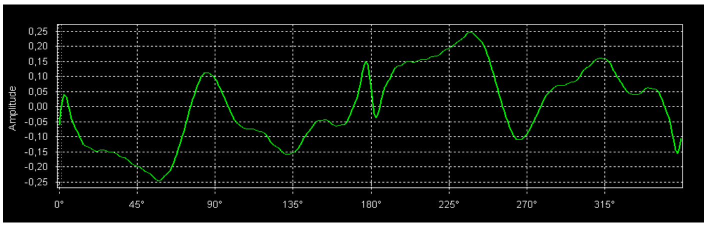
Fig. 10 - Current waveform of sample 4

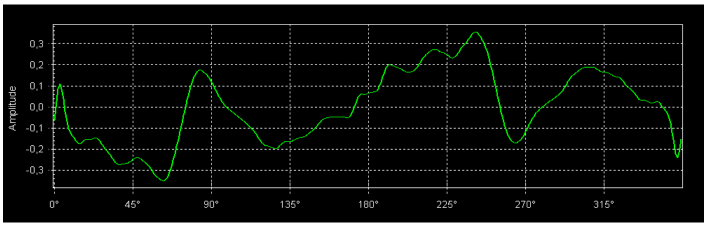
Fig. 11 - Current waveform of sample 5

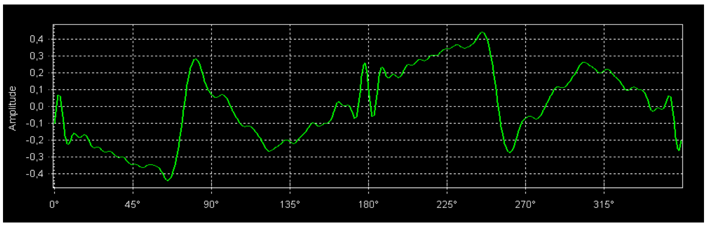
Fig. 12 - Current waveform of sample 6

4.3 Results of measurements on the LED Lamps fed into 127 V

Based on these measurements, it is possible to note that the LED lamps available on the Brazilian market feature a luminous efficiency that is, on average, 50% higher compared with the CFLs, and they feature a large current harmonic distortion, but the issue of low power is not a worried factor. During the test happened an exception case of Sample 13, which have presented a unity power factor of 0.99 and a total harmonic distortion of 16%. Table 4 presents these measured results.

Figs. 13 to 21 show the harmonic contributions in various lamp samples. LEDs and their current waveform are presented in Figs 22 to 30, whereby it is possible to identify harmonic distortions with the exception of Sample 13, evidenced in Figs. 19 and 28, which features some harmonic contribution of the 3^{rd}, 5^{th}, and 7^{th} orders.

Table 4. Measurements of LED Lamps with an Integrated Control Device base fed into 127 V

Parameter	Sample 7	Sample 8	Sample 9	Sample 10
Current (mA)	60	58	88	84
Power Factor	0.65	0.64	0.65	0.65
Power (W)	4.9	4.8	7.3	7.0
Flux (lm)	433	465	660	707
Efficiency (lm/W)	89	98	91	102
THDi (%)	92	94	89	90
Parameter	**Sample 11**	**Sample 12**	**Sample 13**	**Sample 14**
Current (mA)	114	112	80	105
Power Factor	0.65	0.65	0.99	0.61
Power (W)	9.4	9.2	10.0	8.2
Flux (lm)	839	942	947	598
Efficiency (lm/W)	89	102	95	73
THDi (%)	86	86	16	116
Parameter	**Sample 15**			
Current (mA)	144			
Power Factor	0.62			
Power (W)	11.4			
Flux (lm)	949			
Efficiency (lm/W)	116			
THDi (%)	112			

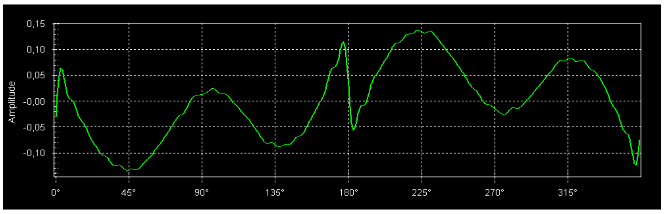
Fig. 9 - Current waveform of sample 3

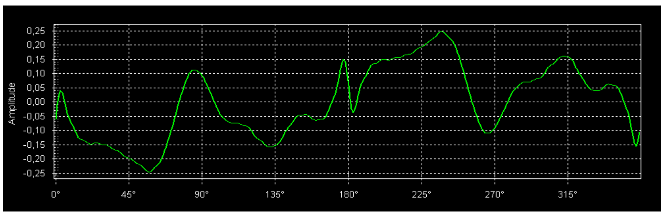
Fig. 10 - Current waveform of sample 4

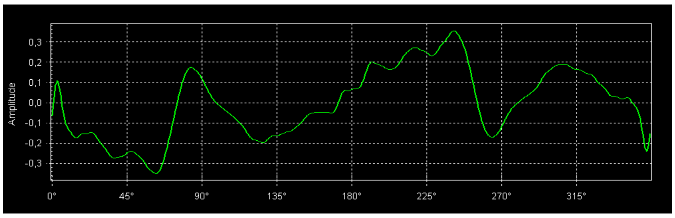
Fig. 11 - Current waveform of sample 5

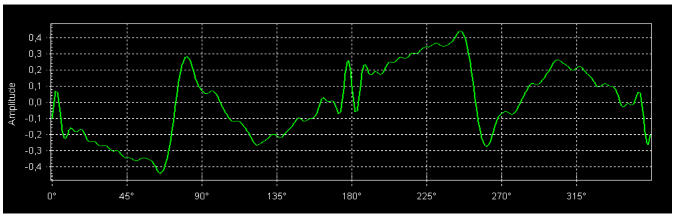
Fig. 12 - Current waveform of sample 6

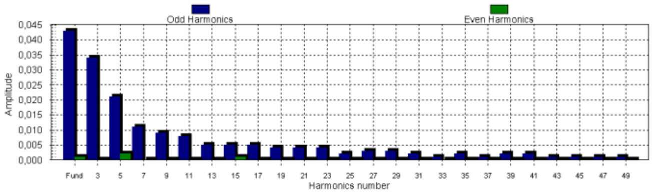

Fig. 13 - Harmonic current spectrum of sample 7, fed into 127V

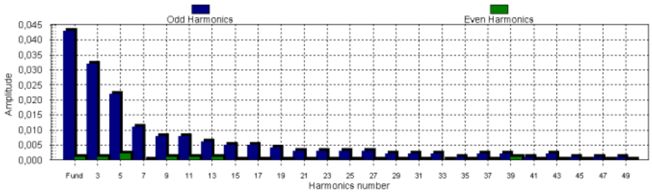

Fig. 14 - Harmonic current spectrum of sample 8, fed into 127V

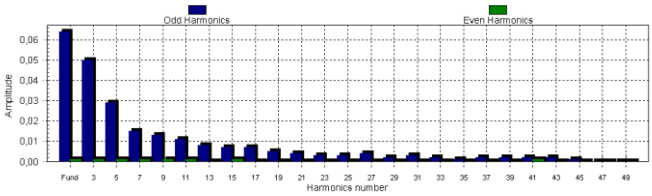

Fig. 15 - Harmonic current spectrum of sample 9, fed into 127V

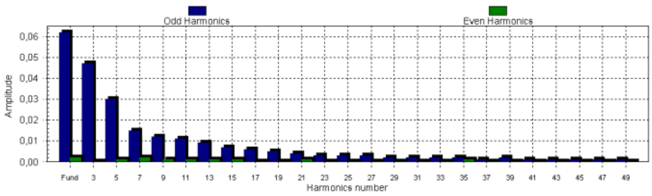

Fig. 16 - Harmonic current spectrum of sample 10, fed into 127V

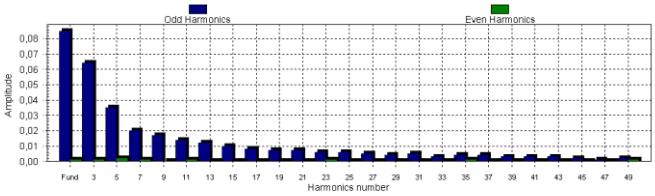

Fig. 17 - Harmonic current spectrum of sample 11, fed into 127V

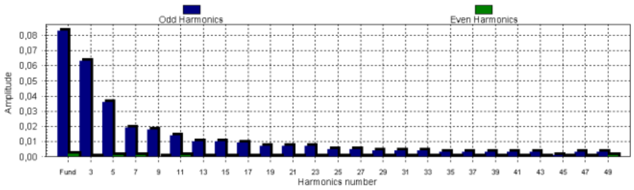

Fig. 18 - Harmonic current spectrum of sample 12, fed into 127V

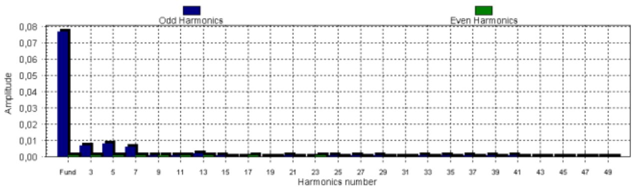

Fig. 19 - Harmonic current spectrum of sample 13, fed into 127V

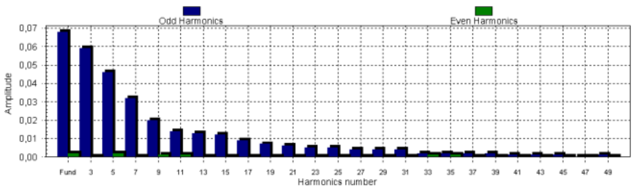

Fig. 20 - Harmonic current spectrum of sample 14, fed into 127V

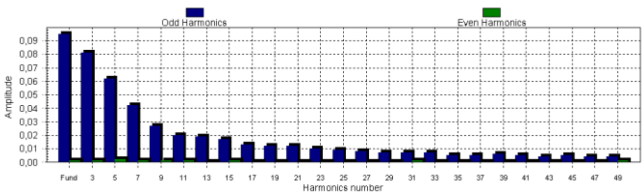

Fig. 21 - Harmonic current spectrum of sample 15, fed into 127V

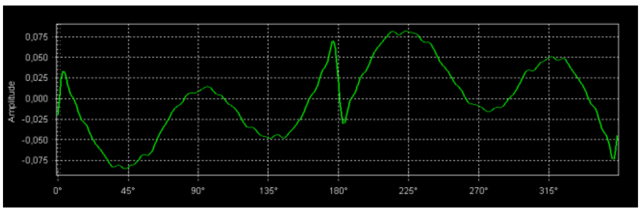

Fig. 22 - Current waveform of sample 7, at 127V

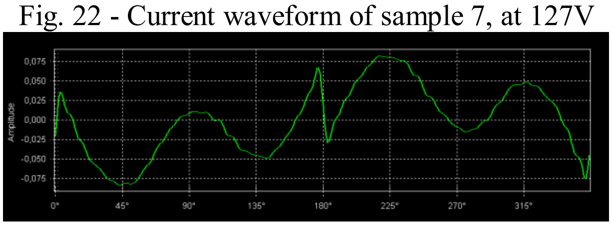

Fig. 23 - Current waveform of sample 8, at 127V

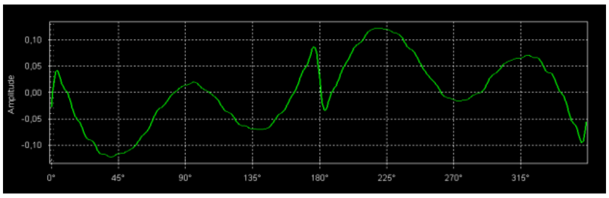

Fig. 24 - Current waveform of sample 9, at 127V

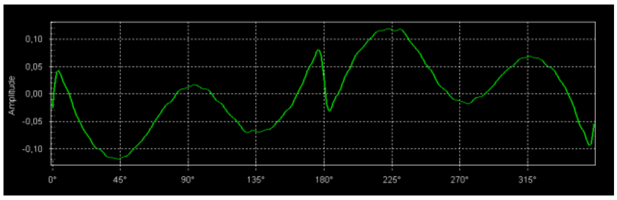

Fig. 25 - Current waveform of sample 10, at 127V

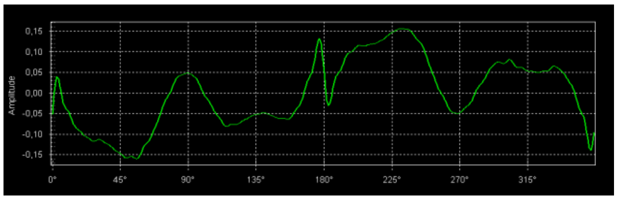

Fig. 26 - Current waveform of sample 11, at 127V

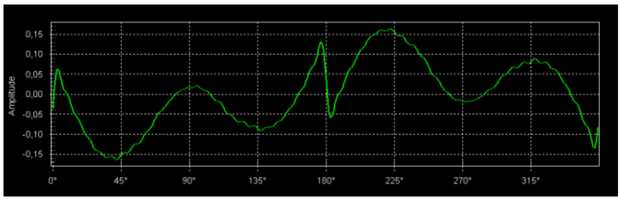

Fig. 27 - Current waveform of sample 12, at 127V

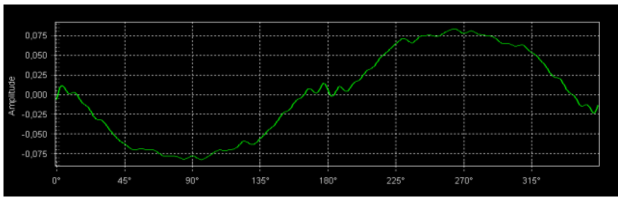

Fig. 28 - Current waveform of sample 13, at 127V

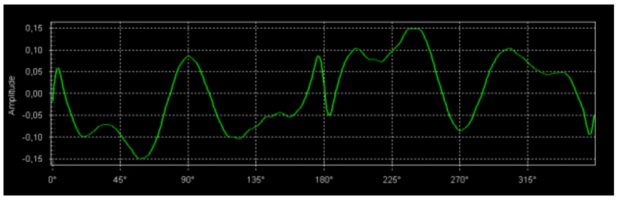

Fig. 29 - Current waveform of sample 14, at 127V

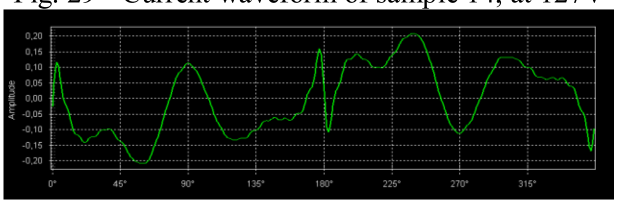

Fig. 30 - Current waveform of sample 15, at 127V

4.4 Results of Measurements on the LED Lamps fed into 220 V

The Table 5 presents the measured results for LED lamps at 220 V.

Table 5. Measurements of LED Lamps with an Integrated Control Device base fed into 220 V

Parameter	**Sample 7**	**Sample 8**	**Sample 9**	**Sample 10**
Current (mA)	38	38	56	54
Power Factor	0.57	0.57	0.58	0.58
Power (W)	4.8	4.7	7.2	6.9
Flux (lm)	432	468	657	701
Efficiency (lm/W)	89	99	92	102
THDi (%)	132	133	128	130
Parameter	**Sample 11**	**Sample 12**	**Sample 13**	**Sample 14**
Current (mA)	73	71	46	69
Power Factor	0.58	0.58	0.98	0.55
Power (W)	9.3	9.1	9.8	8.3
Flux (lm)	833	942	895	594
Efficiency (lm/W)	90	103	91	71
THDi (%)	126	128	14	150
Parameter	**Sample 15**			
Current (mA)	78			
Power Factor	0.56			
Power (W)	9.6			
Flux (lm)	648			
Efficiency (lm/W)	68			
THDi (%)	145			

For these measurements, the LED lamps are considered to be those that can be supplied, according to the manufacturer, in a 110-240V voltage range. The lamps should be fed the same way on any voltage within the rated voltage range; however, this did not happen with these measurements at 220V. Only Sample 13 behaved as it should, maintaining roughly the same power, the same power factor, the same energy, and the same total harmonic distortion. This differentiated sample proves that the lighting market on Brazil still has nonstandard products.

It is possible to observe that the other LED lamps tested have a power factor reduction, an increase in the current harmonic distortion, and, for some, a reduced luminous efficiency. Figs. 31 to 39 show that the harmonic contributions increased in virtually every odd harmonic order in all lamp samples. The LEDs' current waveforms are presented in Figs. 41 to 48, which clearly show the harmonic distortions.

A important point to note is the fact that in [23], a comparison between CFLs and LEDs was done, and the results presented in this research compared with this research test results show that the Brazilian lamps has actually (2015) better quality.

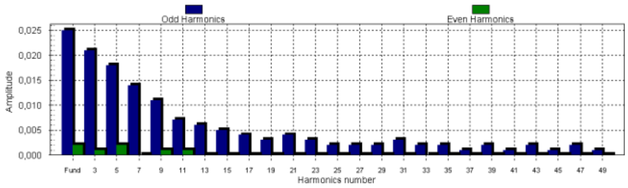

Fig. 31 - Harmonic current spectrum of sample 7, fed into 220V

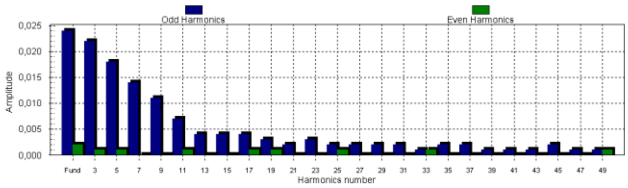

Fig. 32 - Harmonic current spectrum of sample 8, fed into 220V

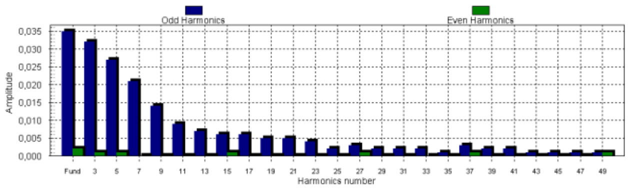

Fig. 33 - Harmonic current spectrum of sample 9, fed into 220V

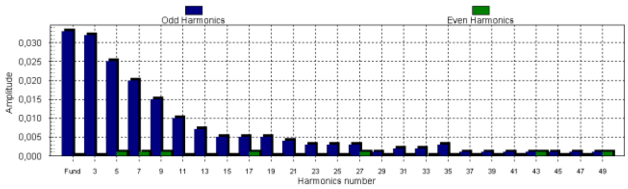

Fig. 34 - Harmonic current spectrum of sample 10, fed into 220V

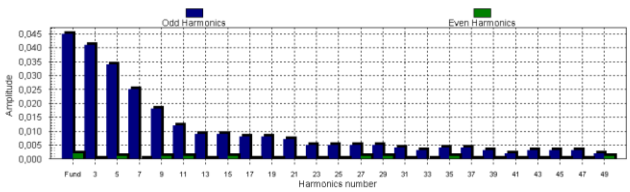

Fig. 35 - Harmonic current spectrum of sample 11, fed into 220V

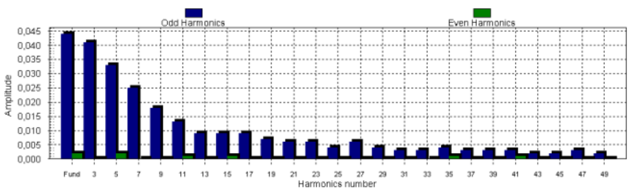

Fig. 36 - Harmonic current spectrum of sample 12, fed into 220V

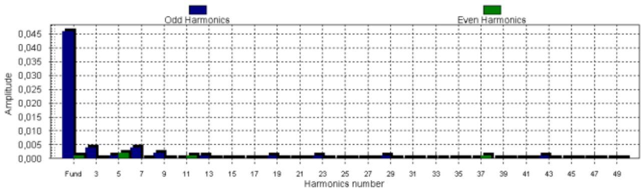

Fig. 37 - Harmonic current spectrum of sample 13, fed into 220V

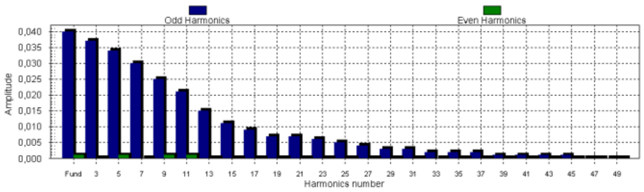

Fig. 38 - Harmonic current spectrum of sample 14, fed into 220V

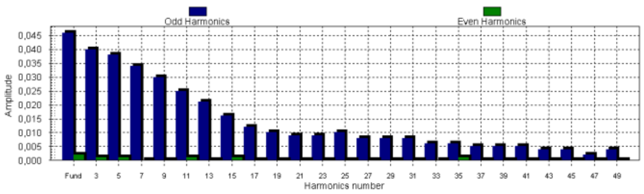

Fig. 39 - Harmonic current spectrum of sample 15, fed into 220V

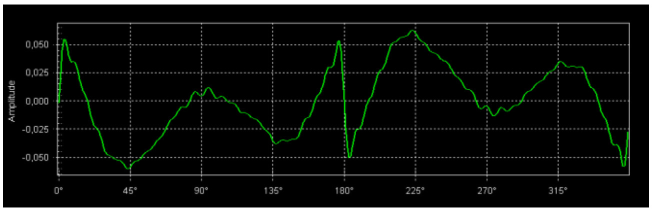

Fig. 40 - Current waveform of sample 7, power fed in 220V

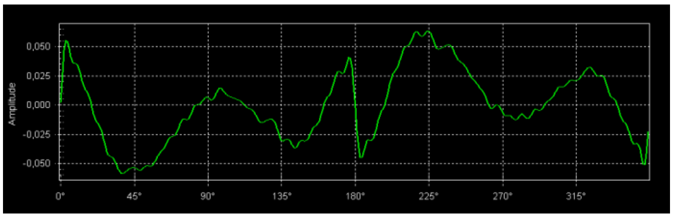

Fig. 41 - Current waveform of sample 8, power fed in 220V

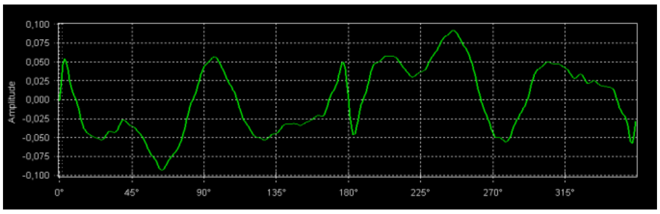

Fig. 42 - Current waveform of sample 9, power fed in 220V

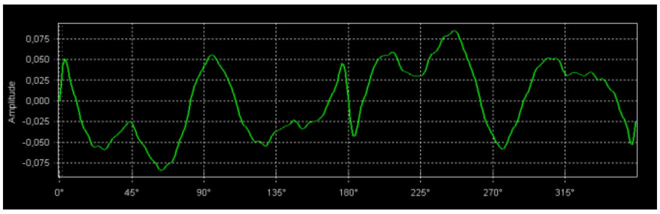

Fig. 43 - Current waveform of sample 10, power fed in 220V

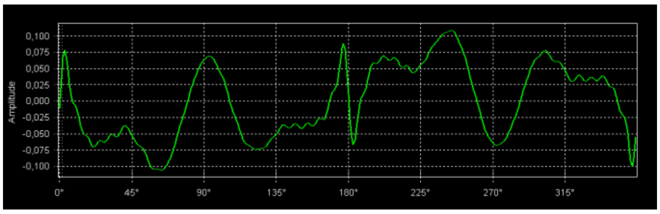

Fig. 44 - Current waveform of sample 11, power fed in 220V

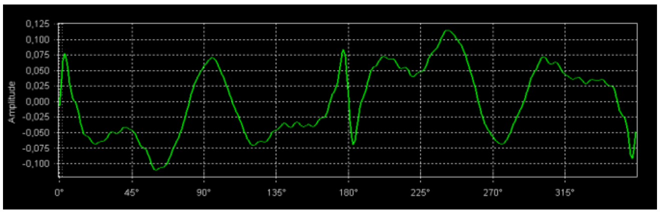

Fig. 45 - Current waveform of sample 12, power fed in 220V

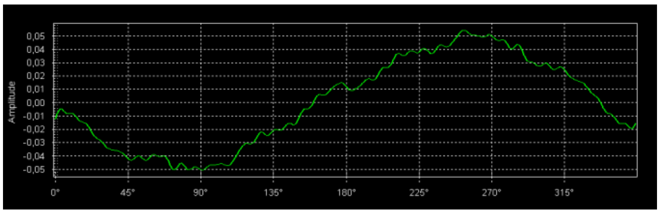

Fig. 46 - Current waveform of sample 13, power fed in 220V

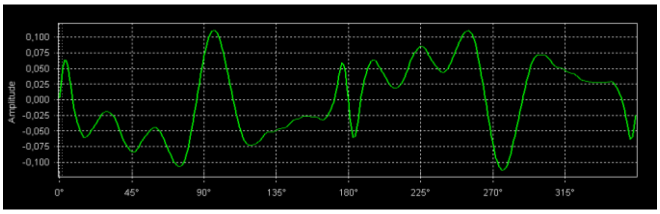

Fig. 47 - Current waveform of sample 14, power fed in 220V

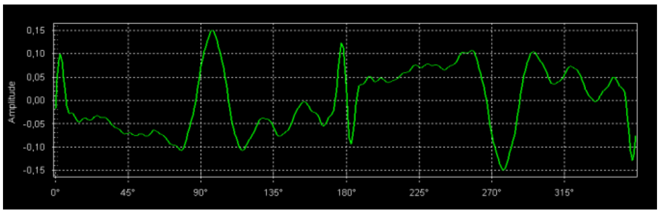

Fig. 48 - Current waveform of sample 15, power fed in 220V

5 Conclusions

This study aimed to show the behavior of the lamps available in the Brazilian market, especially the behavior of the LED bulbs, due to the lack of regulation of this product for the Brazilian market.

The incandescent light bulbs, as expected, showed a very low efficiency in comparison with CFL and LED lamps. The LED lamps showed, on average, 50% more luminous efficiency than CFLs, but they presented similar characteristics in power factor and total harmonic distortion. It was possible to observe that the Brazilian market has adequate LED bulbs with a power factor unit and a low harmonic distortion, exemplifying efficiency and power quality. In other words, the appropriate surveillance of marketed products can ensure that improved technology actually contributes to the reduction of consumption in residences and other buildings.

The results of this evaluation can be extended to other types of buildings, and a similar analysis can be developed.

It is significant to note that not all marketed products will have a good energy quality, if standards are not applied and audited. The energy policies established to reduce consumption in buildings via new technologies should include the application of certified products, thus ensuring that the information generated by energy planning teams will achieve the expected results. This paper confirms that the measurement of energy quality of lighting devices is an important action and this act must be repeated for all new equipment introduced on the market.

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