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Power Quality in modern lighting: comparison of LED, microLED and CFL lamps

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Abstract. This paper presents a study for the electric performance of different energy saving lamp types like LED, microLED and Compact Fluorescent Lamp (CFL), under nominal operating conditions (sinusoidal waveform of 230 Vrms and 50 Hz) along with abnomal conditions such swells, sags, notch or harmonic distortion in the voltage source. A set of diferent test is also carried out for the selected lamps to determine the power quality values.

Key words

Lighting, Led, CFL, Power Quality, Harmonics

1. Introduction

In 2012, the lighting accounts for 10% of residential electricity consumption in the European Union countries (12% in 2000) [1]. In the USA, the household lighting accounts for 11% in 2014 according to the US Energy Information Administration. This trend reflects a significant increase in the adoption of compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) types in the past years at the expense of incandescent light bulb (IL) [1]. Although ILs and halogens type are cheaper to purchase, they are rather energy inefficient. Moreover, the U.S. Energy Independence and Security Act [2] and a European ban on incandescent bulbs type [3] have been enacted with the aim to enhance and increase energy efficiency and conservation for general lighting.
A strong indicator that confirms this trend is the fact that the consumers are replacing incandescent light sources with compact fluorescent lamp (CFL) type and light emitting diode (LED) bulb type that use about 70% and 85% less energy and have 10 and 50 times longer lifetimes, respectively [4,5].
LEDs type have also important benefits and advantages like the absence of mercury in CFLs type and higher energy efficiency for indoor lighting [6], but as a part of their energy saving strategy and energy policy, nations across the world still promote the use of CFLs type.
Many researchers around the world focus in reducing electrical loading by using efficient energy lighting methods which has resulted in a high-level interest in replacing conventional incandescent lamp type with Compact Fluorescent Lamps type and LED lamp type [7].

Recently, LED lamp types are more widely accepted than CFLs type because of their important advantages in lower power consumption and longer lifetime. Also, LED lamps type, similar to CFLs type, are non-linear in nature and hence induce harmonics into the distribution system [7].

2. Material and Methods

A. Lighting technology and type

In this work, two main types of lighting sources have been chosen as the most used models in the market: LED and CFL.
LED's principle of operation has been widely studied [8,9] and can be described as a two-lead semiconductor diode, which emits light when activated. When the electric current flows, electrons are able to recombine with holes within the device, releasing energy in the form of photons. Inside the semiconductor material of the LED, the electrons and holes are contained within energy bands. The separation of the bands (i.e. the bandgap) determines the energy of the photons (light particles) that are emitted by the LED. The photon energy determines the wavelength of the emitted light, and hence its colour. Different semiconductor materials with different bandgaps produce different colours of light. The precise wavelength (colour) can be tuned by altering the composition of the light-emitting, or active, region. Figure 1 shows the illustration of this process.

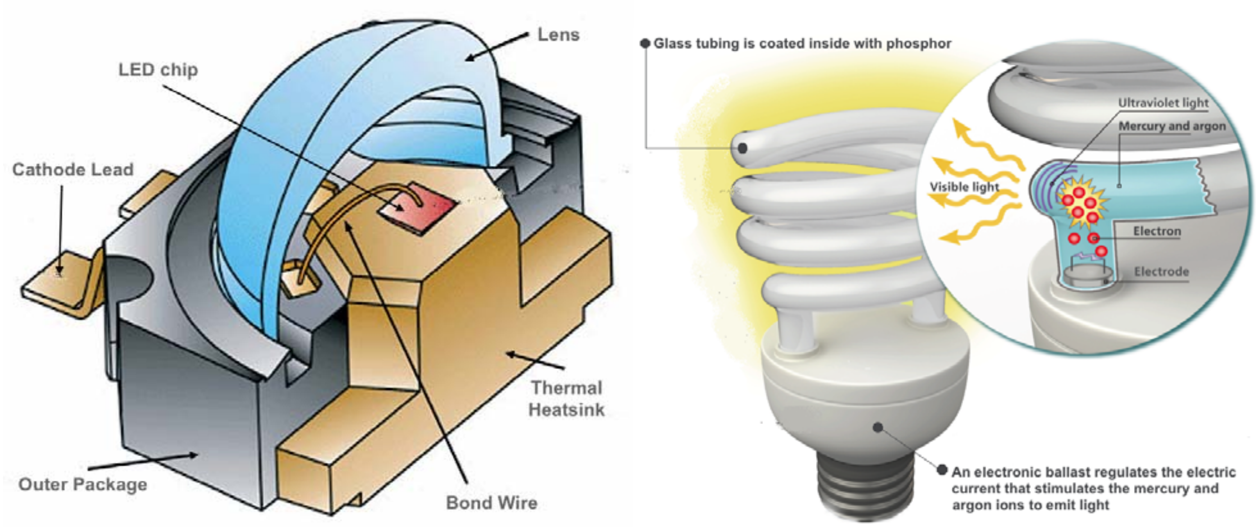

Fig. 1. Light emitting diode (LED) principle of operation (left) and Compact Fluorescent Lamp (CFL) principle of operation (right). Adapted from http://ehp.niehs.nih.gov.

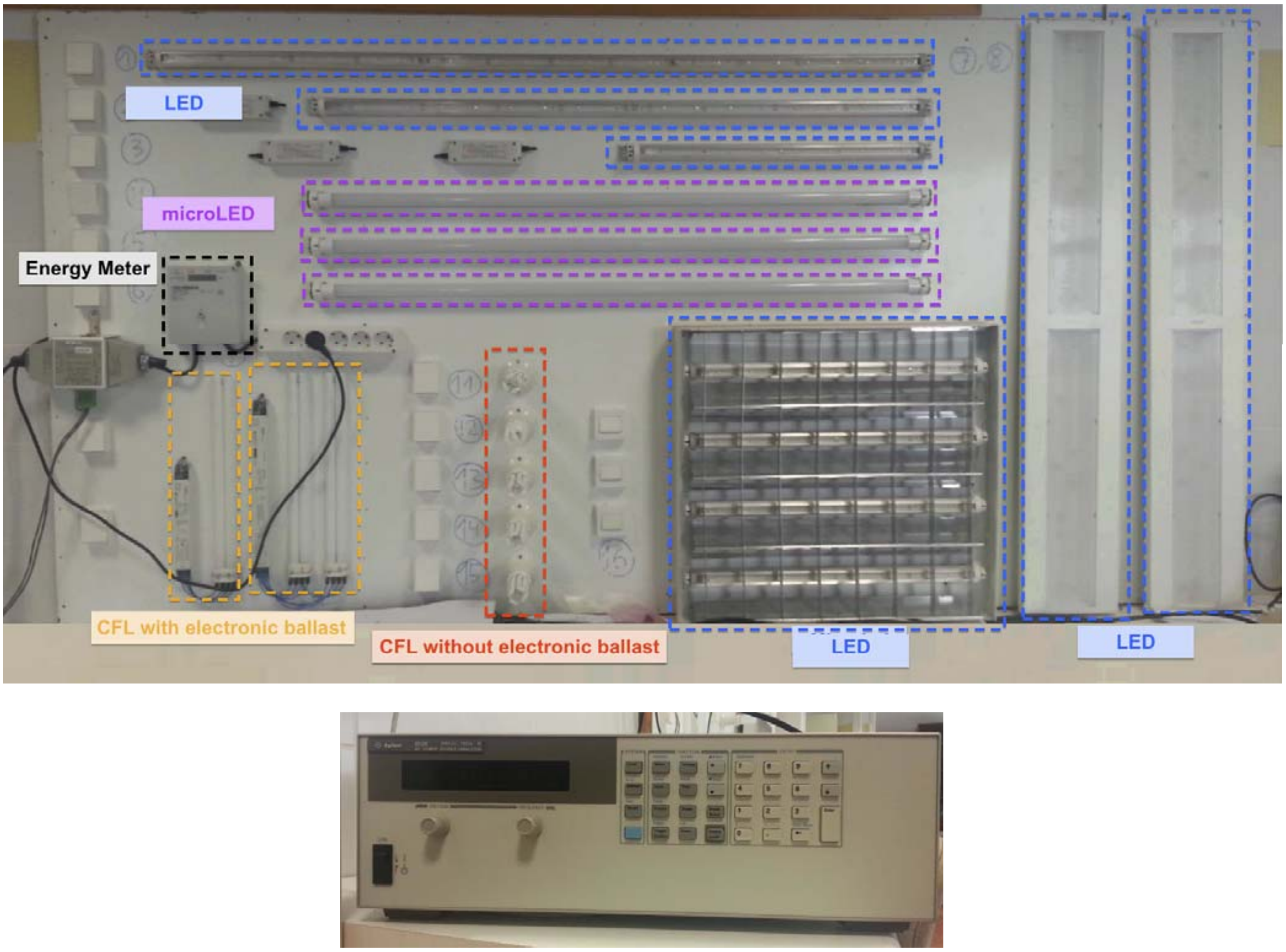

Fig. 2. Experimental setup with LED, microLED and CFL lamps (up) and Agilent 6812B digital power source (bottom).

The principle of operation in a CFL bulb is exactly the same as the fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they will radiate ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is converted into visible light as it strikes the fluorescent coating on the bulb (as well as into heat when absorbed by other materials such as glass). The main drawback compared to LED and, especially, incandescent is the content of hazardous elements like lead, zinc and mercury.

A total of 16 different lamp types have been used for the tests carried in this work (see Table I). The energy consumed was also registered with a digital energy totalizer. Up to 4 different lamp types were employed, including LED, microLED and CFL with and without electronic ballast (CFL1 and CFL2, respectively). However, two main groups can be considered upon the basis of their operating principle, i.e., luminescence for CFL lamps and electro luminescence for LED and microLED lamps. No incandescent lamp has been tested because of their obsolescence and its ban by the European laws [3]. The figure 2 shows the setup in the laboratory.

Table I. – Lamp types

Lamp	Type	Power (W)	Lifespan (h)	Luminous efficacy (Lm/W)	Colour Temp (ºK)
1	LED	14.3	50 000	94	4 000
2	LED	12.7	50 000	94	4 000
3	LED	7.9	50 000	94	4 000
4	MicroLED	18	50 000	80	5 500
5	MicroLED	18	50 000	80	5 500
6	MicroLED	18	50 000	80	5 500
7	LED	36	50 000	94	4 000
8	LED	36	50 000	94	4 000
9	CFL1	36	10 000	80	4 000
10	CFL1	72	10 000	80	4 000
11	CFL2	20	10 000	60	4 000
12	CFL2	20	10 000	60	4 000
13	CFL2	20	10 000	60	4 000
14	CFL2	20	10 000	60	4 000
15	CFL2	20	10 000	60	4 000
16	LED	36	50 000	94	4 000

B. Power source

The digital power supply Agilent HP6834B with arbitrary waveform output was used as the programmable power source. It combines the capabilities of a power amplifier and an arbitrary waveform generator. This allows simulating normal waveforms and many types of distorted power waveforms. The built in power analyser combines the capabilities of a multimeter, oscilloscope, harmonic analyser and power analyser. The power supply has extensive 16-bit precision measurement capabilities and also includes:

- RMS, DC, AC + DC voltage and current
- Peak voltage and current
- Real, apparent, and reactive power
- Harmonic analysis of voltage and current waveforms providing amplitude and phase up to the 50th harmonic
- THD (total harmonic distortion)

3. Cases of Study

Several experiments have been carried out to test different combination of lamps and voltage waveform conditions. Three groups of trials have been established and results were obtained for each of them based on the voltage source conditions applied:

- Nominal voltage
- Transient voltage
- Distorted harmonic voltage

A. Nominal voltage operating conditions

As previously stated, a total of 16 lamps of different types (LED, microLED and CFL with and without electronic ballast) were used in the tests. Nominal voltage was generated using the Agilent power source, i.e., perfect sinusoidal of 230 RMS voltage and 50 Hz frequency (eq. 1).

$$v(t) = \sqrt{2} \cdot 230 sin(2\pi 50 t + \varphi) \qquad (1)$$

Several power electric parameters were measured in order to categorise the severity of the distortion produced by the non-linear load lamp electric equivalent. Namely, RMS current, active power, reactive power, apparent power, distortion power, harmonic content, power factor, THD and peak current.
Figure 3 shows the current waveform for all the lamp type under test. It can be noted that LED lamp 1,2 and 3, and, especially, CFL2 lamps present a high distorted shape. That means there is a strong presence of harmonics in the demanded current of these types of lamps. Table II shows the main measured power values for this configuration.

Table II. – Power values under nominal conditions

Lamp	THDi (%)	Active Power (W)	Reactive Power (VAr)	Distorted Power (VAd)	cos φ
1	21.96	14.33	-8.70	3.84	0.83
2	25.34	12.72	-8.42	3.94	0.83
3	36.21	7.85	-5.84	5.83	0.69
4	18.71	20.07	-8.82	3.54	0.90
5	15.84	19.26	-8.55	3.39	0.90
6	16.03	19.97	-8.63	3.44	0.91
7	12.64	36.24	-9.24	4.99	0.96
8	12.57	36.27	-9.23	4.86	0.96
9	19.54	33.47	-9.81	7.09	0.94
10	13.67	60.37	-15.84	9.05	0.96
11	107.21	19.55	-9.03	22.91	0.62
12	112.69	19.81	-9.16	24.04	0.61
13	107.44	19.25	-8.95	22.39	0.62
14	104.58	18.96	-8.64	22.29	0.62
15	105.11	19.92	-9.35	22.94	0.63
16	18.81	32.41	-14.80	6.04	0.90

Note that for all lamps, the reactive power is negative, so it means they behave as capacitive loads. CFL1 lamps present a THDi above the rest along with a high distortion power D.
The figure 4 shows the current waveform and the Fourier analysis when all the lamps are connected at the same time. Notice the relevance of harmonics up to 9^{th} order (450 Hz).

B. Transient voltage operating conditions

In order to emulate situations where transient voltage occurs, such sags, swells or notches, the HP6834B power source has been programmed accordingly. The tests revealed that neither sags nor swells produced harmful

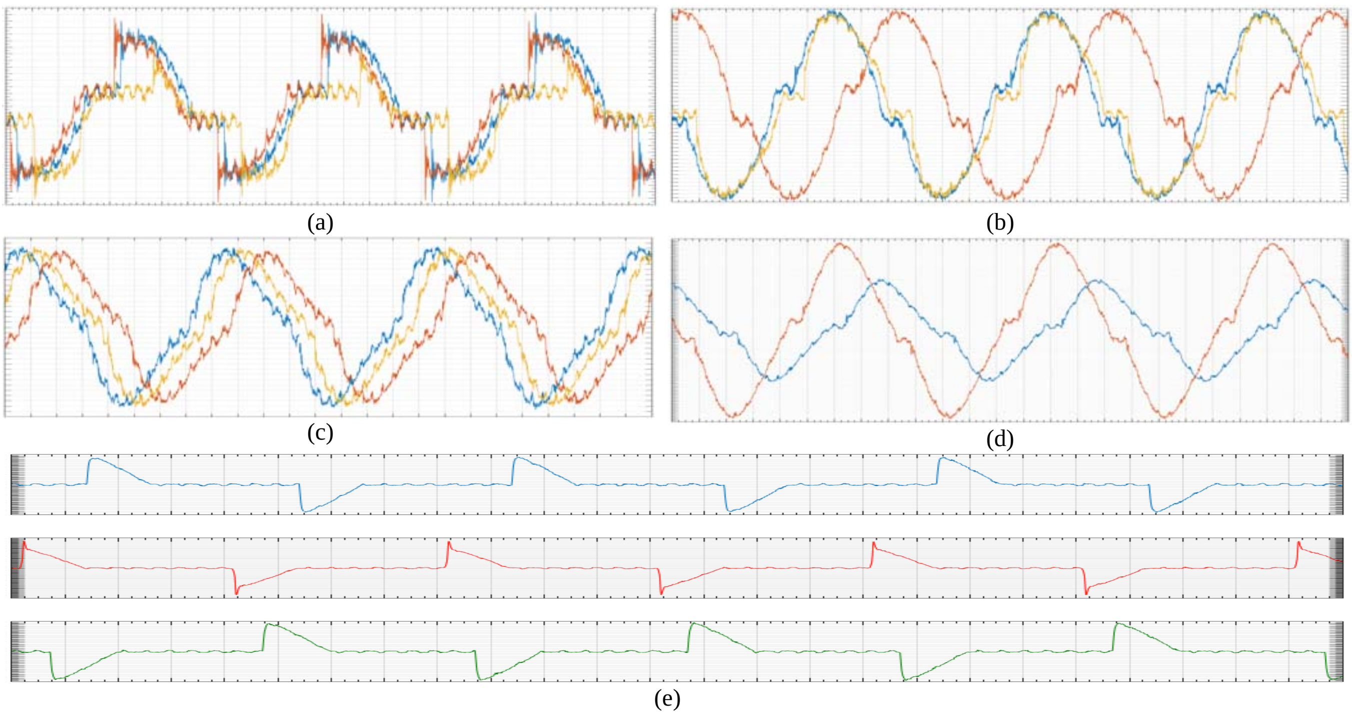

Fig. 3. Current waveform for lamps (a) 1,2,3 LED; (b) 7,8,16 LED; (c) 4,5,6 microLED; (d) 9,10 CFL1; (e) 11,12,13 CFL2

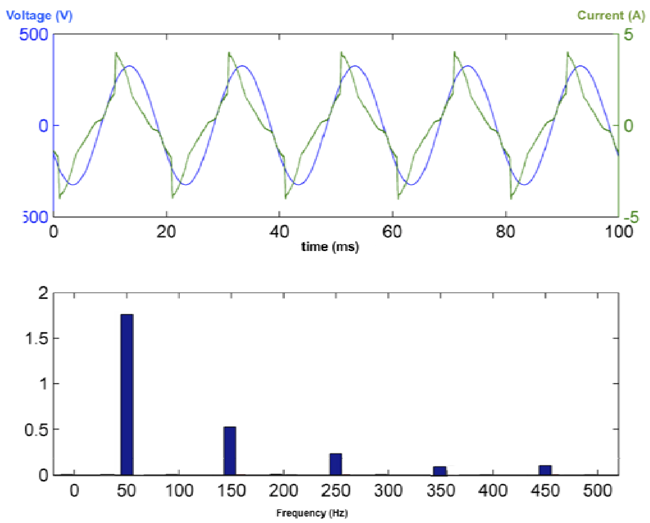

Fig. 4. Current waveform for the 16 lamps set (up) and Fourier analysis (bottom)

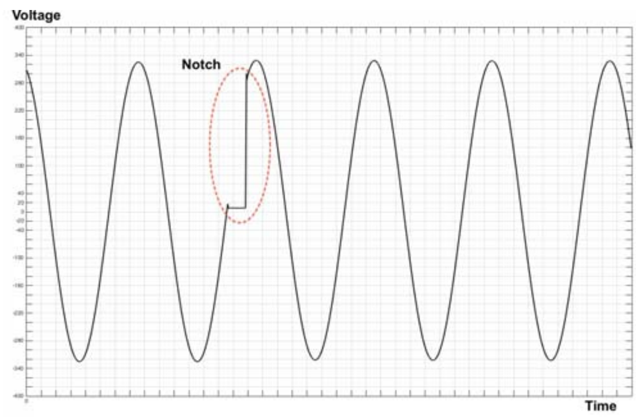

Fig. 5. Notch in voltage source

effects beyond the observed in nominal conditions. However, notches were identified as a potential source of damages for the lamps. To demonstrate this situation, notches of a maximum of 3 ms were added to the nominal voltage source in eq. (1). Figure 5 shows an example of such transient phenomenon. Similar waveform was applied to lamps 1, 4, 10 and 11 being representative of the four different types. Additionally, phase jumps were taken into account for the notch in 15º steps, starting from 0º to 90º. Figure 6 shows a detailed view of the result for a specific phase jump. It can be noted that high current peaks compared to nominal values are present in all lamp types, regardless of the phase jump, except for lamp 11 (CFL2 type) where the peak value was very dependent on phase.
LED type lamp showed the poorest behaviour with a current peak over 16 times its nominal value. Also CFL2 presented a bad performance with 12.35. On the contrary, CFL1 peak is only 4.5 times higher than nominal value.

C. Distorted harmonic voltage operating conditions

In this experiment, the voltage applied to the lamps was formed by adding some harmonics to the fundamental. In particular, the harmonic spectrum was the following:

- Fundamental 230 Vrms.
- Third harmonic of 20%.
- Fifth harmonic of 10%.
- Seventh harmonic of 5%.

Only odd harmonics were taken into account (even harmonics are almost negiglible in real power networks).
Figure 7 shows the results for lamp 1, 4, 10 and 11. It can be noted the high current distortion caused by the voltage harmonics. Table III also shows the THDi increment for the distorted test compared to the nominal test. As a consecuence of the harmonic addition, the distortion level for the current is higher than the obtained in nominal conditions, except for lamp 11 (CFL2). As can be seen in Figure 7, lamp 1, 4 and 10 present a waveform with

higher distortion compared to Figure 3, in contrast with lamp 11 where the new waveform looks less distorted as the THDi confirms in Table III. This can be explained assuming the poorer waveform for lamp 11 under nominal condition, so the new voltage harmonics are causing an improvement at the expense of the cancellation of some old harmonics.

Table III. – Distortion comparison. Nominal conditions vs distorted harmonic conditions

Lamp	THDi % (nominal)	THDi % (distorted)	Increment (%)
1	21.96	44.99	104.87
4	18.71	30.40	62.48
10	13.67	22.53	64.81
11	107.21	87.92	-17.99

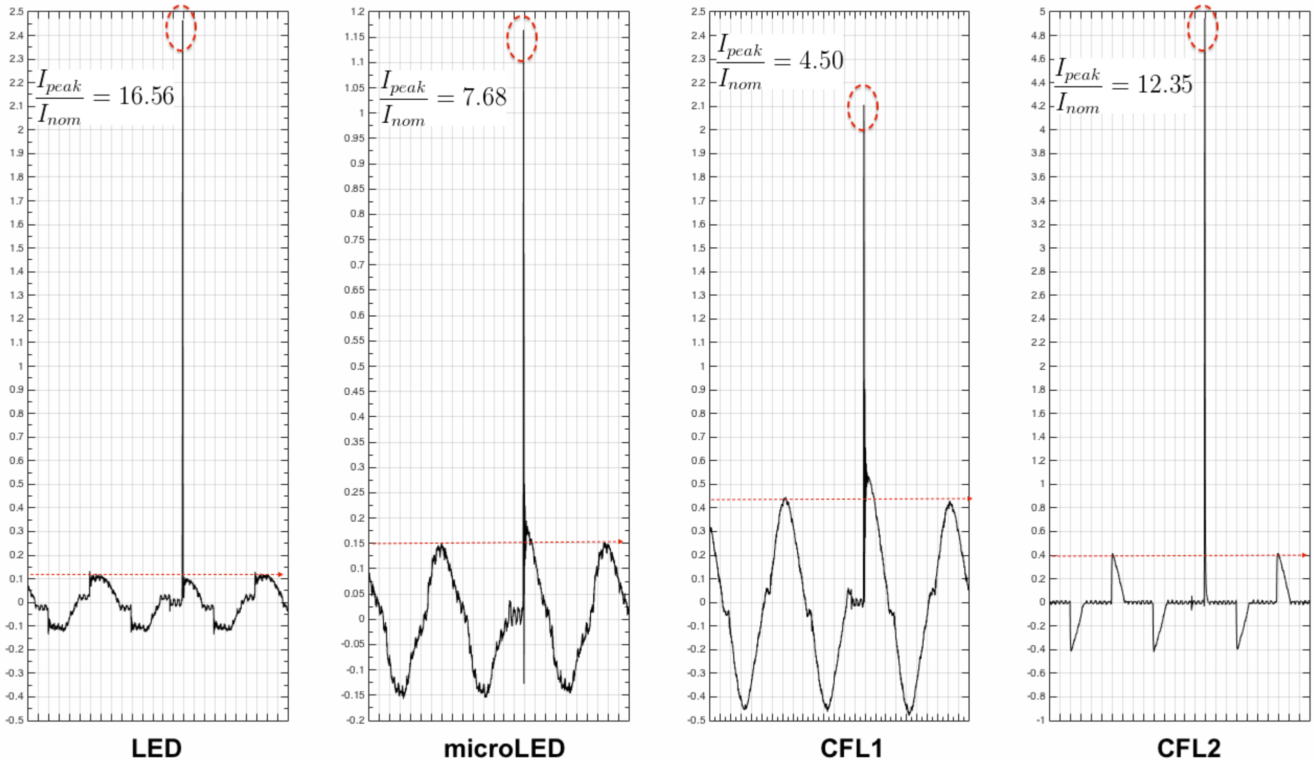

Fig. 6. Current peaks for lamps 1, 4, 10 and 11 under transient notch voltage.

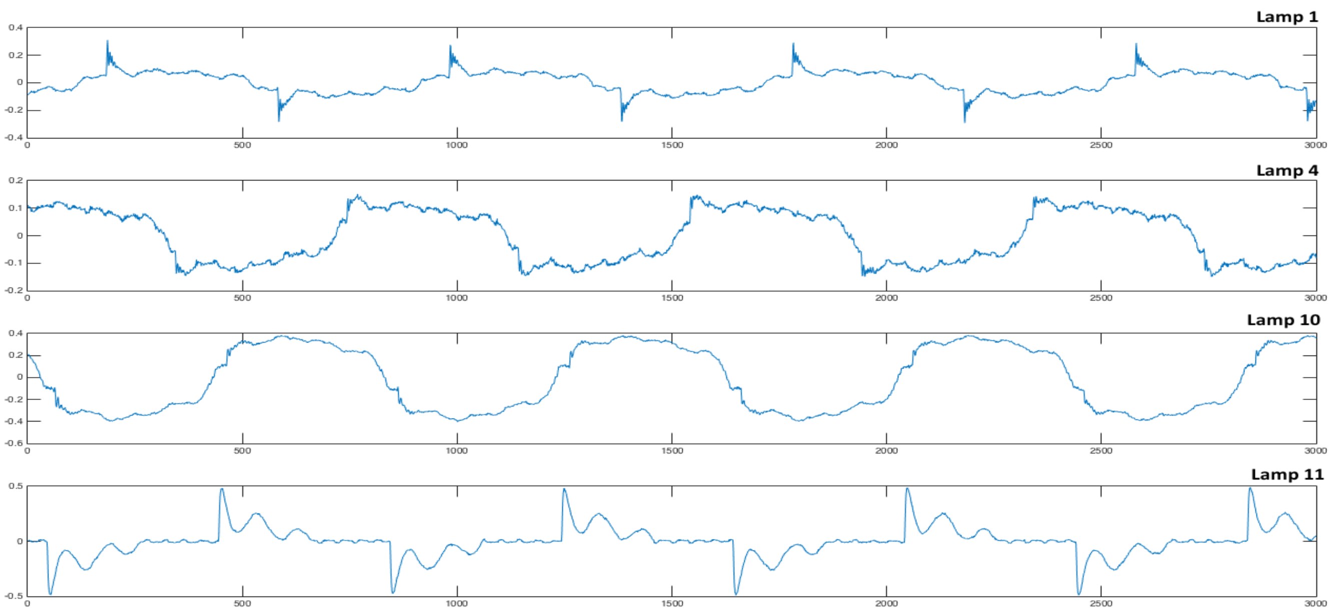

Fig. 7. Current distortion for lamps 1, 4, 10 and 11 under harmonics voltage.

4. Conclusion

Various types of energy saving lamps used in general lighting have been analysed for their power quality properties under laboratory conditions. It is well known that modern lighting is an important source of harmonics and can cause bad power quality in the electrical system.

The study of such source of harmonics will in fact help to avoid malfunction of other equipment connected to the grid. The measurements carried out in this work show that CFL equipment without electronic ballast are, by far, the worst lamp type because of their high emission of harmonics. On the contrary, CFL with electronic ballast, LED and microLED showed moderated harmonic emission. In other words, power quality concerns should be a reason for not using CFL lamps with electromagnetic ballast.

Measurement under transient and distorted voltage yielded bad results, especially when notches arise, causing peak overcurrent up to 16.5 times higher than nominal values. The spectrum obtained in the test showed a wide range in emission levels.

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