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Harmonic Investigation of Compact Fluorescent Lamps Low Energy Consumption Lamps of Cameroonian Market

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Abstract

This article presents a study of compact fluorescent lamps (CFLs) low energy consumption lamps found in the Cameroonian market. The current obtained in the experimental setup has been analyzed in Matlab Simulink. The results obtained show that the THD of different lamps does not respect the standard IEC-61000-3-2. These values increase with the power of lamps. Spectral analysis of these lamps shows that the probable cause of their premature degradation results from the effects of harmonics on the capacitors. This degradation is all more precocious as the rank and the concerned THD_i is great. That's why 75 W lamps are more sensitive than others.

Subject Areas

Electric Engineering

Keywords

Harmonic, Pollution, Compact Fluorescent Lamp, THD, Spectrum Harmonic

1. Introduction

Deficit electric energy in the world and mainly in Africa has led states to adopt energy efficiency policies. These policies concern production and consumption fields. Consumption of electrical energy by electric lighting is estimated at 20% world consumption. To reduce this, Cameroonians have chosen low-energy lamps. Among these, we find mainly LED lamps and compact fluorescent lamps (CFLs) with electronic ballast. The lifespan ranging of CFL is estimated between 6000 h and 15,000 h but in pratic we observe a premature deterioration of these.

Analysis of power supplies of these faulty lamps shows that they are RCD (resistor, capacitor and diodes) types [1] and the most critical element is capacitor. These failures can have several causes; harmonic pollution is one of them. Harmonic currents originate from the absorption of non-sinusoidal currents by non-linear loads [2]. CFLs by their alimentation structures are nonlinear load [3]. Effects of harmonics are numerous, ranging from abnormal heating of conductors to the destruction of electric components [4] [5] [6]. These effects concern the components connected to the same node of an electrical network and vary according to the harmonic rank and their rate in the signal. The electromagnetic compatibility standards limit this harmonic pollution depending on type and power of load [7] [8] [9]. Several solutions exist to this phenomenon, among them: sizing, compensation, and filtering [10]. Knowledge of harmonic spectrum makes it possible not only to diagnose failures causes of electric components, but also to design adapted filters. The article aim is to investigate the harmonic pollution of CFLs. It is subdivided into three parts. The first is a review of the literature on harmonics and analysis methods, the second presents the methods and tools used to carry out our investigation and the last is a presentation of results.

2. Related Work

Harmonics are the sinusoidal voltages or currents whose frequency is an integer multiple of frequency network (50 hz in Cameroon) called fundamental. A signal polluted is a superposition of this different harmonics that can modeled by following equation:

$$f(t) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos(nwt) + b_n \sin(nwt) \right) \tag{1}$$

where n is harmonic rank and $w = \frac{2\Pi}{T}$ the electric pulse

a_0, a_n, b_n, are real constants with:

a_0 the average value of the electrical signal given by:

$$a_0 = \frac{1}{T} \int^{T} f(t) \mathrm{d}t$$

a_n the real part of signal amplitude

$$a_n = \frac{2}{T} \int^{T} f(t) \cos(n\omega t) \mathrm{d}t$$

b_n the imaginary part of signal amplitude

$$b_n = \frac{2}{T} \int^{T} f(t) \sin(n\omega t) \mathrm{d}t$$

For $n = 1$ we have the fundamental.

2.1. Harmonics Sources

Main harmonics perturbations causes are nonlinear charges. They are generated by equipment (electronics components) who supply by DC current. computers, variable speed drives and CFLs are examples. This load type is characterized by generation of deformed current which remains periodic and created sequences zero harmonics like: rank 7 and 13 witch are sequence positive; rank 5 and 11 witch are sequence negative; rank 3 and 9 witch are sequence zero [11].

2.2. Harmonic Currents Characteristics

Electric characteristics of a periodic signal deformed are:

- The total rms value

If I_k is rms value of harmonic current at rank *k*, the total *rms* value is given by Equation (2)

$$I_{rms} = \sqrt{\sum_{k=1}^{n} I_k^2} \tag{2}$$

- The individual harmonic distortion rate

It gives relation between *rms* value of harmonic and the fundamental

$$THD_i\% = \frac{I_K}{I_1} \times 100 \tag{3}$$

- Total harmonic distortion

It characterizes signal distortion rate, their expression is given by Equation (4)

$$THD\% = \frac{\sqrt{\sum_{k=2}^{n} I_k^2}}{I_1} \times 100 \tag{4}$$

- The harmonic spectrum

It consists of determining magnitude or THDI (voltage or current) at different signal harmonics rank. the spectral density gives similar information. Figure 1 shows an example of a spectrum.

- The power factor

It is ratio between active power (*P*) and apparent power (*S*). It does not translate difference phase between voltage and current of load. Equation (5) give their expression:

$$\lambda = \frac{P}{S} \tag{5}$$

- The distortion factor

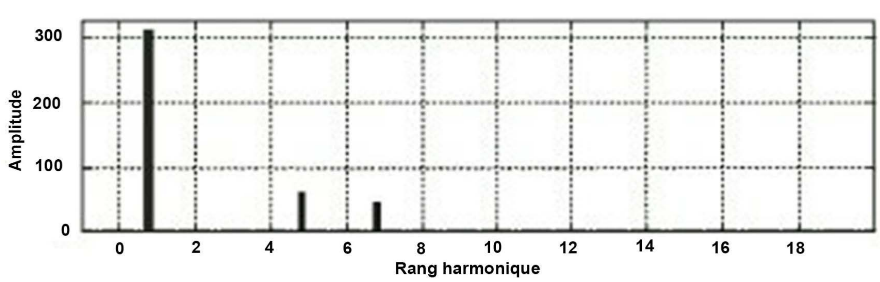


Figure 1. Harmonic spectrum.

It is ratio between power factor and difference phase between current and voltage. It characterizes deformation of the phase shift. If it equal to one, it means that signal has not harmonics. It is given by Equation (6)

$$\nu = \frac{\lambda}{\cos\varphi_1} \tag{6}$$

With φ_1 phase shift between voltage and current at the fundamental

- The distortion power

The presence of Harmonics in signal create a power distortion given by following relation [12]:

$$D^2 = S^2 - P_1^2 - Q_1^2$$

where P_1 and Q_1 are active and reactive powers at the fundamental.

2.3. The Effects of Harmonics

Harmonics have several effects in the electric network equipment's, including [1] [4] [5] [6]:

- The heating of cables by joule effect, translated by following equation:

$$\text{Perte} = r\sum_{k=1}^{n} I_k^2 \tag{7}$$

With r the cable resistance.

This heating also concerns the protective conductor if spectrum is rich in rank 3 harmonic.

- Destruction of capacitors

Capacitor current is given by following relation:

$$I = 2\Pi kfCU \tag{8}$$

where k is the harmonic rank and f the fundamental frequency.

This current increases with the harmonic rank. If capacitor is connected parallel with a transformer or an inductor it can enter resonance at the corresponding eletric pulsation given by Equation (9)

$$w_k^2 = \frac{1}{LC} \tag{9}$$

With $w_k = 2\Pi kf$

Apart from these consequences we can cite: the nuisance tripping of circuit breakers, sources disturbance, sensitive electronic equipment and others.

2.4. Standards and Harmonics

To limit harmonic pollution several standards and directives on electromagnetic compatibility are imposed. These are presented in **Table 1**.

Like any device electric, CFLs lamps must comply with IEC 61000-3-2 standard, which states that harmonics emission limits for lamps are subdivided according to their active power (**Table 2**) [7].

Table 1. Standards for harmonic emission limits [7] [8] [9].

Standards	Description
IEC-61000-2-2	Compatibility Levels for Low Frequency Conducted Disturbances and Signal Transmission in Low Voltage Distribution Networks
IEC-61000-2-4	Compatibility levels for low-frequency disturbances in industrial installations
IEC-61000-3-2	Limitation of harmonic current emissions (equipment with input current less than 16 A per phase)
IEC-61000-3-4	Limits for harmonic current emissions on low-voltage networks for equipment with a rated current greater than 16 A.
IEC-61000-3-12	Limits for harmonic currents produced by equipment connected to public low-voltage networks with input currents greater than 16 A and less than or equal to 75 A

Table 2. Maximum harmonic current allowed.

Table Head	Power less than 25 W. one of these 2 limits applies		Power greater than 25 W
	% of the fundamental current	Harmonic current in relation to the active power	% of the fundamental current
3	86	3.4 ma/W	30
5	61	1.9 ma/W	10

3. Methodology

Investigation we carried out focused on 3 lamps whose characteristics are given in **Table 3**.

3.1. Presentation Experimental Setup

Measurement of current absorbed by lamps was carried out using the experimental setup shown in **Figure 2**.

Experimental setup consists of the following elements:

- Connection box to connect lamps and different elements of the bench;
- Switch for switching lamps;
- Computer (output interface) for viewing electrical signal;
- VOLCRAFT digital oscilloscope interface connected to computer;
- A measuring probe; A shunt for currents measurement through voltages image.

3.2. Treatment and Analysis Platform on Matlab Simulink

Signal coming from oscilloscope (computer) being noisy, **Figure 3** presents Simulink processing and analysis platform.

4. Results and Discussion

Voltages at the terminals of our different shunt are presented in **Figure 4**.

Table 3. Characteristics of investigated lamps.

	Power (W)	Voltage (V)	Frequency (Hz)	Life time (h)
	20	220 - 240	50 - 60	8000
	40	220 - 240	50 - 60	8000
	75	220 - 240	50 - 60	8000

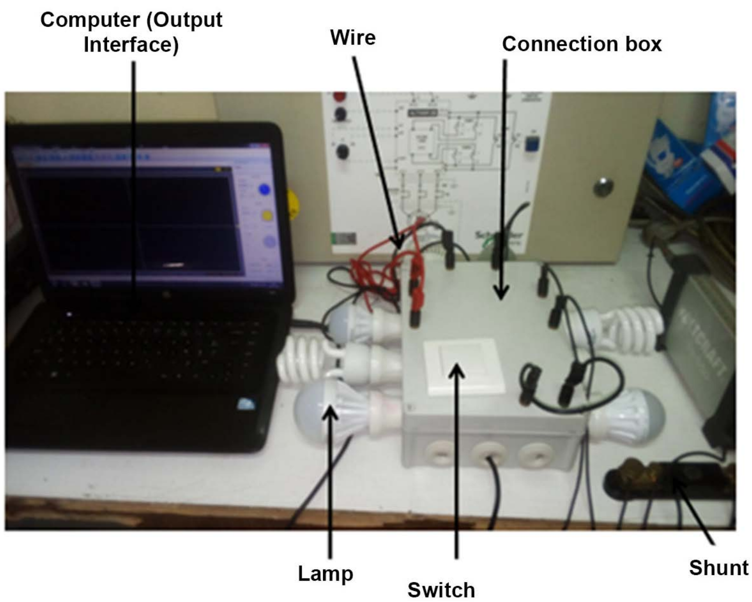


Figure 2. Harmonic spectrum experimental setup.

We note that obtained measurements are quite noisy hence need to filter for better exploitation. After measurement, signal obtained are processing on matlab simulink platform. Results are presented in Figure 5.

Currents obtained are less noisy. Their different THD are presented in Table 4.

It is found that THD increases with the lamps power. values obtained are much higher than the 3% predicted by standard for class C equipment. Analysis of spectral density gave the following results in Figure 6.

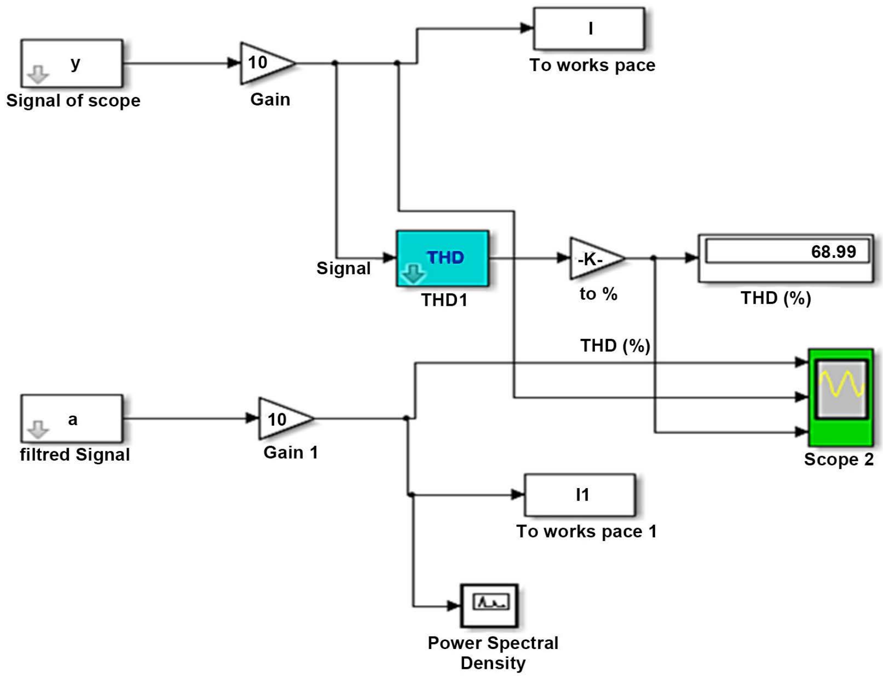
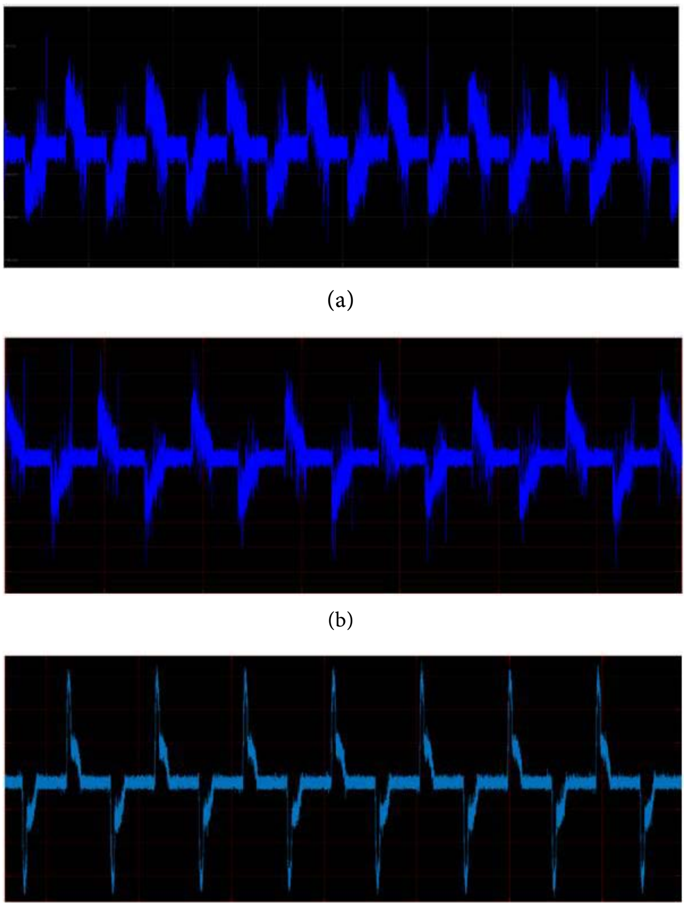


Figure 3. Signal processing and analysis platform.

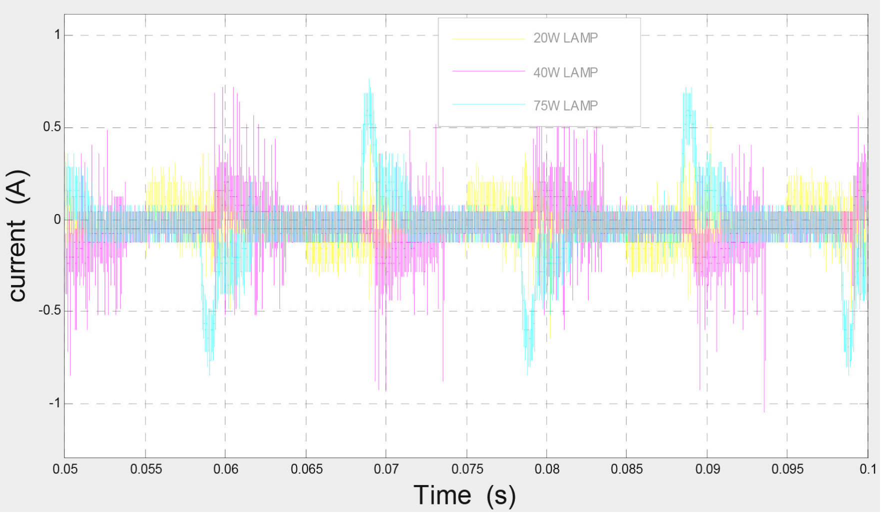


(a)

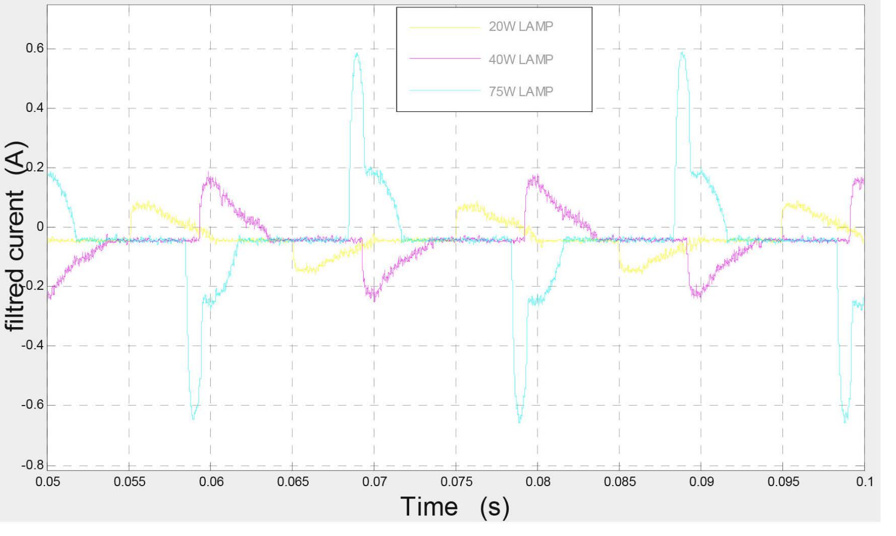
(b)

(c)

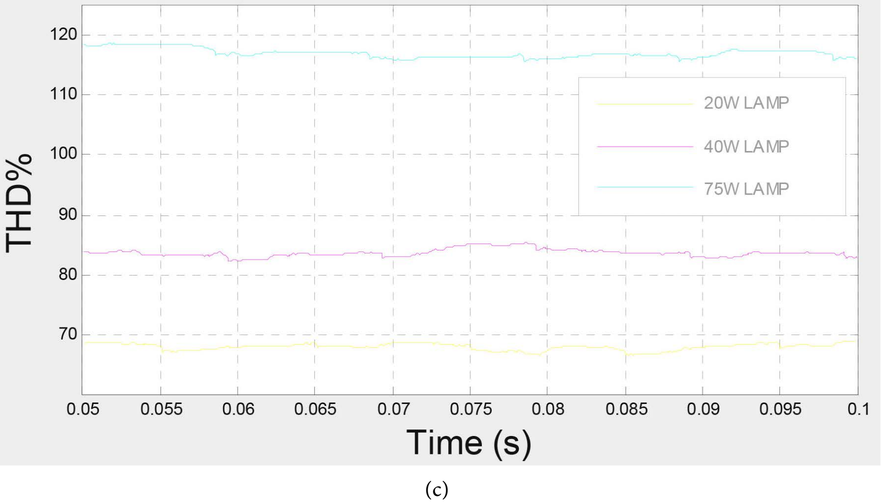
Figure 4. Shunt voltage. (a) 20 W lamp; (b) 40 W lamp; (c) 75 W lamp.



(a)



(b)



(c)

Figure 5. Simulink platform results. (a) Experimental currents obtained; (b) Filtred currents; (c) THD lamp.

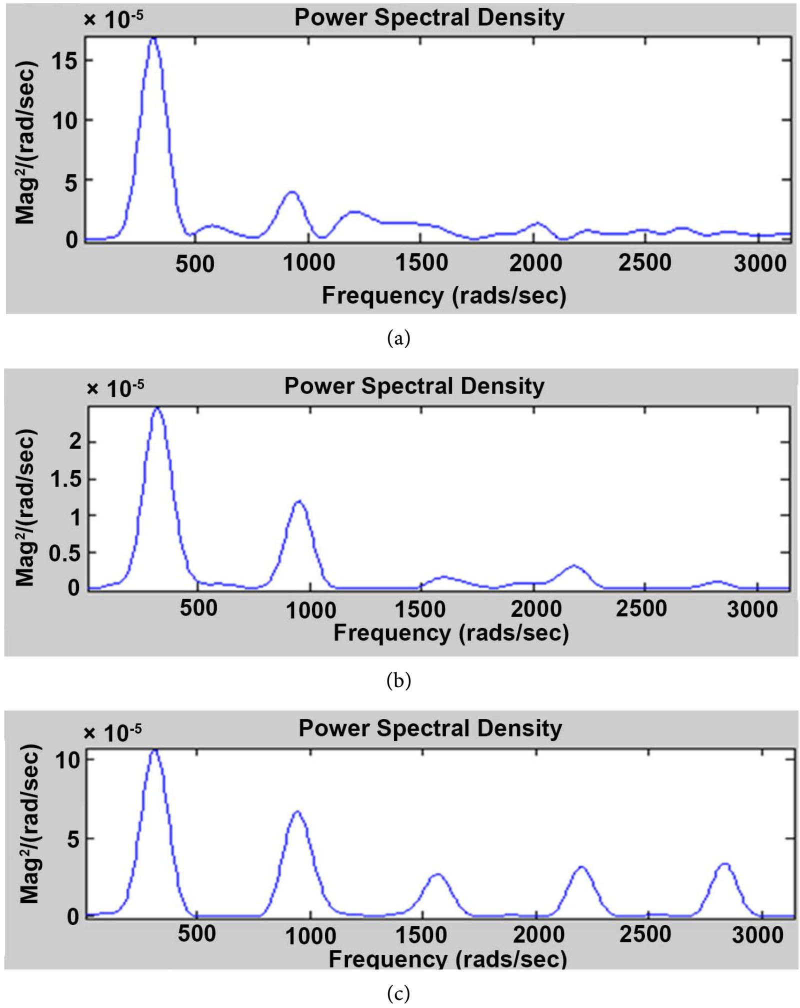


Figure 6. Spectral density of the currents absorbed by the studied lamps. (a) 20 W lamp; (b) 40 W lamp; (c) 75 W lamp.

Table 4. Obtained currents with a THD.

Lamp	THD (%)
20 W	68.99
40 W	82.94
75 W	116.04

Table 5 shows the results of calculation of the THD_i resulting from this spectral density.

We note that at each harmonic rank, THD_i increase with power of lamps. According to the IEC-61000-3-2 standard only the 20 W lamp is in adequacy with standard (**Table 2**). In addition, Equations (8) and (9) predict risk of overcurrent in capacitors, and resonance between capacitors, transformer and inductance of the CFLs supply. according to results of **Table 5** the 75 W lamp is most likely to degrade prematurely.

Table 5. THDi of investigated lamps.

Rank of the harmonic	THDi lamps (%)		
	20 W	40 W	75 W
1	100	100	100
3	37.5	58.3	64
5	-	8.83	30
7	10	16.6	37
9	-	4.16	40

5. Conclusion

This article investigates the harmonic pollution of CFLs lamps in order to diagnose the causes of premature degradation of these lamps. For this purpose, experimental setup has been set up to carry out the various tests. Noisy signal obtained was filtered and analyzed in the Matlab Simulink platform. Obtained results show that harmonic spectrum of investigated lamps mainly comprises harmonics of zero sequence. THD obtained increases with power as well as THDi. Comparison of different results with IEC-61000-3-2 IEC standard shows that only the 20 W lamp is inadequacy at the harmonics 3 and 5. High rate of these THDs suggests that the rapid deterioration cause of these type lamps are effects of harmonics on the capacitors (Equations (8) and (9)).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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