Proceedings of the IASTED International Conference
Power and Energy Systems
November 8-10, 1999, Las Vegas, USA

Effects of changing line voltage on the harmonic current of compact fluorescent lamps

F. V Topalis
topalis@softlab.ntua.gr
National Technical University of Athens
Athens, Greece

I. F Gonos
igonos@softlab.ntua.gr
National Technical University of Athens
Athens, Greece

M. B. Kostic
Kostic@buef31.etf.bg.ac.yu
University of Belgrade
Belgrade, Yugoslavia

Abstract

This paper describes the evaluation of the harmonic current of various compact fluorescent lamps and the distortion introduced to distribution systems. Standard self ballasted lamps, which operate at a low power factor, were investigated with electronic high-frequency ballast. The effects of changing line voltage with different types of lamps were measured. In all cases, reducing the line voltage reduces the harmonic current. On the other hand, the operation of these lamps when connected in parallel was also investigated. In this case the total harmonic distortion is reduced. From these measurements remarkable conclusions concerning the problem of harmonics are drawn.

Keywords: compact fluorescent lamps, harmonics, harmonic distortion, power quality

1. Introduction

The widespread usage and the constant rise of the produced electric energy has caused the growth of electric energy systems and accordingly has increased the obligations of the energy utility companies for better energy quality: stable frequency and voltage, high power quality, undistorted waveforms. However, the problem of grid circulating harmonics is of great importance, since it represents a possible source of faults and troubles for loads (motors, home electrical appliances, computer systems etc.).

Compact fluorescent lamps (CFL) consume less energy and last longer than the incadescent lamps with comparable luminous output [1]. They represent promising alternatives to incadescent lamps but their operation is associated with some problems in the power quality [2, 3]. The current of CFLs is not a smooth sinusoidal waveform. On the contrary, it is characterized by rapid changes of the amplitude that creares distortion of the voltage waveform. High levels of distortion in the distribution system can harm electrical equipment. An apparent phase displacement between voltage and current also reduces the efficiency of the system. Most incandescent lamps do not affect the power quality of a distribution system because they have sinusoidal current waveforms that are in phase with the voltage waveform. Fluorescent, high-intensity discharge, and low-voltage incandescent lighting systems, which use ballasts or transformers may have distorted current waveforms.

All the above energy saving lamps will be remarkable sources of harmonics and disturbances in supply systems in the near future, due to the expected wide spread of their use. Some CFLs have current THD greater than 100%, but they have low active power compared with other high-THD sources such as personal computers, so standards organisations have not set power quality requirements for CFLs [4 - 6]. ANSI defines a limit of 32% for the maximum current THD of electronic lamps [4]. This standard also specifiies the limit of the amplitude of all high-order harmonics to 30% of the fundamental amplitude. The limit of all the higher than the 11^{th} order harmonics is 7% of the fundamental. The limit of the current THD of electronic ballasts is 20%, according IEC and IEEE [5, 6].

The study and the investigation of the harmonic distortion, of the possible problems caused by compact fluorescent lamps and the presentation of the harmonic voltage and current obtained with tests on these lamps, compose the main interests of this paper. The tests were performed at the Photometry Laboratory of National Technical University of Athens. Remarkable conclusions concerning the problem of harmonics are drawn at the end of the paper.

2. Experimental setup

The investigated lamps are compact fluorescent lamps with E27 screw mount and the starter, as well as the electronic ballast, are included in the base. All these lamps are designed for the 230 V, 50 Hz electric utility systems. These lamps have: 9 W-400 lm, 11 W- 600 lm and 15 W - 900 lm nominal power and nominal luminous flux respectively. The investigated lamps operate at a very low power factor.

The main electrical characteristics (voltage and current) were measured with a data acquisition system for various connections and wattages of the investigated lamps. The voltage was regulated by a voltage stabiliser. The output voltage of the stabiliser has a THD less than 0.1%. An 8-bit data acquisition system, with 40 MHz sampling frequency, controlled by a personal computer was used for the recording of the current and voltage waveforms of the lamps. All the measurements on each lamp were performed simultaneously.

The recorded waveforms were analysed using the Fast Fourier Transform of MATLAB in order to determine the harmonic spectrum of the current waveforms.

3. Test results

The relevant experimental results were analysed in order to determine the harmonic spectrum of the current waveforms. The normalised amplitude of harmonics components and the Total Harmonic Distortion (THD) of the investigated lamps are presented in Tables 1 - 4.

The THD according to IEEE definition [4] is:

$$THD = \frac{\sqrt{(I_2)^2 + (I_3)^2 + ... + (I_N)^2}}{I_1} \cdot 100 \qquad (1)$$

where:

I_1: root-mean square of the fundamental current waveform

I_N: root-mean square of the N-order harmonic current waveform

N: N-th harmonic component

The THD according to IEC and ANSI [5, 6] is:

$$THD = \frac{\sqrt{(I_2)^2 + (I_3)^2 + ... + (I_N)^2}}{\sqrt{(I_1)^2 + (I_2)^2 + ... + (I_N)^2}} \cdot 100 \qquad (2)$$

All the tested CFLs present a significant current distortion. A typical current waveform and the harmonic spectrum of one lamp is shown in Fig. 1. The current waveforms and the harmonic spectrums of the parallel connection of CFL lamps operating at 230 V line voltage are shown in Figs. 2 to 5. The normalized amplitude of the harmonics (ratio of the harmonic to the fundamental) is presented in Tables 1 and 2.

Table 1: Normalised amplitude (%) of harmonics (line voltage 230 V).

Harmonic order	9W	11W	15W
3	76.4	69.8	78.0
5	48.5	46.1	51.3
7	42.9	46.2	44.3
9	42.6	39.1	48.4
11	34.3	26.5	44.2
13	26.7	23.5	35.8
15	24.8	16.2	32.3
17	20.5	8.2	30.4
19	14.3	7.5	25.4

Table 2: Normalised amplitude (%) of harmonics for parallel operation (line voltage 230 V).

Harmonic order	9-11W	9-15W	11-15W	9-11-15W
3	72.6	75.5	70.7	70.6
5	44.5	46.0	40.0	37.9
7	40.5	38.4	35.6	31.5
9	36.2	40.1	32.7	28.9
11	23.7	32.8	21.3	17.6
13	17.1	24.2	13.7	9.6
15	13.8	21.5	12.1	7.9
17	7.9	18.2	10.8	5.3
19	2.9	12.7	9.0	2.8

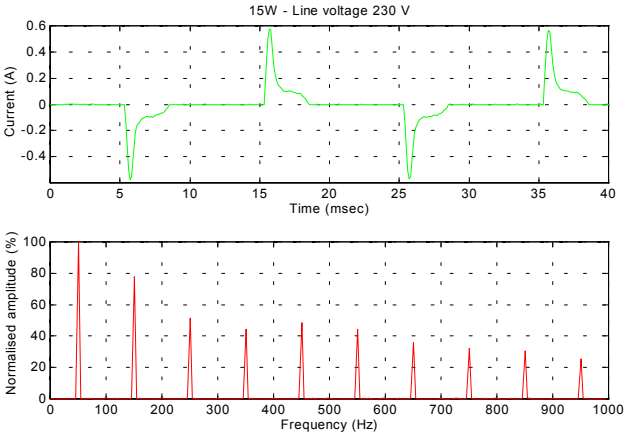

Fig. 1: Current and harmonic spectrum of 15 W lamp (line voltage 230 V).

The THD which is calculated using the Fast Fourier Transform and the definition of Eq. 1 are presented in Tables 3 and 4. Also, the variation of the THD vs the supply (line) voltage is shown in Figs. 6 to 9 for various connections of the investigated lamps.

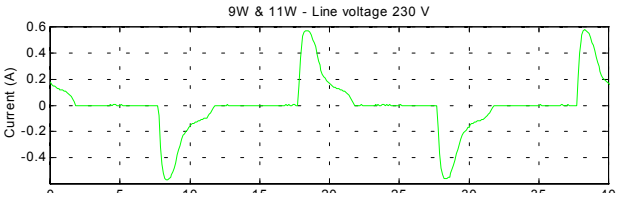

Fig. 2: Current and harmonic spectrum of the parallel connection of 9W and 11 W lamps (line voltage 230 V).

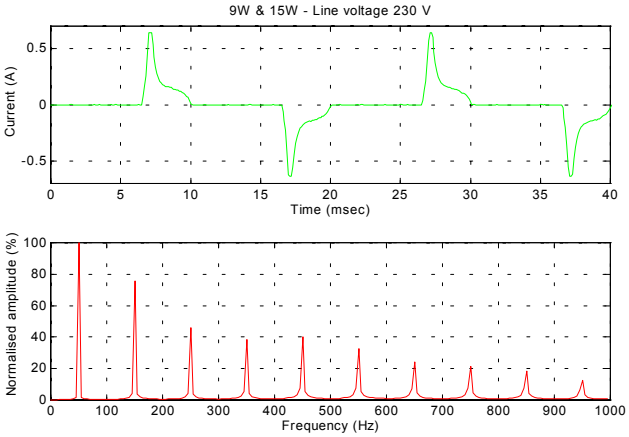

Fig. 3: Current and harmonic spectrum of the parallel connection of 9 W and 15 W lamps (line voltage 230 V).

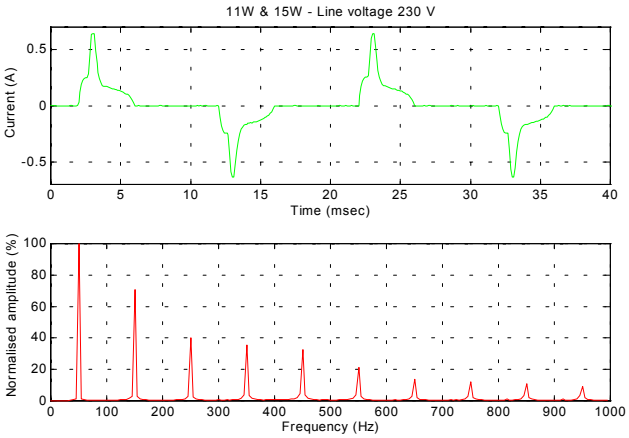

Fig. 4: Current and harmonic spectrum of the parallel connection of 11 W and 15 W lamps (line voltage 230 V).

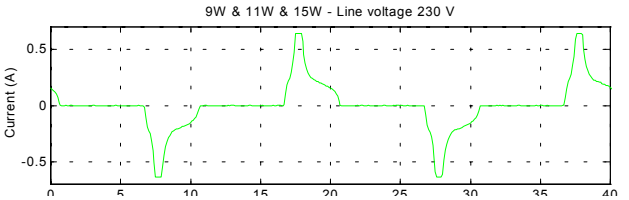

Fig. 5: Current and harmonic spectrum of the parallel connection of 9 W, 11 W and 15 W lamps (line voltage 230 V).

Table 3: THD according to IEEE 1035-1989 vs. line voltage.

THD (%)			
U [V]	9W	11W	15W
190	117.2	102.4	128.2
200	118.3	104.6	133.1
210	120.4	107.9	133.9
220	121.7	108.9	134.5
230	122.4	110.9	137.4

Table 4: THD according to IEEE 1035-1989 of CFLs operating in parallel vs. line voltage.

THD (%)				
U [V]	9W-11W	9W-15W	11W-15W	9W-11W-15W
190	94.2	114.5	93.2	88.7
200	97.4	116.1	94.1	90.7
210	101.7	116.3	98.5	92.6
220	104.1	118.2	99.6	92.7
230	106.4	118.3	100.5	93.6

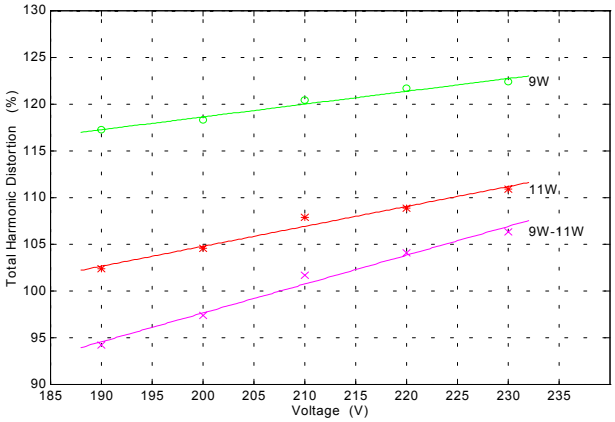

Fig. 6: THD of parallel connection of lamps 9 W and 11 W vs. line voltage.

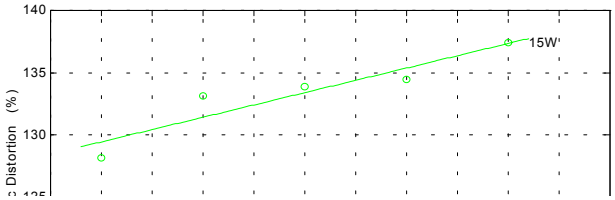

Fig. 7: THD of parallel connection of lamps 9 W and 15 W vs. line voltage.

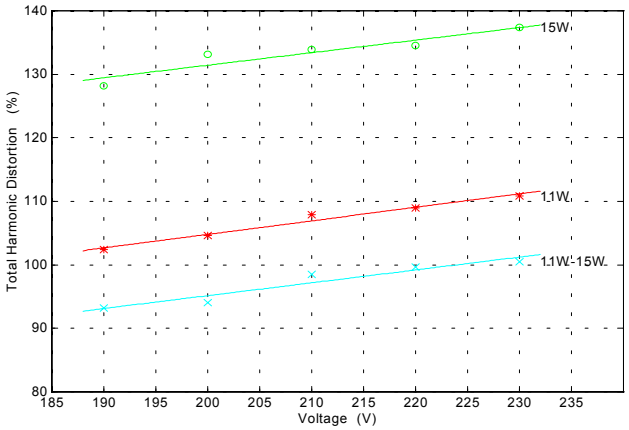

Fig. 8: THD of parallel connection of lamps 11 W and 15 W vs. line voltage.

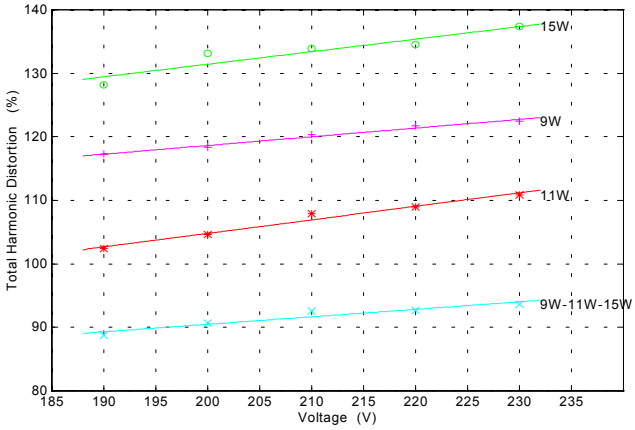

Fig. 9: THD of parallel connection of lamps 9 W, 11 W and 15 W vs. line voltage.

4. Conclusions

Compact fluorescent lamps consume less active power and their use will result in reducing the active power demand of the electric power system. On the other hand, the low power factor of these lamps requires additional reactive power from the electric utility system. In addition, extensive use of these lamps causes problems to interference sensitive devices because of the associated current distortion. The investigated lamps have only odd harmonics. The significantly distorted current of CFLs is possibly owed to the construction method in order to decrease the ballast size.

The total harmonic distortion of the current of the lamps increases with the increase of the supply voltage. When the lamps operate in parallel, the THD is lower comparing to the one of the single operation of each lamp.

The extensive future use of energy efficient lamps must be associated with simple and low cost filtering and power factor correction techniques.

5. References

[1] Topalis F.V.: “Efficiency of Energy Saving Lamps and Harmonic Distortion in Distribution Systems”, IEEE Trans. Power Delivery, Vol. 8, No. 4, October 1993, pp.2038-2042.

[2] Wolsey R.: “Lighting Answers: Power Quality”, Vol. 2, No. 2, Lighting Research Center, Rensselaer Polytechnic Institute, February 1995.

[3] Arseneau R., Quellette M: “The Effect of Supply Harmonics on the Performance of Compact Fluorescent Lamps”, IEEE Trans. Power Delivery, Vol. 8, No. 2, April 1993, pp.473-479.

[4] Institute of Electrical and Electronics Engineers: “IEEE Recommended Practice: Test Procedure for Utility-Interconnected Static Power Conventers”, IEEE 1035-1989, 1989.

[5] American National Standards Institute: “American National Standard for Lamp Ballasts: High Frequency Fluorescent Lamp Ballasts”, ANSI C82.11 1993, New York, NY, 1993.

[6] International Electrotechnical Commission: “Disturbances in Supply Systems Caused by Household Appliances and Similar Electrical Equipment, Part 1: Definitions”, IEC 555-1-1982, Geneve, Switzerland, 1982.