Harmonic Distortion in Electric Power Systems Introduced by Compact Fluorescent Lamps

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Abstract - The purpose of this paper is the investigation of the harmonic distortion introduced by the compact fluorescent lamps to the distribution systems. The results of some measurements on compact fluorescent lamps and on self - ballasted fluorescent lamps of various wattages are presented. Some of the most important electrical characteristics (voltage, current and power factor) were measured by a data acquisition system. The harmonic spectrum and the total harmonic distortion (THD) of the lamps were calculated using Fourier analysis of the recorded current waveforms. The measurements were performed with supply voltage other than the nominal one in order to determine the dependence of the THD variation upon the mains supply voltage. From these measurements remarkable conclusions concerning the problem of harmonics are drawn.

Keywords: Compact fluorescent lamps, Self ballasted electronic lamps, Harmonics, Harmonic distortion, Power factor.

I. 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.) [1-3].

A remarkable harmonic source is the increased use of energy saving lamps. These lamps operate at a low power factor and produce current distortion which cause problems to the operation of the sensitive electric power systems. The problem is more significant in isolated power utility systems where the power potential is rather low and unstable because of wind generators, photovoltaic systems etc. (probabilistic behaviour of wind and solar potential) which are used as power plants [4,5].

The Public Power Corporation (PPC) of Greece has installed wind turbine parks and photovoltaic systems on some Aegean Sea islands, either autonomous or interconnected to the distribution system of the island.

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On the other hand, the PPC promotes the use of energy saving lamps on these islands in order to minimise the serious problems which are presented during some time periods with high energy demand.

The study and the investigation of the harmonic distortion, of the possible problems caused by energy saving lamps and the presentation of the harmonic voltage, current and power factor obtained at tests on these lamps, compose the main interests of this paper. Also remarkable conclusions concerning the problem of harmonics are drawn.

II. INVESTIGATED LAMPS

The list of investigated lamps is shown in Table 1. All these lamps are designed for the 230 V, 50 Hz electric utility systems. They belong to two categories:

- Compact Fluorescent Lamps (CFL) with external ballast and the starter included in the base.
- Self Ballasted electronic Lamps (SBL) with E27 screw mount and the starter as well as the ballast included in the base.

TABLE 1: LIST OF INVESTIGATED LAMPS

Lamp type	Nominal Power [W]	Nominal Flux [lm]
CFL	5	250
CFL	7	400
CFL	9	600
CFL	11	900
SBL	9	400
SBL	11	600
SBL	15	900
SBL	20	1200

III. EXPERIMENTAL APPARATUS

All the investigated lamps are designed for 230 V, 50 Hz electric utility systems. 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 (Fig. 1). All the measurements on each lamp were performed simultaneously.

The recorded waveforms were analysed using the MATLAB software package. The final analysis was performed using Fast Fourier Transform in order to determine the harmonic spectrum of the current waveforms.

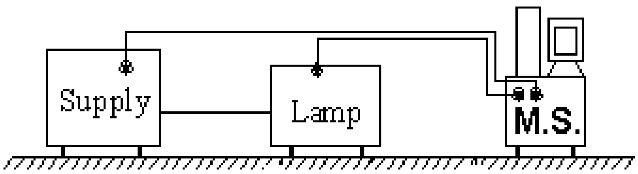

Fig. 1: Experimental apparatus
M.S.: Measuring System

IV. TEST RESULTS

A large number of experiments were performed at the Photometry Laboratory of N.T.U.A. and the relevant experimental results are presented in Tables 2 - 5. All the measurements were conducted under the consideration that the nominal voltage of the Greek electric distribution system is 220 V.

The Total Harmonic Distortion (THD) is obtained by the formula:

$$THD = \frac{100 \cdot \sqrt{A(f_2)^2 + A(f_3)^2 + \ldots + A(f_N)^2}}{A(f_1)}$$

where:

$A(f_1)$: amplitude of fundamental component
$A(f_N)$: amplitude of N-th harmonic component
N : N-th harmonic component

All the tested CFLs do not present a significant current distortion (Table 2). Typical current waveform of the CFLs lamps under different voltage supply are shown in Figs. 2-5. Also, the typical harmonic spectrum of these lamps is presented in Figs. 2-5.

All the tested SBLs present a significant current distortion (Table 3). Typical current waveform of the SBLs lamps under different voltage supply are shown in Figs. 6-9. Also, the harmonic spectrum of these lamps are presented in Figs. 6-9.

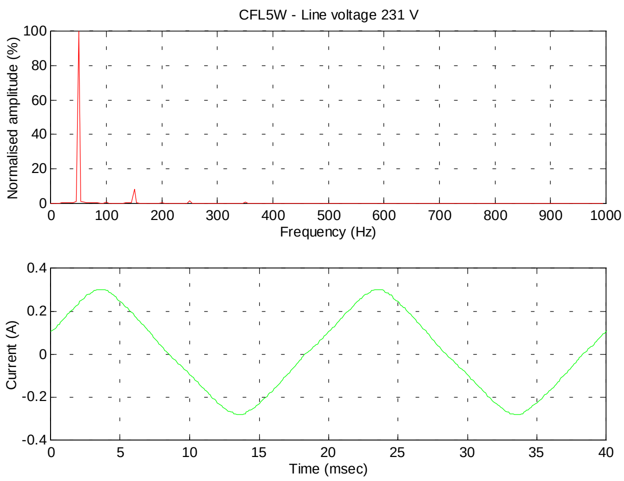

Fig. 2: Harmonics and current waveform of CFL5W at 231 V (220+5%)

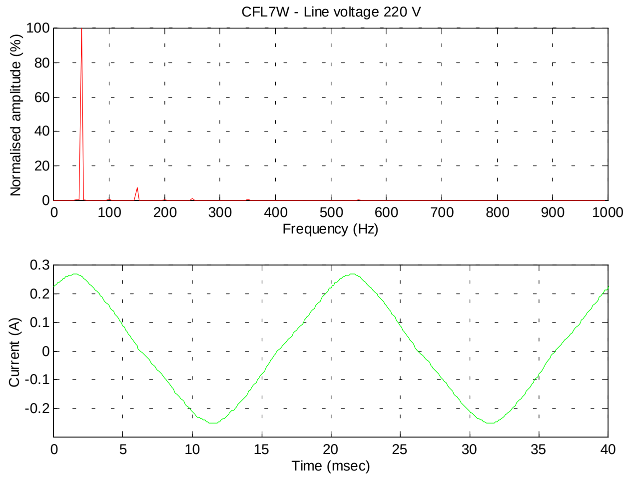

Fig. 3: Harmonics and current waveform of CFL7W at 220 V

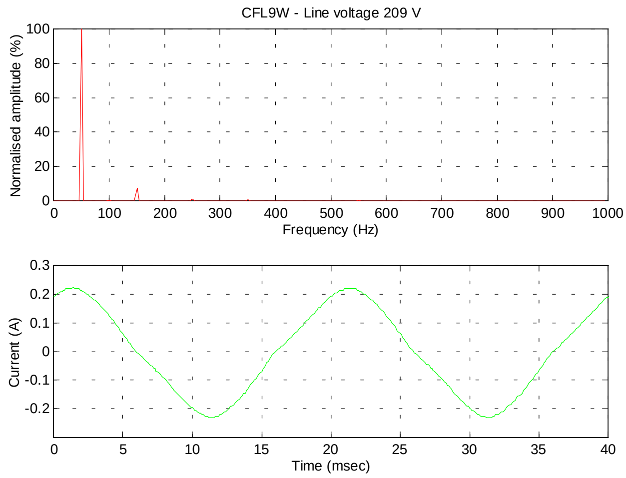

Fig. 4: Harmonics and current waveform of CFL9W at 209 V (220-5%)

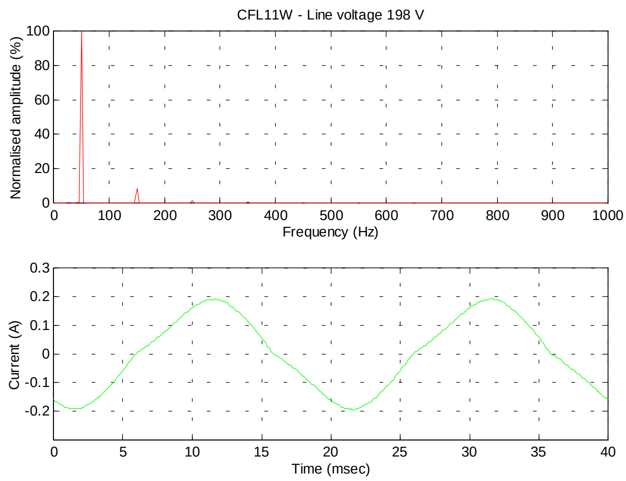

Fig. 5: Harmonics and current waveform of CFL11W at 198 V (220-10%)

TABLE 2: NORMALISED AMPLITUDE OF HARMONIC COMPONENTS

Harmonics	CFL5W 231 V	CFL7W 220 V	CFL9W 209 V	CFL11W 198 V
3	0.0833	0.0745	0.0732	0.0879
5	0.0157	0.0119	0.0113	0.0148
7	0.0077	0.0073	0.0078	0.0098
9	0.0016	0.0003	0.0016	0.0053
11	0.0021	0.0023	0.0034	0.0037
13	0.0008	0.0011	0.0021	0.0029
15	0.0011	0.0009	0.0013	0.0017
17	0.0003	0.0009	0.0008	0.0018
19	0.0005	0.0007	0.0003	0.0017

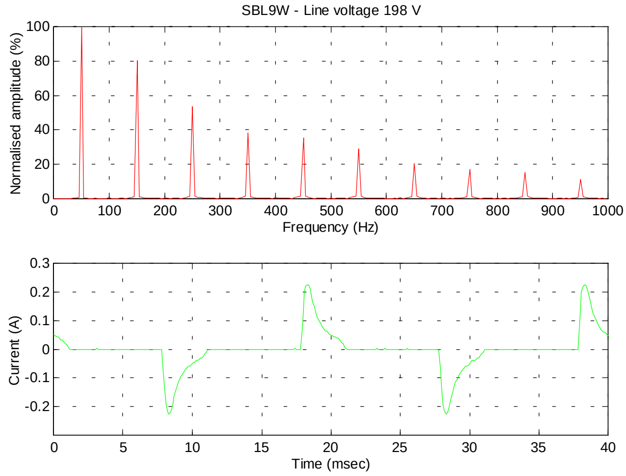

Fig. 6: Harmonics and current waveform of SBL9W at 198 V (220-10%).

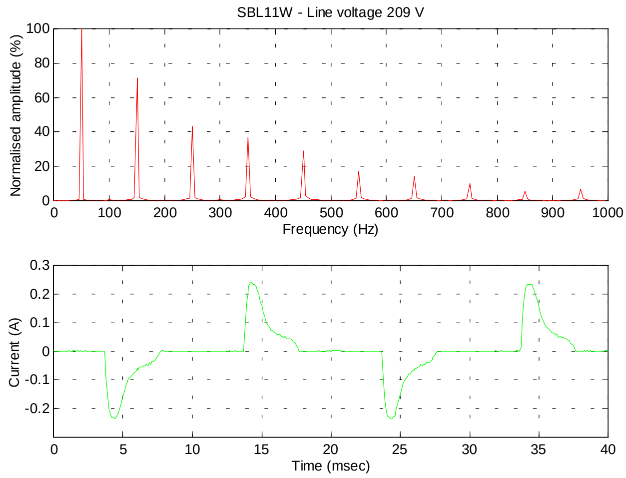

Fig. 7: Harmonics and current waveform of SBL11W at 209 V (220+5%)

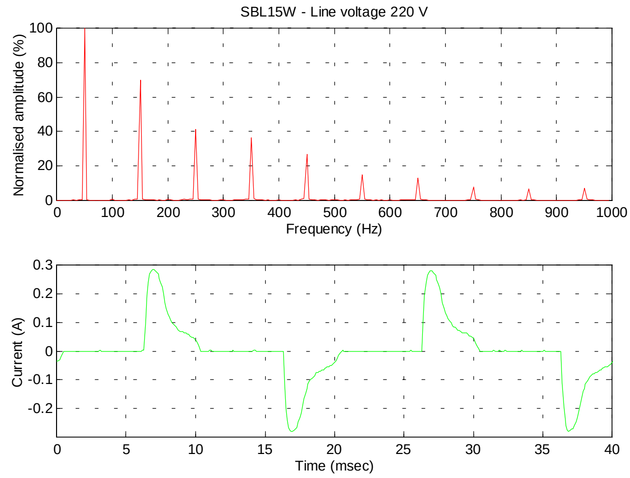

Fig. 8: Harmonics and current waveform of SBL15W at 220 V

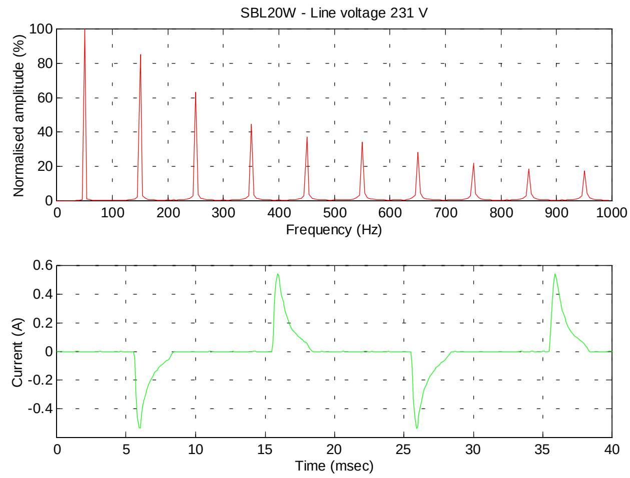

Fig. 9: Harmonics and current waveform of SBL20W at 231 V(220+5%)

TABLE 3: NORMALISED AMPLITUDE OF HARMONIC COMPONENTS

Harmonics	SBL9W 198 V	SBL11W 209 V	SBL15W 220 V	SBL20W 231 V
3	0.8014	0.7170	0.6971	0.8535
5	0.5342	0.4315	0.4153	0.6310
7	0.3855	0.3698	0.3660	0.4466
9	0.3561	0.2925	0.2674	0.3713
11	0.2933	0.1731	0.1503	0.3418
13	0.2065	0.1403	0.1281	0.2858
15	0.1700	0.1000	0.0798	0.2206
17	0.1534	0.0603	0.0687	0.1879
19	0.1140	0.0670	0.0719	0.1744

The THD measurements are presented in Tables 4 and 5 for both types of lamps. Also, the variation of the THD vs the supply (line) voltage is shown in Figs. 6 and 7 for both types of lamps.

TABLE 4: THD OF COMPACT FLUORESCENT LAMPS WITH EXTERNAL BALLAST VERSUS LINE VOLTAGE.

THD (%)				
U [V]	CFL5W	CFL7W	CFL9W	CFL11W
198.0	6.0	6.3	7.0	9.0
203.5	6.2	6.6	7.5	9.2
209.0	6.4	7.0	7.5	9.3
214.5	6.9	7.3	7.7	9.2
220.0	7.3	7.6	7.9	9.2
225.5	7.9	8.0	8.2	9.4
231.0	8.5	8.6	8.7	9.4

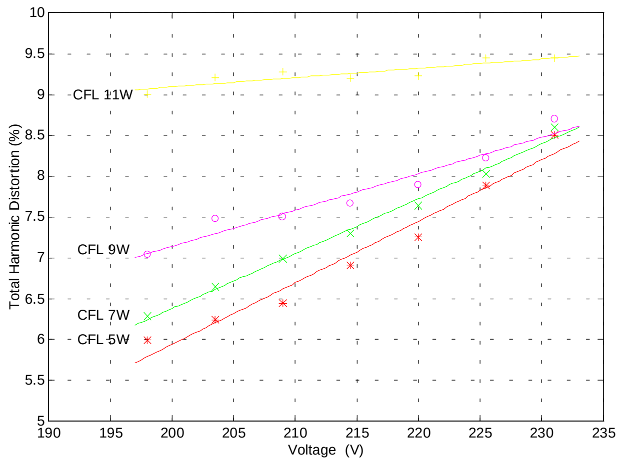

Fig. 10: THD of compact fluorescent lamps with external ballast vs line voltage.

TABLE 5: THD OF SELF BALLASTED LAMPS VERSUS LINE VOLTAGE.

THD (%)				
U [V]	SBL9W	SBL11W	SBL15W	SBL20W
198.0	118.2	100.3	87.9	131.0
203.5	118.7	98.2	88.5	131.2
209.0	118.4	99.5	90.9	131.9
214.5	119.1	101.9	93.8	132.3
220.0	119.4	102.0	95.9	132.4
225.5	121.3	105.9	97.3	131.5
231.0	120.5	106.9	97.3	133.3

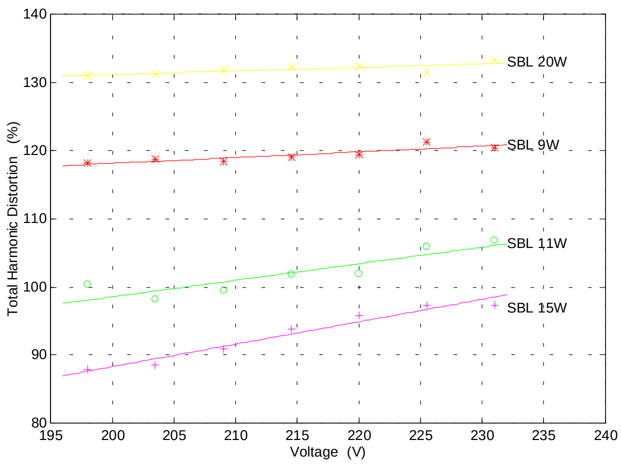

Fig. 11: THD of self ballasted lamps vs line voltage.

The investigated lamps operate at a very low (0.40-0.48) power factor. The results of the power factor measurements are presented in Table 6.

TABLE 6: POWER FACTOR OF INVESTIGATED LAMPS.

Lamp type	Power factor
SBL9W	0.44
SBL11W	0.48
SBL15W	0.45
SBL20W	0.48
CFL7W	0.40
CFL9W	0.43

V. CONCLUSIONS

The energy saving 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 total harmonic distortion of the lamp current increases with the increase of the supply of the voltage. The current of SBLs is significantly distorted comparing with the one of CFLs . Both types of investigated lamps have only odd harmonics and the amplitude of CFLs is higher than the one of the SBLs. The THD of the CFL is significantly less than the THD of SBL, because the spectrum of SBL includes more harmonics than the spectrum of SFL. In fact, this is possibly owed to the construction method in order to decrease the ballast size.

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

VI. REFERENCES

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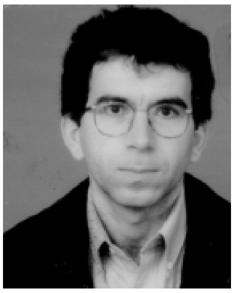

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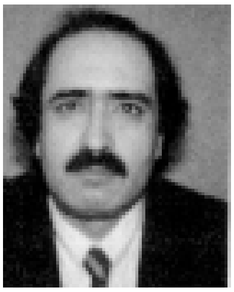

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