COMPARATIVE ANALYSIS OF ENERGY EFFICIENCY FOR DIFFERENT TYPES OF LIGHTING LAMPS

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Abstract - There were determined the active, the reactive and apparent power for different types of lightning lamps as well as their illuminance level. Following the processing and analysis of the experimental results, there was showed that the ratio of illuminance level / power is maximum in the case of LED lamps, with the disadvantage of a low power factor ($\lambda \approx 0.5$).

Keywords: Lightning lamps, illuminance level, active power, reactive power.

1. INTRODUCTION

In the prospect of a sustainable development, the efficient use of energy resources is of great importance.

In the power balance, the lighting has a significant share.

The main evaluation criteria of lighting systems are:

- Convenience of the luminous environment that is produced;
- The power demand - specific consumption;
- Reliability - durability;
- Safe operating;
- Specific costs (investment, operating, maintenance).

The main quantities which characterize the artificial light sources (photometric sizes system) are:

- the luminous flux;
- the luminous efficiency;
- the luminous intensity;
- the illuminance level;
- the luminance.

The luminous flux Φ represents the spectral power emitted by a light source in the visible spectrum, respectively (1):

$$\Phi = \int_{380\,nm}^{760\,nm} \varphi_\lambda \cdot d\lambda = \int_{380\,nm}^{760\,nm} k_\lambda \cdot p_\lambda \cdot d\lambda \text{ [lm]} \qquad (1)$$

where:

p_λ - the spectral power emitted by a light source;
k_λ - the spectral sensibility of the human eye;
Φ_λ - the luminous spectrum;

The luminous flux is measured in lumens (lm) representing the luminous flux emitted by a monochromatic source with the power of 1/683 W, whose radiations have a frequency of f = $540{,}0154 \cdot 10^{12}$Hz (the wavelength λ = 555,5nm). It follows that, a luminous flux of 1 lm is obtained, for an ideal transformation of a power equal to 1/683W absorbed by a light source that emits a monochromatic yellow radiation with λ = 555.5 nm [1].

The luminous efficiency η of a light source, expressed in *lm/W*, represents the ratio between the luminous flux emitted by the source Φ and the power used by the light source from the power supply grid P.

$$\eta = \frac{\Phi}{P} = \frac{\int_{380\,nm}^{760\,nm} \varphi_\lambda \cdot d\lambda}{\int_{0}^{\infty} p_\lambda \cdot d\lambda} \qquad (2)$$

In these conditions, there is considered that the *energy efficiency* of an electric light source is:

$$\eta = \frac{\Phi}{P} = \frac{\int_{380\,nm}^{760\,nm} \varphi_\lambda \cdot d\lambda}{UI} \qquad (3)$$

The luminous intensity I_α of a light source (a point source or a source element) in the direction α, expressed in *candela [cd]* represents the spatial (angular) density of the luminous flux emitted in that direction [1],[2]. It is determined, by reporting the luminous flux ΔΦ emitted in the direction α, to the solid angle ΔΩ, where the emission occurs [1].

$$I_\alpha = \frac{\Delta\Phi}{\Delta\Omega} \text{ [cd]} \qquad (4)$$

The illuminance level E, expressed in *lux,* is a value which doesn't depend on the illuminated surface properties and represents the luminous flux reaching the illuminated surface (receiver). The illuminance level obtained in a surface point represents the luminous flux density received by an elementary area *dA* [3].

$$E = \frac{d\Phi}{dA} \text{ [lux]} \qquad (5)$$

The energy efficiency represents the ratio between the illuminance level and the active power absorbed by the lightning lamp, being expressed in *[lux/W].*

The luminance L_α, characterizes the luminous intensity of the emitting surface, and is expressed in candela/ m^2, respectively:

$$L_\alpha = \frac{dI_\alpha}{dA \cdot \cos\alpha} \quad [\text{cd/m}^2] \qquad (6)$$

where α is the observation angle.

The paper aims to analyze the experimental comparative analysis of energy efficiency for different types of lighting lamps commonly used.

2. EXPERIMENTAL DETERMINATION. PROCEDURE

There were determined the energy characteristics of some artificial light sources, namely: 75W incandescent lamp (Philips production), 125W high pressure mercury vapors discharge lamp (type 04273, manufactured by Lohuis), 70W high pressure sodium vapors discharge lamp (code 181923, produced by Philips), 85W fluorescent compact lamp (type 09IV, manufactured by EHBMT), 15W fluorescent tubular lamp (type TL-D G13, manufactured by Philips), and LED lamps, having the power equal to 3W and 5W, respectively (types HPE-G35B-3 and HPE-G60A-5, sold by SC INTORIG SRL RO).

By their specifics, the incandescent lamps, fluorescent lamps (with embedded power supply circuit) as well as the LED lamps (with embedded power supply circuit) have been connected directly to the power supply grid.

The high pressure mercury vapors discharge lamps have been connected to the power supply grid by mounting an inductive ballast in series.

The high pressure sodium vapors discharge lamps have been connected to the power supply grid by using an inductive ballast as well as an igniter for the electric arc ignition.

In order to determine the energy characteristics of the tested light sources, there were used the following:

- A light meter PHYSICS Line CA 811 type, brand ARNAUX CHAUVIN (Fig. 1);
- A power analyzer FLUKE 434 type (Fig. 2) and the corresponding transducers;
- A data acquisition and processing system with specialized FLUKE 434 software.

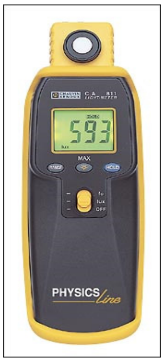

Fig. 1. PHYSICS Line C.A. 811 light meter

Fig. 2. FLUKE 434 power analyzer

The stand used for the characterization of the lighting lamps is shown within Fig. 3.

Fig. 3. The characterization stand

3. EXPERIMENTAL RESULTS

The main electrical parameters determined for the investigated lightning lamps are synthetically summarized in Table 1.

Table 1. Recorded electric parameters

Parameter	Lightning lamp						
	Incandescent 75W	125W Type 04273 *	70W Type 181923*	85W Type 09IV *	15W Type TL-D G13	3W Type HPE-G35B-3	5 W Type HPE-G60A-5
P [W]	76,51	145,9	95,65	42,75	16,9	3,22	5,86
Q [VAr]	3,16	273,8	200,5	61,4	44,01	5,87	8,99
S [VA]	76,58	310,6	221,9	74,99	46,9	6,26	10,54
U_{rms} [V]	235,2	235,3	235,6	235,1	235,8	235,4	235,5
I_{rms} [mA]	322	1320	942	319	199	26	44
$\cos\varphi_1$	1	0,47	0,433	0,92	0,37	0,971	0,99
Power factor PF	1	0,47	0,431	0,57	0,36	0,514	0,55
E [lux]	300	575	870	188,7	22	44	105
Energy efficiency [lux/W]	3,92	3,94	9,09	4,42	1,30	13,66	17,92

* measured for the stabilized operating conditions.

During the determinations, in the case of high pressure mercury vapors discharge lamp (type 04273), high pressure sodium vapors discharge lamp (type 181923) and fluorescent compact lamp (type 09IV), there was revealed that the entry into the normal operating mode occurs with delay, unlike other types of investigated lamps that enter practically instantaneous into operation when connected. The evolution in time of the active power when connected and up to the entry into the normal operating mode for the lamps type 04273, 181923 and 09IV is shown within Fig. 4, Fig. 5 and Fig. 6.

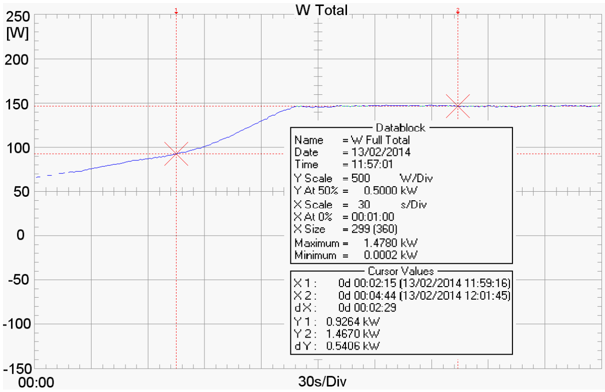

Fig. 4. The active power evolution in time for the high pressure mercury vapors discharge lamp (type 04273)

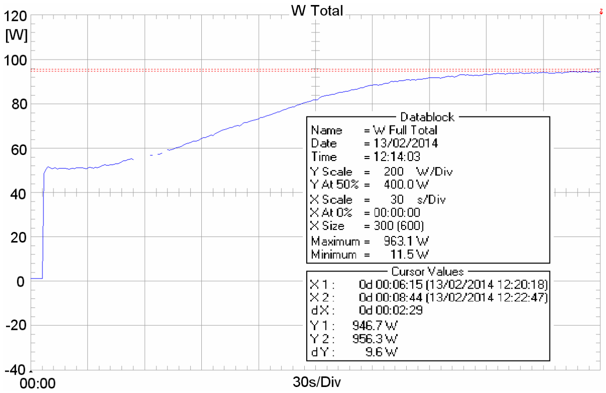

Fig. 5. The active power evolution in time for the high pressure sodium vapors discharge lamp (type 181923)

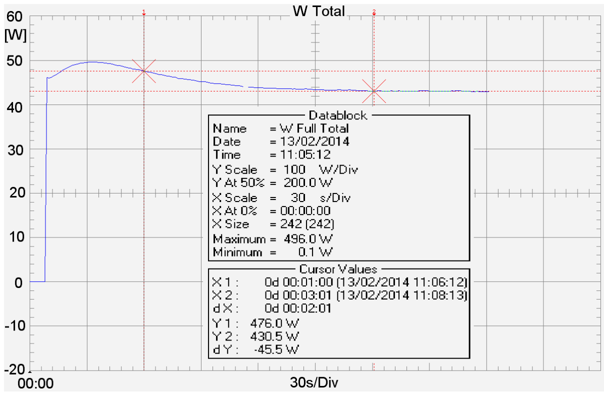

Fig. 6. The active power evolution in time for the fluorescent compact lamp (type 09IV)

By comparing Fig. 4, 5 and 6, it appears that both mercury vapor lamps and sodium vapor ones, require an ignition time equal to several minutes, while the illuminance level is low and the amount of absorbed power increases monotonically up to the nominal value .

In the case of the fluorescent lamp, compact construction, during the ignition (about 2 minutes), although it absorbs more power than the one from the nominal operating mode, the luminance is still reduced.

The analysis of the data presented in Table 1, shows that, excepting the classic incandescent lamp, all the other models of investigated lamps present a low power factor (PF = P / S), which suggests that the power supply system generates a wide spectrum of harmonics. Taking into account this observation, there has been analyzed the harmonics spectrum as well as the absorbed current waveform, (Fig. 7. ÷ Fig. 16.).

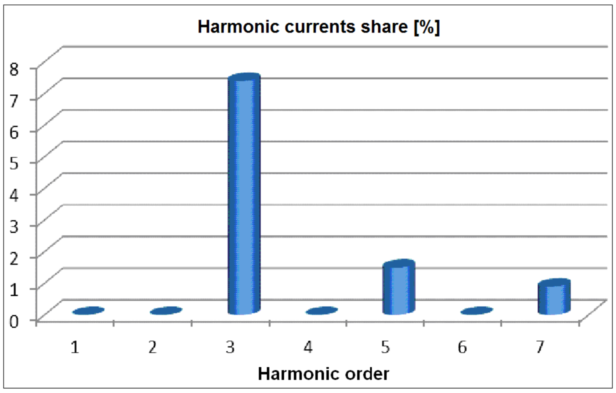

Fig. 7. The harmonics spectrum for the electric current absorbed by the high pressure mercury vapors discharge lamp (type 04273)

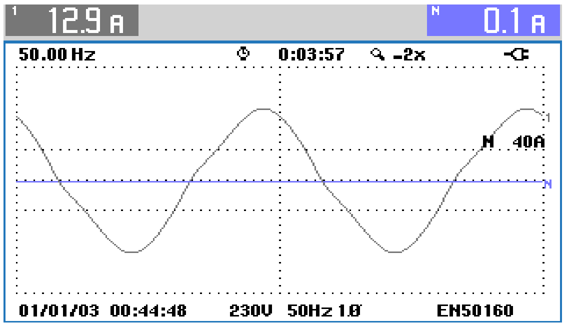

Fig. 8. The evolution in time for the electric current absorbed by the high pressure mercury vapors discharge lamp (type 04273)

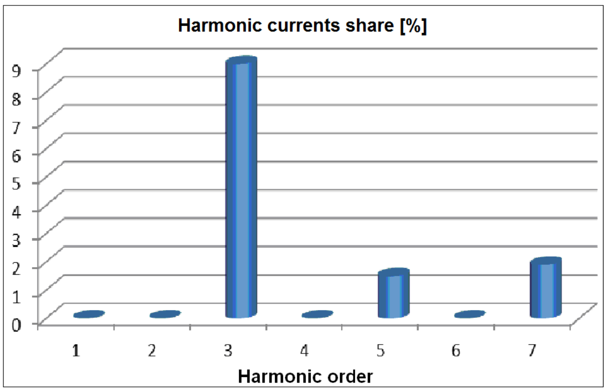

Fig. 9. The harmonics spectrum for the electric current absorbed by the high pressure sodium vapors discharge lamp (type 181923)

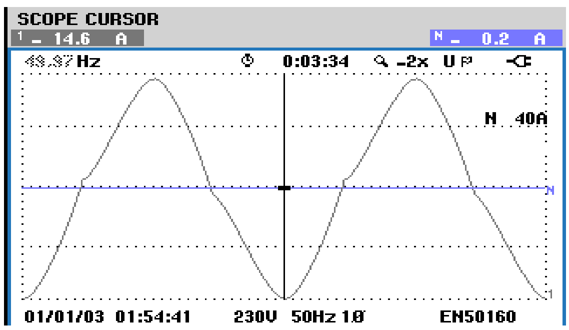

Fig. 10. The evolution in time for the electric current absorbed by the high pressure sodium vapors discharge lamp (type181923)

By analyzing Fig. 7 up to Fig. 10, there can be noticed that in the case of high pressure mercury vapors discharge lamps as well as for the high pressure sodium vapors discharge lamps, the 3rd order harmonics have a maximum share of approx. 8%, the 5th order and 7th order ones of approx. 1%, whilst the waveform of the absorbed currents present a relatively reduced deviation from the sinusoid waveform.

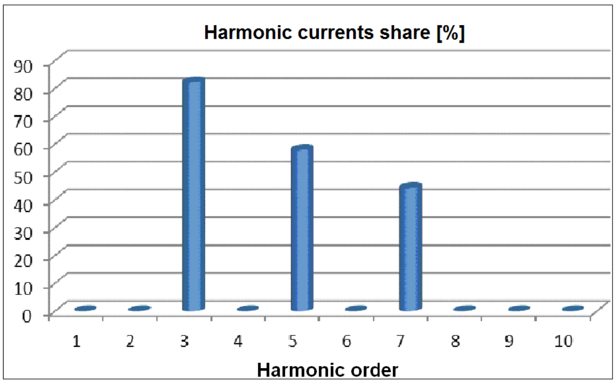

Fig. 11. The harmonics spectrum for the electric current absorbed by the fluorescent compact lamp (type 09IV)

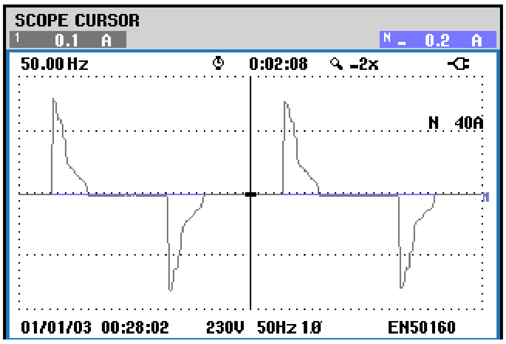

Fig. 12. The evolution in time for the electric current absorbed by the fluorescent compact lamp (type 09IV)

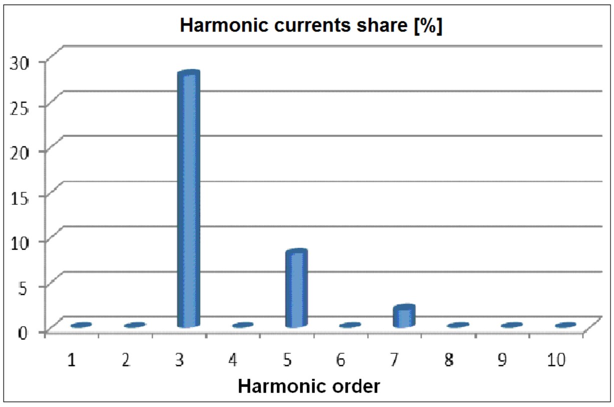

Fig. 13. The harmonics spectrum for the electric current absorbed by the fluorescent tubular lamp (type TL-D G13)

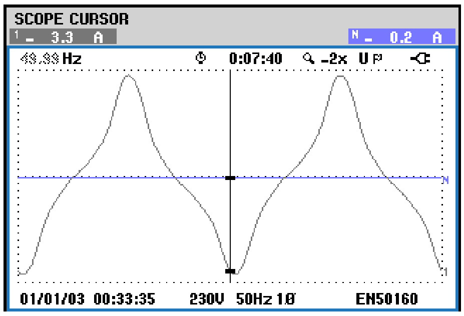

Fig. 14. The evolution in time for the electric current absorbed by the fluorescent tubular lamp (type TL-D G13)

Fig. 13 and Fig. 14 show that, in the case of the fluorescent tubular lamp, the 3rd order harmonics have a range of approx. 27%, the 5th order of approx. 7,5% and the 7th order ones of approx. 1,5%, whilst the waveform of the absorbed current presents major distortions from the sinusoid.

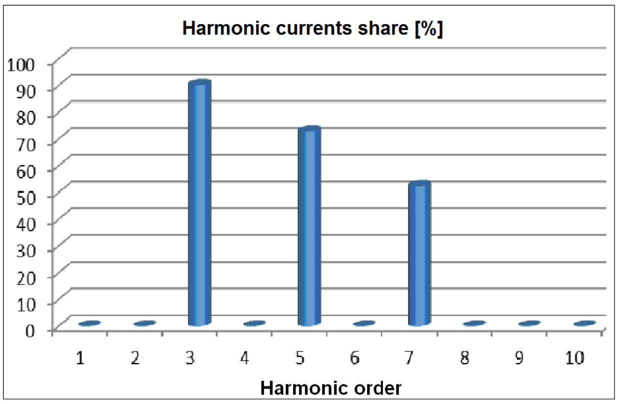

Fig. 15. The harmonics spectrum for the electric current absorbed by the LED lamp type HPE-G35B-3 (3W)

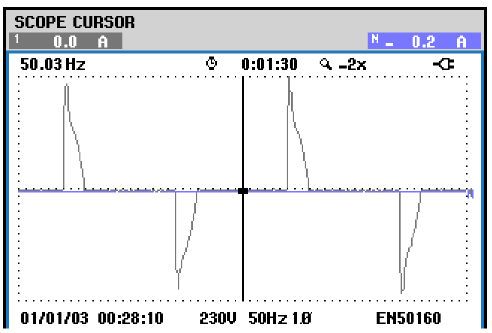

Fig. 16. The evolution in time for the electric current absorbed by the LED lamp type HPE-G35B-3 (3W)

From the analysis of Fig. 11 and Fig. 12, as well as Fig. 15 and Fig. 16, it is noticed that in the case of lamps with embedded power supply circuits, the harmonics value is very high: the range of 3rd order harmonics is approx. 90%, the range of 5th order harmonics of approx. 55%, respectively approx. 70%, for the 7th order harmonics of approx. 40÷50%, high values that are explained by the waveform of absorbed current, which is specific to the chopped sinusoid.

By observing the values presented within Table 1, the energy efficiency for the investigated lamps ranges between 1,3 and 17,92 lux/W, their classification consisting in: LED 5W > LED 3W > sodium vapors > fluorescent compact > mercury vapors > incandescent > fluorescent tubular.

4. CONCLUSION

In order to evaluate the energy efficiency and the impact on the power supply grid of different types of lighting lamps, there were determined the values of: active power, reactive power, apparent power, effective values of electric voltage and current, the cosine of the phase shift angle between the voltage and current fundamentals, the power factor, and well as their illuminance level.

Following the experimental measurements, there has resulted that the maximum energy efficiency has been obtained in the case of luminescent diodes lamps (over 17 lux/W) and the minimum energy efficiency for the fluorescent tubular lamps (about 1.3 lux/W). It was also noticed that, except for the incandescent lamps, all the other investigated ones generate harmonics, the harmonic proportion being particularly high (of approx. 90% for the 3rd order) for the lamps with embedded power supply circuits.

Low power factor lamps cause the development of an apparent power almost twice as high as the active power. Since the calculation of the power supply system for the lighting lamps often implies, only the active power, it results in fact that the circuit is only passed by an electric current practically twice as the useful current, leading to the thermal stress of the supply conductors and active losses equal to at least four times higher than in the case of high power factor lamps. In this regard, efforts undertaken at international level are underway in order to develop electronic ballasts with practically unitary power factor, which implies a current with almost sinusoidal shape in phase with the applied voltage. It results a power factor practically equal to the cosine of the phase shift angle for the fundamental harmonic.

Given the experimental results, it is considered appropriate to continue research in order to develop power supply circuits by which to achieve the perturbation reducing produced by high energy efficiency lamps.

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