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Performance analysis of fluorescent and LED lighting sources

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Abstract. *Artificial lighting is a necessity in the conduct of activities, especially at night. The use of fluorescent and LED lighting sources has led to a decrease in electricity consumption compared to incandescent lighting sources. The paper presents a case study highlighting the voltage and current waveforms in the operation of the analyzed sources. A considerable distortion of the current waveform is found, identifying the need for measures to improve power quality. The photometric measurements showed that for some light sources the luminous flux on the box is higher than the luminous flux actually emitted.*

Keywords: *lighting sources, electrical and photometric measurements, waveforms, efficiency*

1. Introduction

Electricity consumption by residential consumers is significant, accounting for around 30% of total European electricity consumption in 2017. Of this consumption about 15-20% was driven by the use of lighting installations [1]. Hence the need for a correct choice of lighting source.

In a 2013 study, the aim was to identify the type of lighting source that is most efficient. Efficiency was defined by considering average illuminance, maintenance cost, lifetime of sources and related equipment, power input, price and cost of energy consumed. The following types of lighting sources were analyzed: incandescent lamps, halogen lamps, compact fluorescent lamps, linear fluorescent lamps, and LED lamps. The analysis found that tubular fluorescent lamps are the most economical light sources [2].

In the case of fluorescent light sources, for faster priming, the auxiliary elements have been replaced by a high-voltage DC source, which is controlled by the pulse from a triac circuit. With this optimization, the service life was increased, the production cost was reduced, and the power consumption was reduced, since the priming coil was eliminated [3].

Since fluorescent lighting sources operate with a lower power factor than limit, it has been proposed to replace the classical ballast with an amplifier with two current sources: one using the supply voltage and another using a massive, charged capacitor from the amplifier's resonant circuit. This solution was tested on a 32W lamp [4].

In order to reduce electricity consumption in households, incandescent lighting sources have been replaced by LED (Light Emitting Diode) sources in recent years. In the United Kingdom, in 2007, it was found that this replacement led to a reduction in household electricity consumption of about 50.9% [5]. Another study [6] found that replacing halogen lighting sources in aircraft signage with LED sources led to a reduction in energy consumption of more than 57.3% and that the purchase and installation costs were 58% of the purchase and installation costs of halogen sources. This results in considerable savings that can be achieved.

Another method used to reduce energy consumption can be applied to new buildings. Thus in 2005 it was established that it is beneficial to use a window-to-wall ratio of about 0.20 [7]. This suggests the need for the wider use of daylighting and the choice of energy-efficient lighting sources.

The correct choice of the type of lighting source can only be made after proper design. This should consider the location of the lighting sources and the photometric curve so that the quality indicators of the lighting system are met [8, 9].

In all cases, a techno-economic analysis must be carried out to identify the cost, determine the payback time of the investment, the impact of the sources on the quality of the electricity [10, 11].

The paper presents a case study on one tubular fluorescent source, 5 fluorescent sources and 5 LED sources, both bulb types. Photometric measurements were also performed on toroidal fluorescent sources. Measurements were made on the electricity consumption, the luminous flux emitted, and their efficacy was calculated. The values from the measurements were compared with those on the nominal data box. To identify the impact of these sources on power quality, the waveforms of the supply voltage and the absorbed current were recorded. The analysis showed that there are cases where the data on the lighting source box do not correspond to the measurements, being lower. At the same time, a considerable distortion of the current waveform was found for LED and fluorescent sources.

2. Equipment used for measurements

To measure the luminous flux emitted by the analyzed sources, the Ulbricht lumenmeter (Fig. 1.a) was used in combination with the Unitest luxmeter (Fig. 1.b) mounted on the photometer.

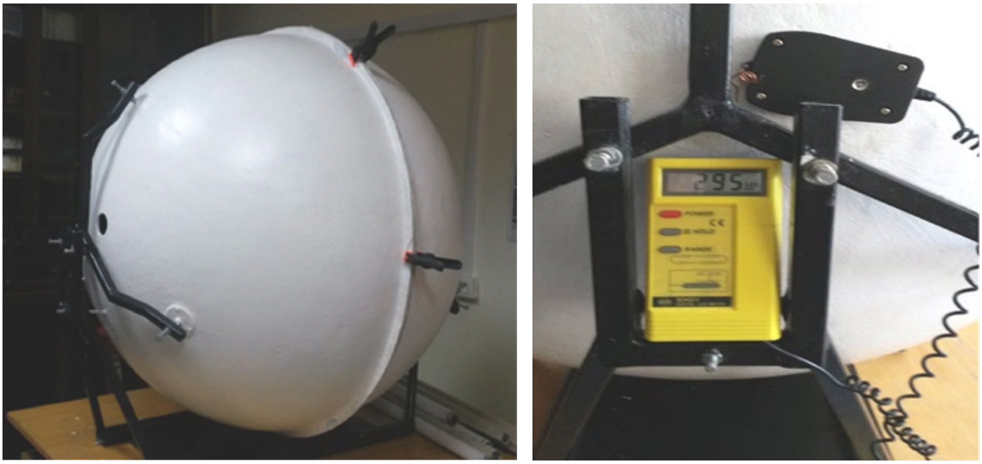

Figure 1. Apparatus used to measure luminous flux: a) lumenmeter; b) luxmeter.

The measurement of electrical quantities (voltage, current, power, power factor, etc.) was carried out using the Chauvin Arnoux C.A. 8336 network analyzer (Fig. 2).

Figure 2. Network analyzer.

The lighting sources were placed on a specially designed and built teaching stand [12] (Fig. 3).

The stand has been designed in such a way as to allow the powering of a tubular LED bulb, 1, 2, 4 or 5 fluorescent or LED bulbs, as well as the simultaneous powering of all lighting sources.

The relation [12, 13-15] was used to determine the luminous flux Φ:

$$\Phi = \frac{E}{k} \ [\mathrm{lm}] \tag{1}$$

where E is the illuminance measured with the luxmeter and k is the integrating photometer constant (k = 1.44), determined using a standard source.

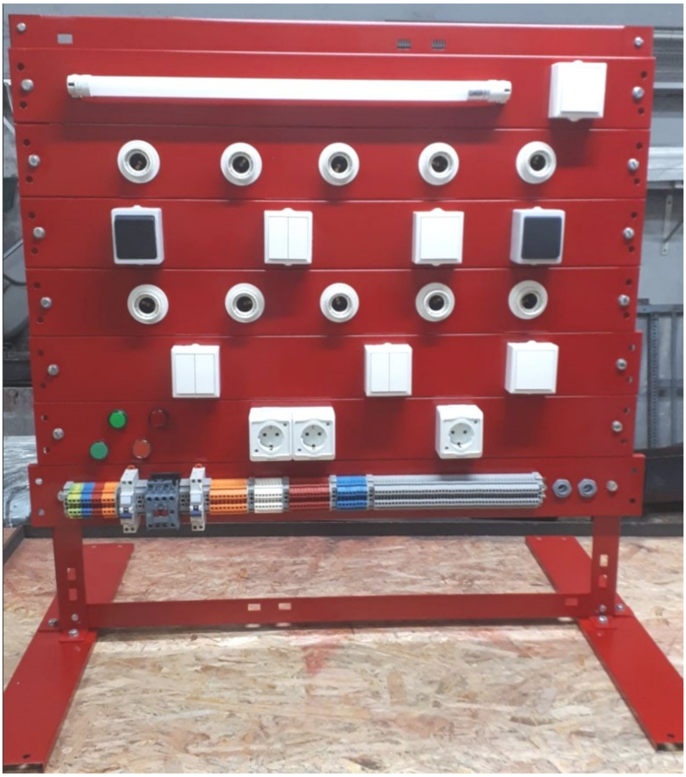

Figure 3. The used stand to study the operation of lighting sources.

The efficiency of the lighting source was calculated with the relation:

$$\mathrm{e} = \frac{\Phi_n}{P_n} \left[\frac{\mathrm{lm}}{W}\right] \tag{2}$$

where Φn is the nominal flux and Pn is the nominal wattage, both of which are commercial data marked on the lighting source box.

For comparison with measured or calculated sizes, the nominal sizes of the lighting sources were identified from their commercial box.

3. Measurements made

Table 1 shows the values identified from the lighting source box as well as the calculated magnitudes for the analyzed lighting sources [12].

Table 1. Electrical and photometric measurements identified, measured, and calculated.

Source type	Luminous flux [lm]		Rated power P_n [W]	Measured illuminance E [lx]	Nominal luminous efficacy e_n [lm/W]
	nominal Φ_n	calculated Φ_c			
Tubular LED	1100	1075	9	1548	122.22
LED bulb	1521	1534	17	2210	89.47
Fluorescent bulb	1450	1062.5	23	1530	63.04
Fluorescent toroidal	1200	881.9	20	1270	60.04

To measure power, current and power factor we used the network analyzer, which we set up accordingly. We measured the tube-type LED source, the 5 bulb-type LED bulbs connected in parallel, and the 5 bulb-types fluorescent bulbs connected in parallel. We did not take measurements for each bulb because the current value was too low and sometimes could not be measured with the network analyzer.

In order to get a picture of the waveforms we made recordings when the stand was powered, but without the lighting sources connected. The waveforms [12] of voltage (red color) and current (black color) are shown in Fig. 4.

2.1. Electrical measurements on tubular LED source

For the analysis of the operation of the tube-type LED source, it was powered via an autotransformer. The voltage at which the light source, with a low luminous flux, started to operate was 85 V, so much lower than the nominal supply voltage.

When connecting the tubular bulb, the maximum current value was 0.2 A and its waveform was strongly distorted by the electronic part in the tube (Fig. 5).

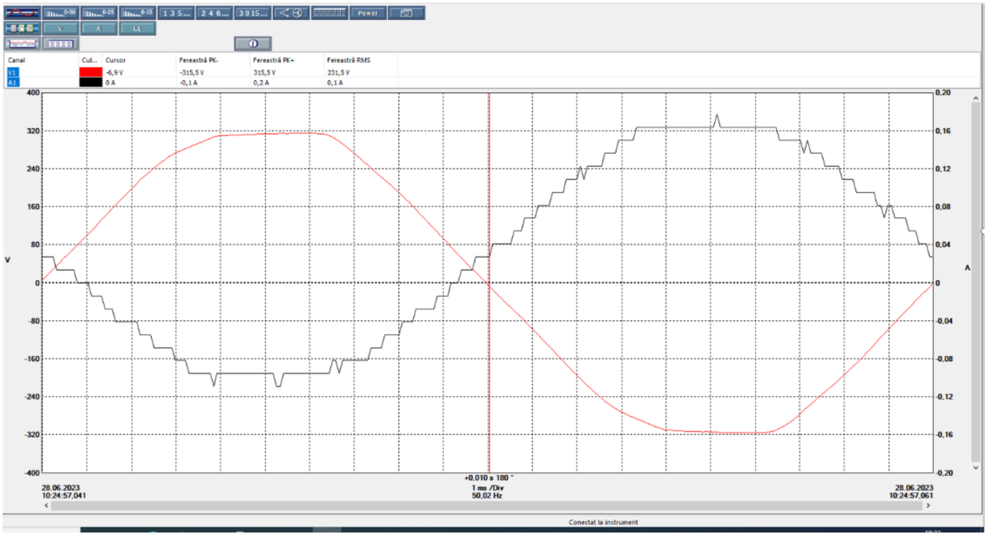

Figure 4. Voltage and current waveforms at stand power.

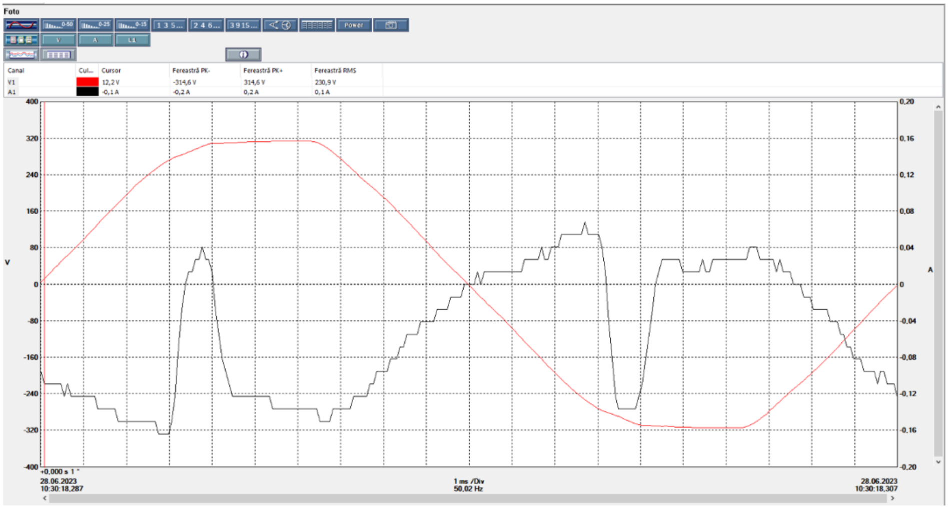

Figure 5. Voltage and current waveforms of the tubular LED source operation.

2.2. Electrical measurements on LED bulb sources

For this type of light source, the minimum voltage at which they started to emit luminous flux was 163.4 V, but with a very low luminous flux.

Since the current through a single LED bulb could not be recorded by the network analyzer, we connected 2 bulbs in series via ladder head switches. The voltage and current variation mode is shown in Fig. 6.

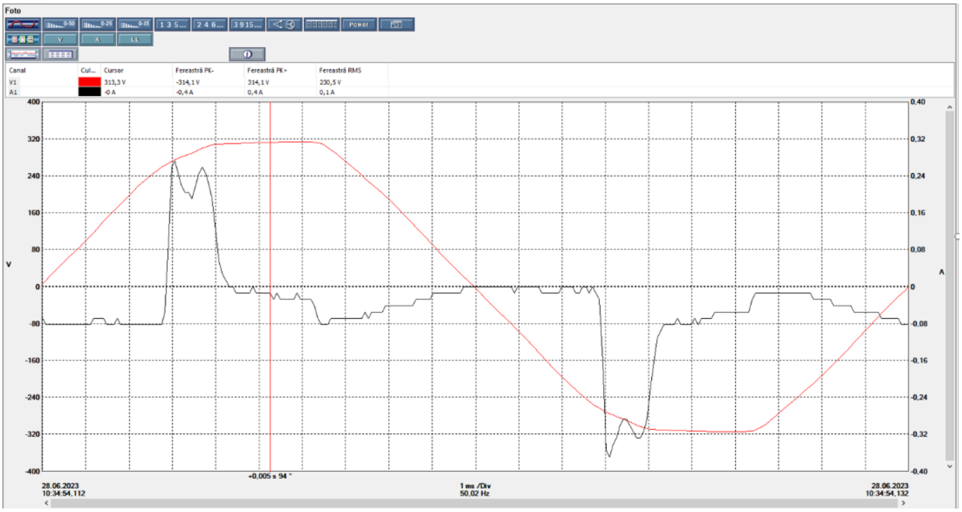

Figure 6. Voltage and current waveforms when operating 2 bulb-type LED sources.

There is a stronger distortion of the current waveform, and the maximum effective current value is 0.4 A.

In Table 2 we have presented the values of active power P, reactive power Q, apparent power S*, deforming power D, power factor cos φ and PF (power factor) [16]. In the table the power S* also takes into account the deforming power and PF takes into account the value of the angle λ between the active power P and the apparent power S*in the power-lipped.

Table 2. Values of powers and power factor corresponding to the operation of different types of sources in different assemblies

Mounting type	I_{max} [A]	P [W]	Q [VAr]	S* [VA]	D [VAr]	cos φ	PF
2 LED bulb	0.4	9.004	0.961	25.05	23.35	0.956	0.36
3 LED bulb	0.5	14.5	2.019	29.91	26.08	0.98	0.485
5 LED bulb	1	39.64	10.59	69.53	56.13	0.965	0.57
1 toroidal fluorescent	0.5	20.1	6.53	36.97	30.33	0.947	0.544

Mounting type	I_{max} [A]	P [W]	Q [VAr]	S* [VA]	D [VAr]	cos φ	PF
2 toroidal fluorescent	0.9	42.49	16.34	70.85	54.3	0.932	0.6
3 toroidal fluorescent	1.3	62.67	25.29	102	76.36	0.926	0.615
5 toroidal fluorescent	2	100.1	40.83	159.2	116.8	0.925	0.629
1 tubular LED, 5 LED bulb, 5 toroidal fluorescent	2.5	135	51.18	205.9	146.8	0.935	0.656

2.3. Electrical measurements on toroidal fluorescent toroidal lighting sources

In this type of sources, we have identified the priming voltage by using the autotransformer. We found that they prime at 132 V and light up to 43.2 V. And for this type of lighting sources, we made measurements with one toroidal fluorescent connected, with two, with three and with 5 toroidal fluorescent. In Fig. 7 we have shown the waveforms for a single connected toroidal fluorescent lighting sources and in Fig. 8 we present the waveforms with 5 toroidal fluorescent lighting sources.

It was found that the maximum value of the current was 0.5 A. The values of the powers and power factor for different power supply configurations are shown in Table 2.

2.4. Electrical measurements on power supply to all lighting sources on the stand

In Fig. 9 we have shown the voltage and current waveforms when all bulbs are connected (one tubular LED bulb, 5 LED bulbs and 5 toroidal fluorescent bulbs). The influence of the 5 fluorescent sources on the current waveform can be observed.

For this combination the maximum current value was 2.5 A. The values of power, power factor and PF are shown in Table 2.

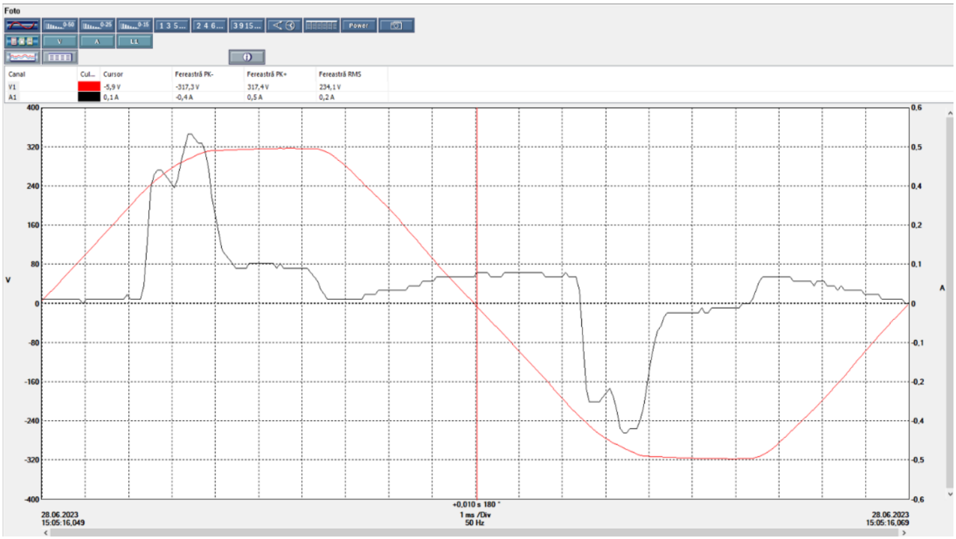

Figure 7. Voltage and current waveforms in operation of a toroidal fluorescent lighting source.

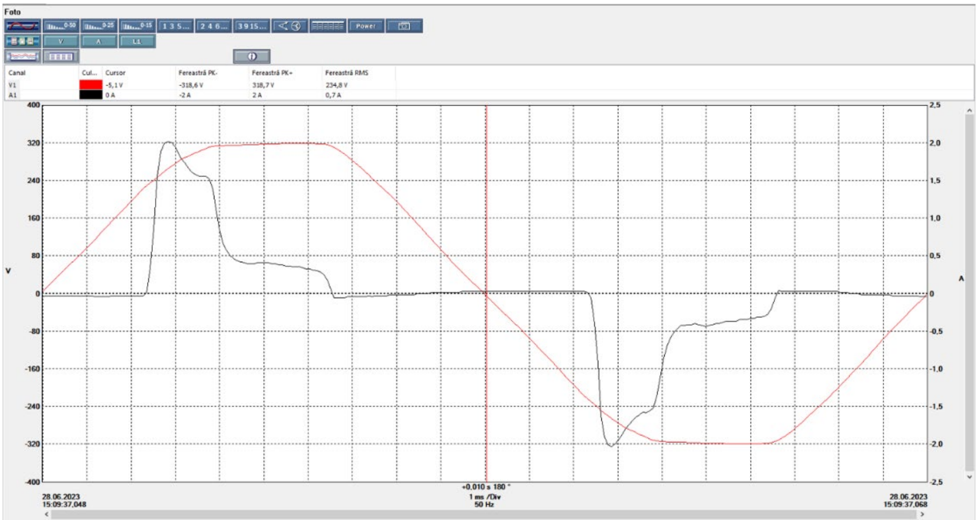

Figure 8. Voltage and current waveforms during operation of 5 toroidal fluorescent lighting sources.

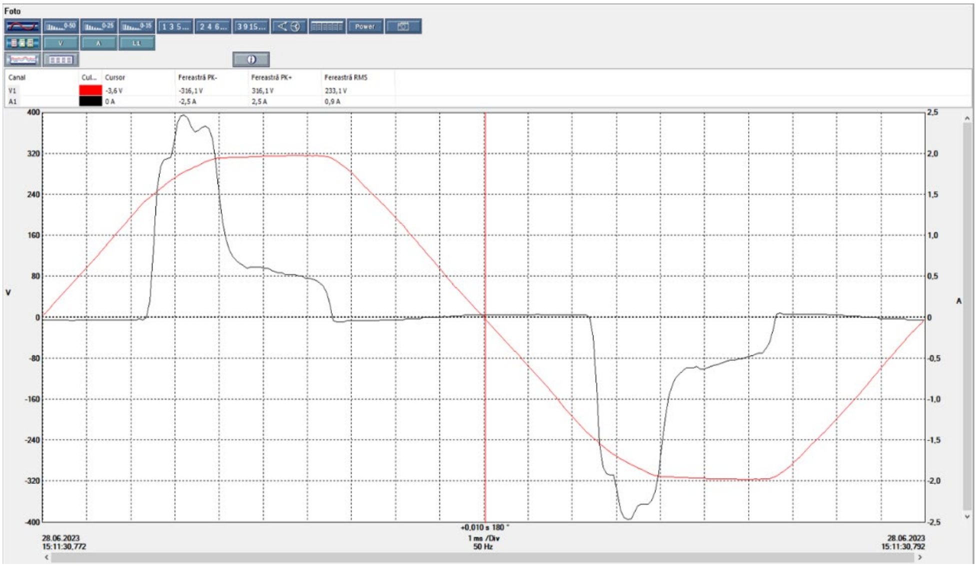

Figure 9. Voltage and current waveforms when operating with all bulbs on the stand.

4. Conclusion

Comparing the luminous flux values written on the light source boxes with the measured flux values shows that the luminous flux values of the LED tube source and the fluorescent sources are lower than the values written on the box with the nominal bulb data.

The calculation of luminous efficacy shows that the highest efficacy is achieved by the tubular LED source, followed by the bulb type LED source and then the fluorescent ones.

The tube-type LED source is operated at 36.96% of rated voltage. So, such sources are not sensitive to voltage variations. There is a strong distortion of the current waveform through the tubular LED source.

In the case of the bulb type LED source, the voltage at which it came on was 71.04% of the nominal voltage, so much higher than in the case of the tube type LED source.

In the case of fluorescent lighting sources, it was found that a time of more than 10 minutes was required for their complete priming and the emission of a constant luminous flux. They start emitting luminous flux at a voltage of 132 V (56.9% of nominal voltage) and remain on until about 18% of nominal voltage.

The analysis shows considerable distortion of the current waveform. This means that solutions need to be found to improve power quality.

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