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Measurements and analysis selected power quality parameters in systems with LED light sources

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The article describes the measurements of power quality parameters of load which is mapping the lighting installation of LED sources. Study were performed on a specially constructed the experimental setup which allows for the measurement of electrical parameters and distortion from electroluminescent lighting. In the paper quoted the legal basis in the field of power quality, referring to the Standards: PN EN 50160 "Voltage characteristics of electricity supplied by public electricity networks" and PN–EN 61000 "Electromagnetic compatibility (EMC)". Also has been presented a comparative study of LED light sources from various manufacturers, working individually and in a group. Shown the waveforms of current intensity and the bar graphs of higher harmonics of current. Additionally has been plotted the characteristics of total harmonic distortion ratio of current intensity THDi in the relation to the active power cooperating LED lamps. Finally the results of research has been analyzed and summarized.

KEYWORDS: electroluminescent diode, experimental setup, LED source, higher harmonics, lighting installation, power quality, THD ratio

1. Introduction

Every buyer of any product requires it to be of highest quality, that is to have a specific usable value. In other words, each product should have a set of characteristics and properties ensuring the actual level of satisfaction of current requirements of the user [3]. Even electrical energy should be of appropriate quality, because it is also a product offered to its customers by the power plant.

However, as it turns out, it is difficult to achieve the acceptable level of quality of electrical energy. The contemporary electric equipment – even though in need of high quality of the power supply – generates various types of interferences deteriorating the quality parameters of electrical energy. In connection with such a big number of receivers interfering the operation of the power grid, many scientific centres continuously perform tests to improve the energy quality. The tests are conducted in some measure in two directions: on the one hand, it is attempted to make the power grid resistant to interference, on the other, the solutions are sought to enable compensating disturbances caused by the recipients already at the level of the internal power supply system [1].

A big problem in keeping high quality of electrical energy in the last years is caused by the lighting systems. Modern lamps with semi–conductor sources of LED lights, the control and power supply systems of which strongly distort the current signal, introducing higher current and voltage harmonics, are used in the lighting industry [7].

2. Legal basis connected with energy quality

Proper operation of electrical and electronic equipment depends on supplying voltage of appropriate quality. Too low level of quality of electrical energy may cause its damage. Therefore, legal provisions in the form of Directives and Standards to be met by the power grids were introduced. The Regulation of the Ministry of Economy of 4 May 2007 concerning detailed conditions of operation of the power system is applicable in Poland. This Regulation is based on the provisions of non–mandatory standard PN–EN 50160 [4] defining "Parameters of Supply Voltage in Public Distribution Grids". The standard refers to low voltage, medium voltage and high voltage networks, however, this publication only presents the data concerning low voltage networks.

One of many power supply parameters are higher harmonics of voltage which are qualified as permanent disturbances of the supply signal. They are generated by non–linear receivers of electrical energy. The standard defines acceptable values of individual higher harmonics (from 2nd to 40th) with reference to the basic harmonic and specifies the allowable value of share in higher harmonics in relation to the 1st harmonic – THD ratio [6]. The acceptable levels of THD ratio and harmonics from 2nd to 25th were presented in the form of the bar chart in Fig. 1. Harmonics from 26th to 40th are described in the Standard but were disregarded in the presented chart because they reach very small values (ca. 0.5 %) [4].

The quoted Standard PN–EN 50160 defines the requirements concerning the parameters of the supply voltage (e.g. higher harmonics of voltage) to be met by the electrical energy supplier. However, not only the energy supplier is obliged to comply with requirements of standards. The recipient shall also observe the provisions of the Standard on electromagnetic compatibility of receiving devices – PN–EN 61000. This standard defines the acceptable levels of emission of interference for various types of receivers and describes how to correctly conduct measurements of energy quality.

Part 3–2 of the PN–EN 61000 Standard defines the acceptable levels of emission of current harmonics for receivers with the rated current not exceeding 16 A [5]. The requirements are set for the four groups of equipment: A, B, C and D. The electroluminescent sources of light (LED diodes) were included in group C (lighting equipment) [2]. The acceptable values of higher harmonics of the current for the receivers included in group C were presented in Table 1.

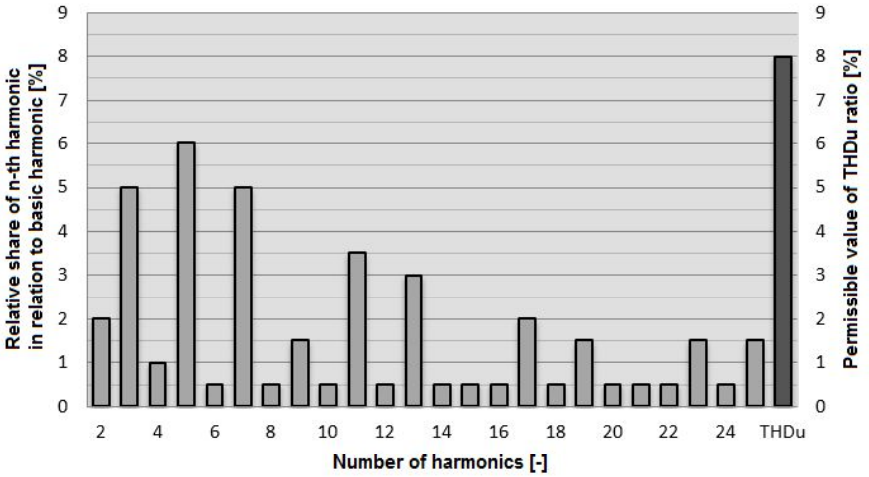


Fig. 1. Permissible levels of higher harmonics of voltage from 2nd to 25th and THDu ratio in LV networks (based on [4])

Table 1. Permissible levels of higher harmonics of current for equipment from group C (based on [5])

Number of higher harmonic of current n	Maximum permissible current of higher harmonic expressed as a percent of basic harmonic of current [%]
2	2
3	30·PF
5	10
7	7
9	5
11, 13, …, 39	3
PF – Power Factor on the input of electric equipment	

The Standard does not define the maximum value of THDi ratio. Considering only the values of higher harmonics indicated in the Standard and using the following formula:

$$THD = \frac{\sqrt{\sum_{k=2}^{n} X_k^2}}{X_1} \tag{1}$$

where: THD – total harmonic distortion, X_k – effective value (e.g. of current) of k–th harmonic, X_1 – effective value (e.g. of current) of basic harmonic, it is possible to calculate THDi ratio. It will amount to about 35 %. However, this is not the value which may be considered as the threshold value for meeting

the requirements of the Standard. This result may also be obtained when one or a few harmonics considerably exceed the acceptable scope, while, at the same time, other harmonics are very low or do not occur at all.

3. Measurements of THDi ratio in LED lighting systems

The tests were conducted at a specially constructed experimental setup for determining the parameters of energy quality of the lighting systems with LED lamps (Fig. 2). The objective of tests was to analyse the changes of total harmonic distortion of current THDi during cooperation of two types of LED sources with different power. The following lamps were used for tests: LEDLEADER, OSRAM, PHILIPS and WHITENERGY. The parameters of these lamps were presented in Table 2 [8].

Table 2. Parameters of the LED lamps used in research

Brand	Power [W]	Base	Flux [lm]	Color temp. [K]	Lot of lamps	Measurement		
						Total power [W]	Total current [A]	PF
OSRAM	10	E27	810	2700	20	202,5	0,954	0,92
PHILIPS	9	E27	806	2700	20	181,9	0,948	0,83
WHITENERGY	3	GU10	250	2800	30	84,4	0,928	0,39
LEDLEADER	8	E14	700	3000	20	156,4	1,186	0,57

The switched power supply incorporated in the LED lamps and used to control the light diodes causes very strong distortions of the current signal and hence generates higher harmonics of the current (Fig. 3). The higher harmonics of the current were measured using FLUKE 434/PWR energy quality analyzer and THDi ratio was determined. The results turned out to be much varied, which was presented in Table 3 [8].

From the tested LED sources, the Osram product has the lowest coefficient of total harmonic distortion – 24.6 %. The worst result was achieved by Ledleader lamps, because they have very high THDi ratio reaching 119.3 %. The LEDs manufactured by Philips and Whitenergy have similar THDi reaching respectively 52.7 and 43.6 % (Table 3) [9].

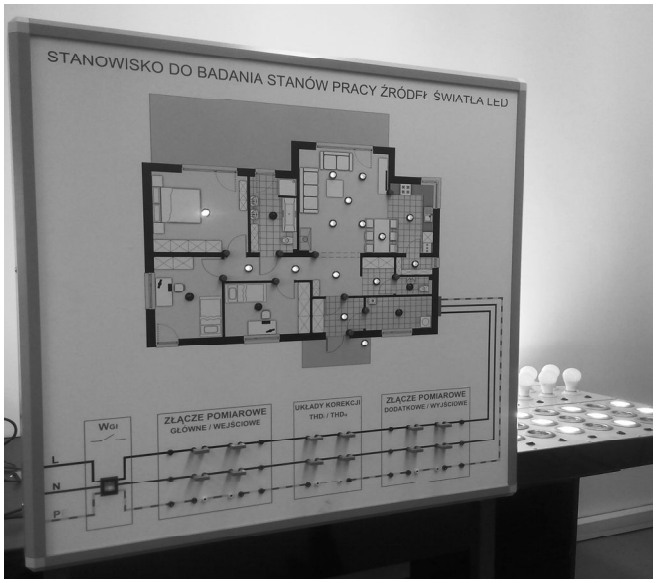


Fig. 2. View of the working experimental setup to research the power quality parameters in lighting systems with LED lamps

Table 3. The measured values of current higher harmonics in LED lamps

No of harmonic	LEDLEADER	OSRAM	PHILIPS	WHITENERGY
H2	0,1 [√]	0,0 [√]	0,0 [√]	0,0 [√]
H3	82,9 [×]	14,9 [×]	45,1 [×]	37,2 [×]
H5	59,0 [×]	16,3 [×]	24,4 [×]	11,7 [×]
H7	37,1 [×]	4,4 [√]	10,2 [×]	13,3 [×]
H9	26,9 [×]	4,8 [√]	3,9 [√]	5,2 [×]
H11	24,1 [×]	3,9 [×]	1,2 [√]	10,8 [×]
H13	19,5 [×]	5,3 [×]	0,5 [√]	6,1 [×]
H15	13,9 [×]	1,4 [√]	2,0 [√]	1,0 [√]
H17	11,9 [×]	3,1 [×]	0,5 [√]	1,8 [√]
H19	11,6 [×]	1,8 [√]	1,7 [√]	1,6 [√]
H21	9,4 [×]	1,9 [√]	2,0 [√]	1,9 [√]
H23	6,7 [×]	2,0 [√]	1,0 [√]	1,7 [√]
H25	6,4 [×]	1,5 [√]	1,0 [√]	2,0 [√]
THDi	119,3	24,6	52,7	43,6
[√] – compatibility with PN–EN 61000 Standard [×] – incompatibility with the Standard				

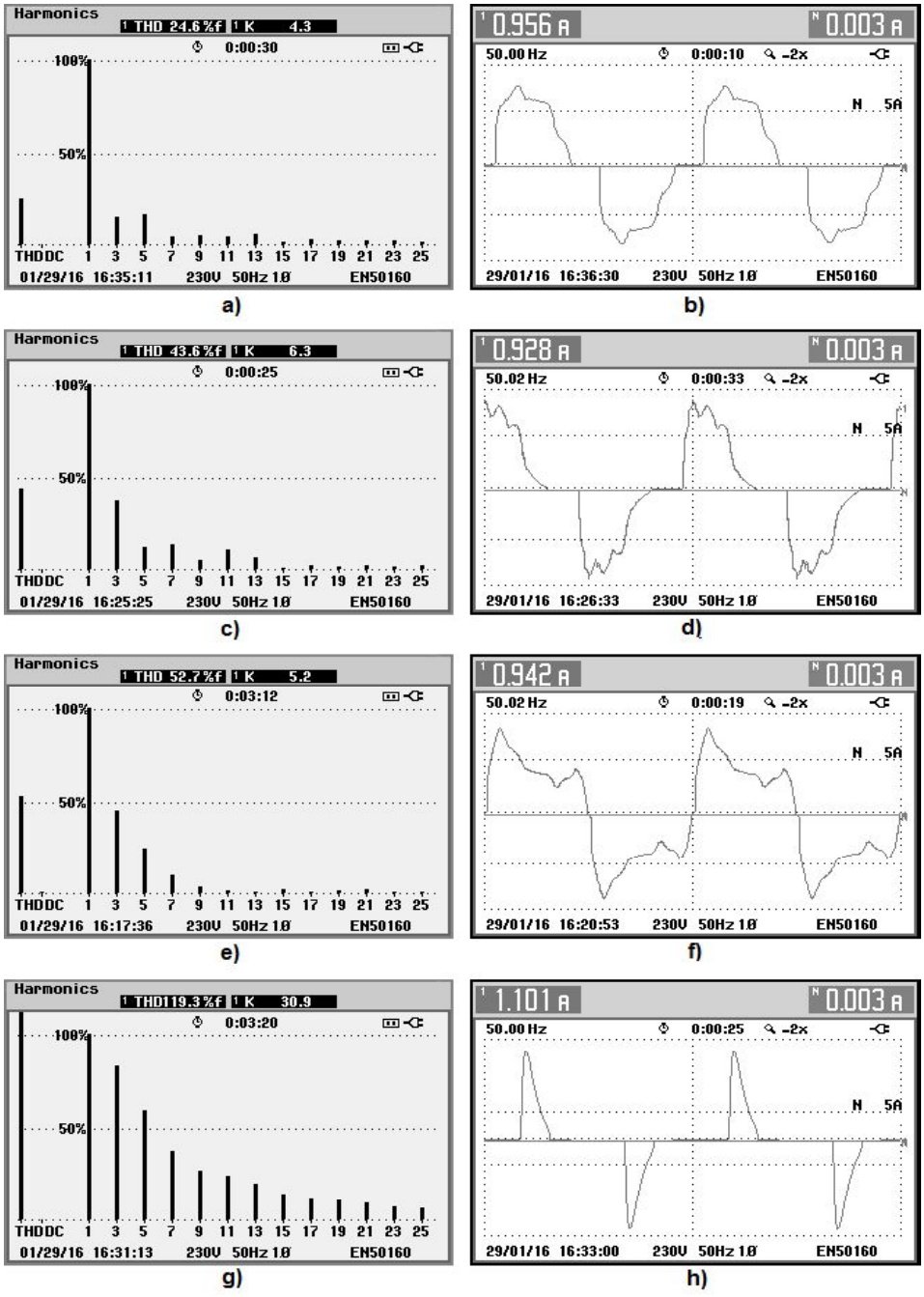


Fig. 3. Fluke 434/PWR (Power Quality Analyzer) printscreens for current higher harmonics and current waveforms: Osram – a), b); Whitenergy – c), d); Philips – e), f); Ledleader – g), h)

However, Standard PN–EN 61000 does not define the acceptable value of THDi indicator and it is necessary to compare individual harmonics, mostly the uneven ones. After the conducted tests one may find that none of the light sources meets all the requirements of the Standard concerning current harmonics. Each product meets the requirements of even harmonics, and in particular 2nd harmonic, as this one barely occurs. The Philips lamps exceed the acceptable values solely for 3 harmonics, while LEDs manufactured by Osram and Whitenergy do not meet the requirements in total for 5 or 6 higher harmonics.

The worst results were obtained for Ledleader lighting where each uneven harmonic exceeds the acceptable level. Osram lighting diodes are noteworthy because in spite of unacceptable levels of as many as five higher harmonics the levels are only slightly exceeded. For comparison, Philips lamps exceed this Standard quite considerably. This translates into the shape of the time functions of current – Philips LED lamps have more distorted signal (Fig. 3f) than the waveform of Osram LED lamps (Fig. 3b). Ledleader lamps have the most distorted current function (Fig. 3h) resembling more the pulse than the sinusoidal signal and generate a lot of uneven current harmonics [9].

Tests of higher harmonics of current with variable electrical power of electroluminescent sources of light were also conducted at the constructed station. In the case of Ledleader, Osram and Philips products the power was changed by switching on or off up to 20 of the same LED lamps (the same model of a given manufacturer) with a minimum power surge corresponding to two light sources. In the case of Whitenergy product, this surge falls every three lamps, while the maximum number amounts to 30 pieces. Hence, in each case the stepwise change of power every 10% of the maximum value is possible [8].

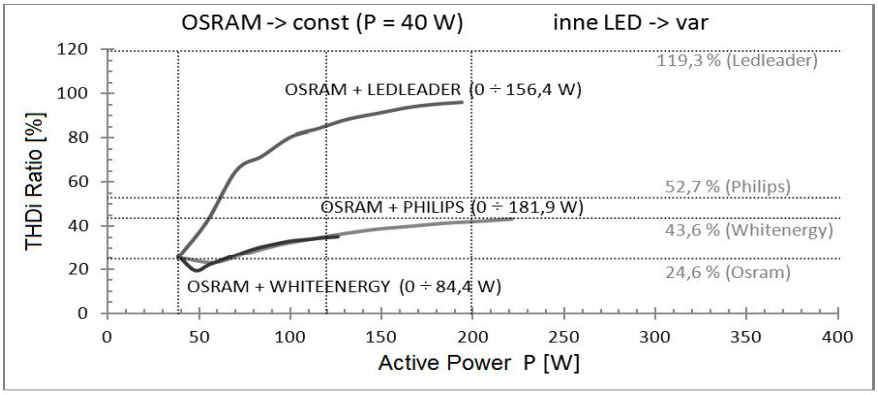
After the conducted tests it can be found that when the lighting system operates solely with one type of light sources, the total harmonic distortion of current remains constant irrespective of change of power (pieces) of the light fixtures. This relation is perfectly visible in Table 4. Small oscillations of the value of THDi indicator may have a few reasons, for example:

- measurement error of the energy quality analyzer,
- transient state caused by the change of power,
- unequal parameters coming from the side of the electric system.

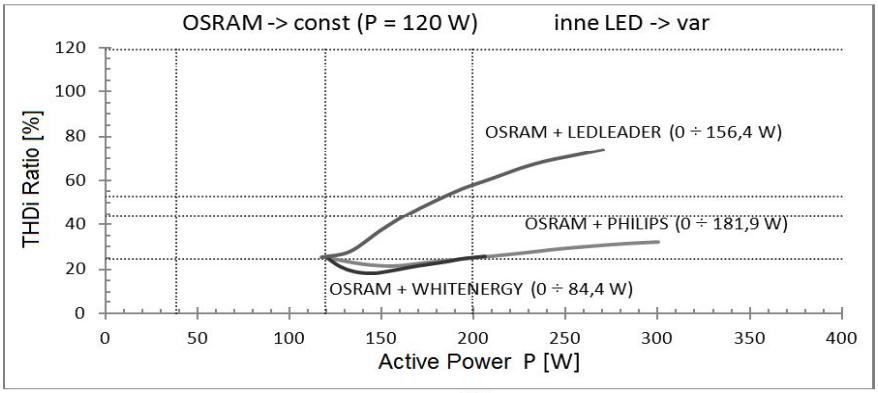
Completely different characteristics of the total harmonic distortion of current intensity THDi in the function of the active power of load were obtained when LED light sources manufactured by various companies operated at the same time (Fig. 4). One could expect that the resultant THDi indicator of the two cooperating lamps will be the result of averaging the value of their THD keeping the proportion of the load power of each of the lights. With regard to the above, the resultant THDi should be within the value limited from the bottom by the lower THD ratio of the better lamp and the higher total harmonic distortion of the worse lamp.

Table 4. Current total harmonic distortion ratio THDi in relation to active power P received by the LED lamps

Power [W]	THDi ratio [%]			
	OSRAM	WHITENERGY	PHILIPS	LEDLEADER
9	–	43,5	–	–
16	–	–	–	118,9
18	–	43,7	53,1	–
20	24,9	–	–	–
27	–	43,6	–	–
32	–	–	–	119,0
36	–	43,5	52,7	–
40	24,6	–	–	–
45	–	43,4	–	–
48	–	–	–	119,1
54	–	43,6	52,7	–
60	24,7	–	–	–
63	–	43,8	–	–
64	–	–	–	119,2
72	–	43,7	52,8	–
80	24,6	–	–	119,3
81	–	43,7	–	–
90	–	43,6	52,8	–
96	–	–	–	119,3
100	24,9	–	–	–
108	–	–	52,3	–
112	–	–	–	119,4
120	24,3	–	–	–
126	–	–	52,7	–
128	–	–	–	119,4
140	24,3	–	–	–
144	–	–	52,5	119,5
160	24,5	–	–	119,7
162	–	–	52,9	–
180	24,8	–	52,6	–
200	24,4	–	–	–
Average:	**24,6**	**43,6**	**52,7**	**119,3**



a)



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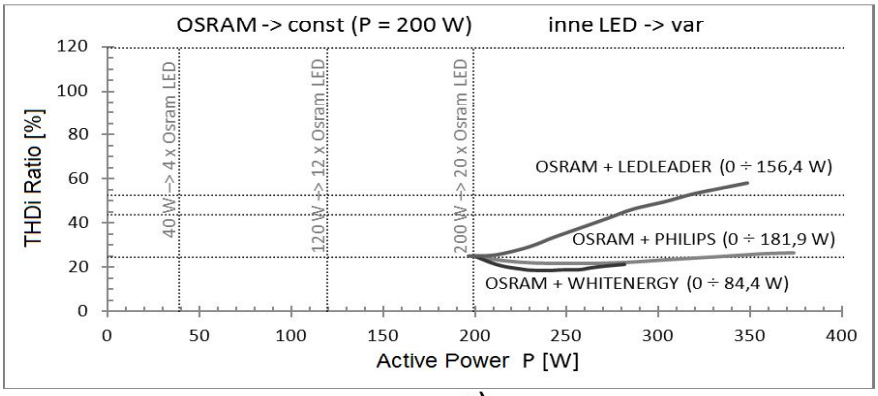

c)

Fig. 4. Total harmonics distortion of current in relation to active power for Osram LED lamps in cooperation with other LED light sources, when Osram LED lamps active power is equal: a) 40 W, b) 120 W, c) 200 W

However, it is not quite so, as it turns out. It is possible to obtain such configuration of two LED lamps, so that the resultant THD indicator is still lower than the one for the better lamp. The described phenomenon is shown in the characteristics in Fig. 4. During the tests connections of Osram lamps with LED lamps manufactured by Ledleader, Philips and Whitenergy were analysed. The characteristics (Fig. 4) were graphically shown with constant active power of Osram lamps, while the power of the second lamp was regulated.

Three measurement series were conducted for the Osram lamps with 40, 120 and 200 W. In each case the powers of the remaining light sources were regulated with the step every 10 % to the maximum value of a given LED source type (specified in Table 2) [9].

From the characteristics it can be observed that if the powers of Ledleader, Philips and Whitenergy lamps were still increased (irrespective of the set active power of Osram light source) the charts of THDi ratio would get stabilized at the same level as LEDs reached in the case of individual operation (Table 3).

4. Summary

The following conclusions can be drawn from the conducted tests:

- resultants of THDi of the two types of LED lamps are not the weighted average of their THDi (where active power is the weight);
- if THDi of two light diodes differs by order of magnitude, it can be assumed that the resultant total harmonic distortion of current is the weighted average of individual THDi (where active power is the weight);
- specification of two LED light sources with similar THDi gives the resultant THDi smaller than the lower total harmonic distortion of the lamp that operates individually; the assumption is correct if the power of the LED source with worse THDi is lower than the power of the lamp with better THDi.

The observed phenomenon is very interesting. It is sufficient to properly compare different LED lamps to compensate the total harmonic distortion of current of these lamps. It is advisable to perform further tests in this scope.

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