Przemysław TABAKA[1], Stanisław DERLECKI[2]

Technical University of Lodz, The institute of Electrical Power Engineering (1), The Institute of Electrical Engineering Systems (2)

Analysis of electrical parameters of light sources used by household and municipal customers

Abstract. *This paper presents the analysis, based on measurement results, of electrical parameters of energy-saving light sources used by household and municipal customers. This paper particularly pays attention to current distortion received from the mains which has been presented in terms of several light sources equipped with electronics and of different power characteristics, made by different manufacturers. Additionally, compact fluorescent lamps accompanied in a circuit by incandescent light bulbs in a few configurations, have been researched. Finally, the paper presents the results of measurements conducted in a storey distribution board for an individual apartment in a ten-storey building.*

Streszczenie. *W publikacji przedstawiono na podstawie wyników pomiarów analizę parametrów elektrycznych energooszczędnych źródeł światła stosowanych przez odbiorców bytowo-komunalnych. Szczególną uwagę zwrócono na odkształcenie prądu pobieranego z sieci, które przedstawiono dla kilkunastu wyposażonych w układ elektroniczny źródeł światła różnych mocy, różnych producentów. Dodatkowo obiektem badań były świetlówki kompaktowe włączone w układzie z tradycyjnymi żarówkami w kilku konfiguracjach. Na koniec zaprezentowano wyniki pomiarów przeprowadzone w piętrowej tablicy rozdzielczej dla pojedynczego mieszkania w 10-cio piętrowym budynku. (**Analiza parametrów elektrycznych energooszczędnych źródeł światła stosowanych przez odbiorców bytowo-komunalnych**)*

Key words: luminars intensity, surface of intensity distribution light reflection, total harmonic distortion, uncertainty in measurement
Słowa kluczowe: żarówka tradycyjna, energooszczędne źródła światła, współczynnik odkształceń harmonicznych,

Introduction

Incandescent light bulbs have been one of the first electrical light sources commonly used. Their simple construction, low manufacturing costs and wide variety of power and rated voltage ranges made them a very popular light source used in households. Taking into consideration their very good ability to reflect light colours and other factors, such as the fact that they flash instantly on switching and they do not need any boot device nor auxiliary device, and the fact that they constitute a non-inductive load and on connecting to the AC mains they do not cause the fall of power factor, one might brand them the “perfect” light source.

Unfortunately, incandescent light bulbs, when compared to other sources of light, characterize of low luminous efficacy (from 8 to approx. 26 lm/W). It stems from the fact that most of the radiation takes place in the infrared parts of the spectrum, to which human eye does not react. Heating of the support wires and contact wires and light absorption by the bulb’s glass as well as the cap sleeve lead to loss of energy; only a few per cent of electrical power is transformed into light. In other words, bulbs are extremely uneconomical light sources.

Over the last years, one could observe raising popularity of gas-discharge light sources i.e. mainly compact fluorescent lamps, which are wrongly called “energy-saving bulbs”. There is a number of reasons underlying their popularity: firstly, inexpensive electronics, which are used during manufacturing of switchstart unit, secondly the general tendency to save electrical energy, and lastly the legal regulations, which are soon to eliminate the energy-consuming light sources – mainly the incandescent light bulbs.

Apart from compact fluorescent lamps, which are manufactured in a wide variety of powers, there are also other energy-saving light sources available on the market. LED lamps, commonly named as “LED light bulbs” and halogen lamps are among them. The first ones due to relatively high price are not frequently used in households.

All of the above, excluding halogen lamps, may be directly connected to the 230 V rated voltage power system, which feeds most of household and municipal customers. Gas-discharge lamps, among them compact fluorescent lamps, due to their nonlinear current-voltage characteristics and the voltage spike necessary to initiate the electrical breakdown, it is crucial to use a switchstart unit. Yet, LED lamps, due to specified polarization (they are able to conduct without any damage only in one direction) and low forward voltage (approx. from 1,4 V to 3,5 V) need special feeding. Firstly the feeding has to be a DC source, and secondly the voltage must be relatively lowered.

The common use of electronics in energy-saving light sources has its advantages as well as disadvantages. The positive aspects are: boosted bulb life, lowered losses which influence the increase in the luminous efficacy – a parameter that signalizes light source efficiency, reduced light source’s weight and size. However, among disadvantages one could enumerate e.g. dependency between durability and the number of switches per day (electronics does not tolerate frequent switching), low power factor, significant current distortion. From the power quality point of view, the last disadvantage seems the most serious, thus the authors of this paper mostly have focused on the issue.

Subject and scope of study

The comparative research involves three types of energy-saving light sources which are available on the market:

- integrated compact fluorescent lamps (fluorescent sources),
- LED diodes (electroluminescence sources),
- incandescent light bulb with a low voltage capsule (thermal light source).

All light sources contain E27 cap and are fed on 230 V alternating current and 50 Hz frequency.

Referring to individual light sources, voltage and current time run, current harmonic distribution, power factor, active power, reactive and apparent power values have been recorded.

General information on researched light sources (further referred to as sources) is presented in table 1. For the purpose of this paper, the researched sources have been given symbols and they have been arranged alphabetically, taking into account the criterion of manufacturer’s name. Integrated compact fluorescent lamp have been determined with symbols from F1 to F16, LED “light bulbs” – E1, E2, and incandescent light bulbs have been given symbols T1, T2.

Table 1. General information on researched light sources

Manufactu-rer	U [V]	I [mA]	P [W]	Φ [lm]	*Energy Class*	Source symbol
Fluorescent sources						
ANS	230	X	55	3000	A	F1
APOLLO	230	61	15	365	B	F2
GE	220-240	X	15	850	A	F3
GOVENA	220-240	X	20	1300	A	F4
HELIOS[1]	220-240	134	20	1140	A	F5
OSRAM	220-240	X	14	900	A	F6
PHILIPS	220-240	100	14	820	A	F7
PILA	230-240	90	14	760	A	F8
POLUX	230	130	14	X	A	F9
POLUX	230	200	23	1600	A	F10
POLUX	230	X	30	1900	A	F11
POLUX	230	190	40	2678	A	F12
POLUX	230	290	60	4298	A	F13
POLUX	230	X	85	6390	A	F14
YHC	220-240	105	15	880	A	F15
SYLVANIA	220-240	100	15	830	A	F16
Electroluminescent sources						
OSRAM	100-240	X	2	X	A	E1
POLUX	85-265	X	3	210	A	E2
Thermal light sources						
PHILIPS	230	brak	20	370	B	T1
OSRAM	230		60	710	E	T2
X – no info on the packaging or plastic cap of the source						

Additionally, conventional 60 W incandescence light bulbs have been tested; they were accompanied in a circuit by compact fluorescent lamps manufactured by a randomly selected producer. In order to observe the influence of the number of cooperating sources on the degree of current distortion, it was necessary to consider a few cases, which are presented in table 2. All sources were connected in a parallel unit and powered from one circuit (fig. 1).

Table 2. Different cooperation units of conventional incandescent bulbs and integrated compact fluorescent lamps

	Source T2 (incandescent bulb)	Source F15 (fluorescent lamp)
Variant 1. (V1)	1 pcs	3 pcs
Variant 2. (V2)	2 pcs	3 pcs
Variant 3. (V3)	3 pcs	3 pcs
Variant 4. (V4)	3 pcs	2 pcs
Variant 5. (V5)	3 pcs	1 pcs

Devices which are used in households (i.e. computer, LDC TVs, and also compact fluorescent lamps) constitute harmonic sources. In principle, each of the electrical loads, when considered separately, has low rated current, thus the fraction of harmonic source will be slight. However, taking into account the fact that most of the loads may be used simultaneously, their influence on the power mains cannot be ignored. Therefore, it would be worthwhile to make measurements e.g. at the grid connection of the household building and the obtained values of individual harmonic voltage should be referred to requirements contained in the standards [3]. Due to the fact that it is difficult to get access to such grids (special permits are necessary), the measurements have been made in one apartment in a ten-storey building. The power analyzer's current circuit was connected through a fuse holder which was just behind the internal power supply line which runs through individual storeys of the construction. In terms of the operating devices in the examined apartment, two cases have been specified. The first case (P1) involved 7 integrated compact fluorescent lamps, an LCD TV, and an iron. The second case (P2) involved 8 compact fluorescent lamps and 4 halogen lamps.

Measuring system

Laboratory tests have been conducted on a system which structure is presented in fig. 1.

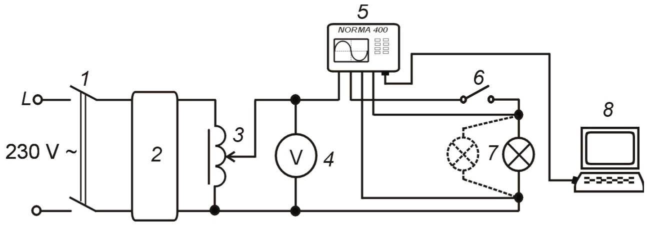

Fig. 1. Diagram presenting measuring system used to define the electrical parameters of researched light sources: *1*, *6* – power switches, *2* – voltage regulator, *3* – autotransformer, *4* – digital voltmeter, *5* – analyzer, *7* – researched light source(s), *8* – PC

Electric power is supplied to voltage regulator (2) through a switch (1). Voltage regulator provides constant rms voltage with accuracy to 0,1%. With the help of autotransformer (3), a value of 230V is set. The value is verified by the voltmeter (4). On closing the switch (6), the researched light source(s) (7) turn on. Power analyzer Norma 4000 manufactured by Fluke (5) was used to record voltage and current time run. Measuring instrument was connected to the PC (8) by RS−232C, a serial communication connector. Communication between the PC and the analyzer is bidirectional i.e. the device transmits data but it can also be controlled by the computer. On finishing measurements, all collected values can be conveyed to the PC and saved on a hard drive. Software on which the meter operates, allows to save the data in a text format accepted by any broadsheet.

Due to distortion of current which is supplied from the mains to the power analyzer and laptop's power supply, the elements used to record electrical parameters of the researched light sources in the measuring system, it was necessary to feed them on a separate circuit.

Measurement results

Electrical parameters of individual sources were recorded after approx. 30 minutes of their operation. However, prior to the test and in compliance with the standards' recommendations [2], the sources had been aged for 100 hours on rated voltage power supply. All light sources during the measurements were placed vertically – with their cap down. Ambient temperature in the laboratory where the tests were carried out was $25^{o}C \pm 1^{o}C$ (the room was air-conditioned).

Measurement results for every of the analyzed sources (excluding conventional incandescent light bulb – source T2) are presented in a form of graphs fig. 2÷6 as well as in table 3. Time run of several light sources which were switched on simultaneously – in different configurations (presented in table 2.) are shown in fig. 7 and 8.

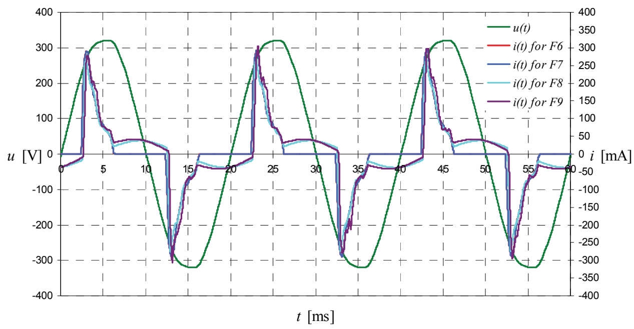

Fig. 2. Voltage and current time run of light sources over 14 W

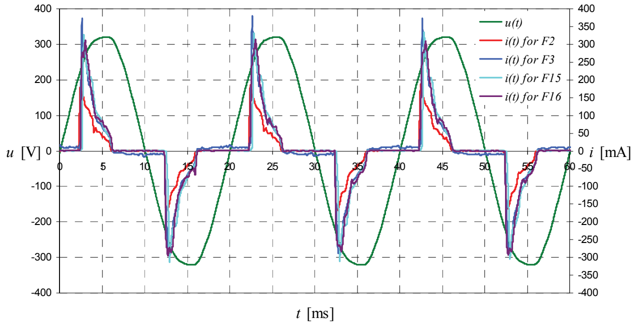

Fig. 3. Voltage and current time run of light sources over 15 W

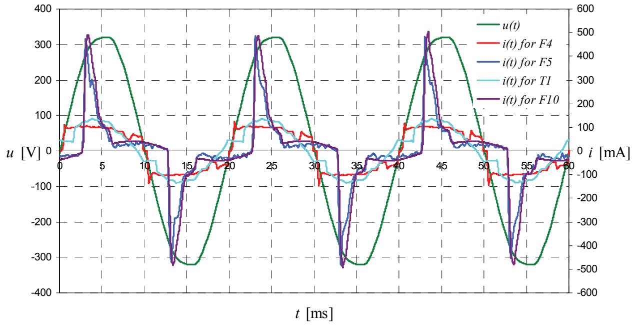

Fig. 4. Voltage and current time run of 20 W power light sources (sources F4, F5, T1) and 23 W (sources F10)

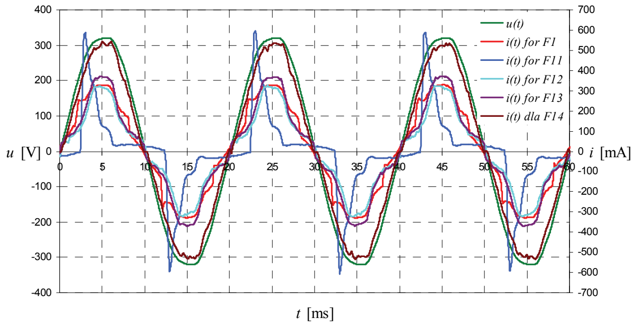

Fig. 5. Voltage and current time run of light sources over 25 W power

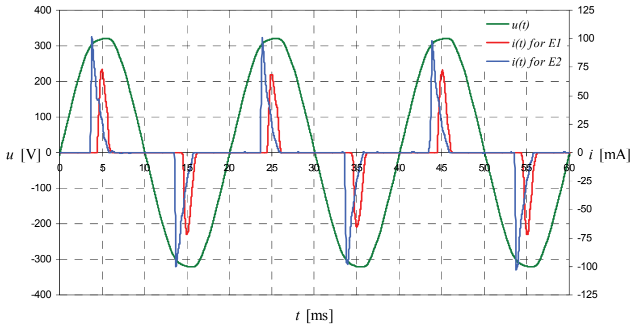

Fig. 6. Voltage and current time run of semiconductor light source

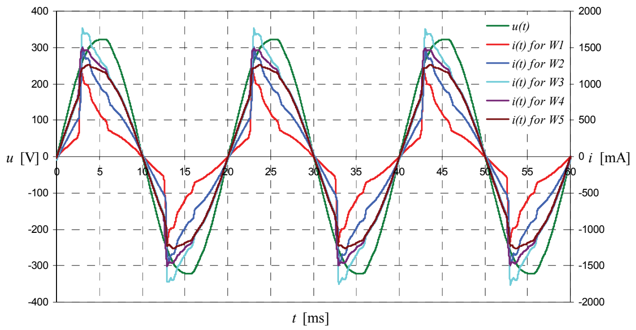

Fig. 7. Voltage and current time run of conventional incandescent light bulbs and compact fluorescent lamps unit

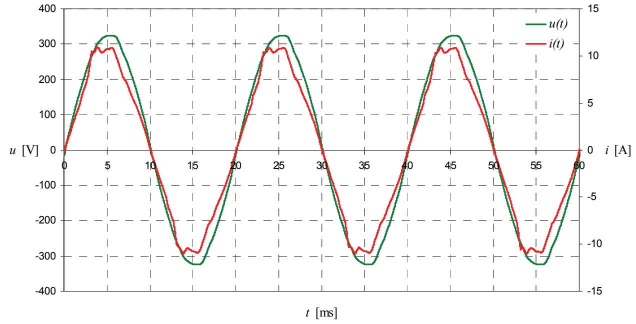

Fig. 8. Voltage and current time run for the apartment – case 1.

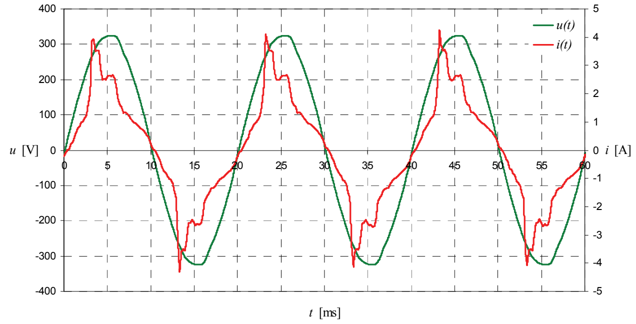

Fig. 9. Voltage and current time run for the apartment – case 2.

Voltage and current time run for this apartment is introduced in fig. 8 and 9, whereas values for individual electrical parameters are presented in tables 1 and 3.

Table 3. Recorded electrical parameters of the researched light sources and electrical loads in the apartment

Source symbol/ variant	U_{rms} [V]	I_{rms} [mA]	P [W]	Q [var]	S [VA]	cos φ [-]
Fluorescent sources						
F1	230,1	227,8	50,61	- 8,18	51,27	0,98
F2	230,2	56,5	8,16	-10,11	12,99	0,63
F3	230,1	95,1	13,16	-17,50	21,90	0,60
F4	230,2	86,2	18,73	- 6,56	19,841	0,94
F5	230,2	137,7	20,20	-24,40	31,685	0,64
F6	230,1	96,7	14,42	-16,96	22,265	0,65
F7	230,2	91,8	14,37	-15,46	21,108	0,68
F8	230,2	94,6	13,35	-17,18	21,765	0,61
F9	230,1	99,5	16,15	-16,23	22,790	0,71
F10	230,1	159,5	24,34	-27,440	36,690	0,66
F11	230,2	193,8	28,45	-34,3	44,615	0,64
F12	230,2	188,7	42,25	-10,14	43,449	0,97
F13	230,3	222,9	49,89	-12,10	51,332	0,97
F14	230,1	364,4	83,59	- 6,36	83,859	0,99
F15	230,1	93,0	13,35	-16,72	21,400	0,62
F16	230,2	98,2	14,08	-17,69	22,610	0,62
Electroluminescent sources						
E1	230,2	19,1	2,11	- 3,87	4,406	0,48
E2	230,1	25,0	2,88	- 4,99	5,775	0,50
Thermal light sources						
T1	230,2	90,4	19,69	- 6,66	20,790	0,95
T2	230,1	276,4	63,39	5,20	63,600	0,99
Conventional incandescent light bulbs in a circuit with compact fluorescent lamps						
V1	230,1	488,5	100,78	- 49,83	112,42	0,89
V2	230,2	736,0	161,78	- 50,17	169,38	0,96
V3	230,1	995,1	223,40	- 50,43	229,02	0,97
V4	230,1	862,6	210,92	- 34,71	213,76	0,98
V5	230,1	862,6	197,63	- 18,70	198,51	0,99
Groups of devices switched in the apatment						
P1	231,0	7429,7	1708,90	-157,10	1716,1	0,99
P2	230,3	1627,8	351,55	-160,00	386,28	0,91

With respect to individual sources cooperating with electronics unit and the electrical loads operating in the analyzed apartment, current harmonic distortion has been measured (up to the 40th inclusive), yet, due to great number of data, it has been excluded from this paper. The paper restricts to presenting total harmonic distortion THD_I, which was calculated on the basis of a pattern (1). The results are presented in table 4.

$$THD_I = \frac{\sqrt{\sum_{k=2}^{n} I_k^2}}{I_1} \cdot 100\%, \quad (1)$$

where: I_1, I_k - respectively the first one and k-th harmonic, n – the last harmonic order taken for calculation.

Table 4. Calculated values of THD_I for the researched light sources and devices in the apartment

Source	F1	F2	F3	F4	F5
THD_I	12,97%	72,06%	72,57%	29,05%	53,87%
Source	F6	F7	F8	F9	F10
THD_I	16,97%	75,77%	77,54%	70,83%	75,39%
Source	F11	F12	F13	F14	F15
THD_I	68,96%	24,38%	24,63%	6,62%	77,77%
Source	F16	E1	E2	T1	
THD_I	73,84%	62,28%	84,07%	12,84%	
Conventional incandescent light bulbs and compact fluorescent lamps unit					
variant	V1	V2	V3	V4	V5
THD_I	49,56%	30,87%	27,19%	20,06%	11,72%
Groups of devices switched in the apartment					
variant	P1		P2		
THD_I	8,21%		40,70%		

Analysis of measurement results

When looking at the current and voltage time runs for individual samples, it is possible to observe differences in the shape of current charged from the supply. Roughly, one can assume that in case of gas-discharge lamps which do not exceed 25 W of power current time runs are similar. They contain typical current peak with characteristic steepness of rise. Due to the fact that none of the analyzed gas-discharge lamps below 25 W of power meets the set of requirements 1 (table 5), which applies to the acceptable value of harmonic distortion, therefore the shape of current depicted in the set of requirements 2 becomes significant.

Table 5. Light equipment requirements specified in a standard [2]

<table>
<tr><td colspan="3">for $P \leq 25$ W *)</td><td colspan="2">for $P > 25$ W</td></tr>
<tr><td colspan="2">requirement set 1</td><td>or requirement set 2</td><td colspan="2">requirement set</td></tr>
<tr><td>n</td><td>$\frac{I_n}{I_1}$ [%]</td><td rowspan="7">$I_3 \leq 86\%$, $I_5 \leq 61\%$, Besides the shape of current time run should:
a) start below or at 60° el.
b) have the last extreme value below or at 65° el.
c) not stop flowing below 90°</td><td>n</td><td>I_n [mA/W]</td></tr>
<tr><td>2</td><td>2</td><td>3</td><td>3,4</td></tr>
<tr><td>3</td><td>30·cos φ</td><td>5</td><td>1,9</td></tr>
<tr><td>5</td><td>10</td><td>7</td><td>1,0</td></tr>
<tr><td>7</td><td>7</td><td>9</td><td>0,5</td></tr>
<tr><td>9</td><td>5</td><td>11</td><td>0,35</td></tr>
<tr><td>11
:
:
39</td><td>3</td><td>13
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:
39</td><td>$\frac{3{,}85}{n}$</td></tr>
<tr><td colspan="5">n – harmonic order
I_n – maximum allowed current of n -th harmonic
I_1 – current of the first harmonic
*) applies to gas-discharge light equipment</td></tr>
</table>

Shapes of current for a few sources which do not exceed 25 W of power for the first alternation are shown in fig. 28. On the axis of abscissa there is electrical angle φ expressed in degrees. It has been assumed that 0° el. corresponds to zero crossing of voltage fundamental component. Axis of ordinates represents current; due to the fact that it has different values for individual sources, it has been expressed in per cents. The maximum value recorded in the first alternation has been used as a reference. Characteristic angles (60°, 65° and 90°) ensuing from the set of requirements 2 have been marked on the same graph.

Fig. 10. Current time runs in the first alternation for several sources below 25 W of power

For all gas-discharge lamps, whose shapes of current are presented in fig. 10., the values of third and fifth harmonic did not exceed required limits of the standard (table 5. set of requirements 2).

In case of lamps over 25 W of power the requirements are more restrictive. The standard does not call here for additional set of requirements when the contents of individual harmonic exceed. Therefore, current time runs are similar to a sinusoid (sources: F12, F13, F14).

A low voltage halogen lamp with an integrated electronics unit which lowers the line voltage, seems an interesting solution – source T1 (fig. 11). Despite the fact that it is an incandescent light source, it meets the requirements of harmonic contents set for gas-discharge lamps below 25 W.

a) b) c) d)

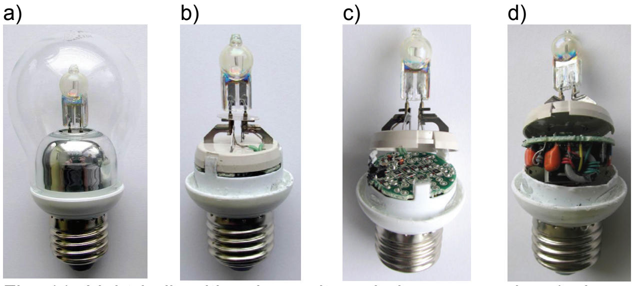

Fig. 11. Light bulb with a low voltage halogen capsule: a) view of the bulb, b) construction of the bulb, c) and d) view of the electronics unit which lowers the line voltage [4]

The problem seems different in case of semiconductor light sources – sources E1 and E2. Current charged by those sources is significantly distorted and does not meet the requirements for gas-discharge light equipment. Relative current values as a function of electrical angle for previously mentioned sources are presented in fig. 12.

The analysis of acceptable harmonics in case of thermal light sources and electroluminescent sources seems problematic. The problem stems from the fact that the electromagnetic compatibility standard divides light equipment into two categories: those above 25 W of active power and those below 25 W of active power. The first category relates generally to light equipment, whereas the latter group's requirements clearly refer to gas-discharge light equipment. One can presume that the loophole in the standard ensues from the fact that both of these categories of light sources are so modern and recent that during the time the standard was being developed they were not commonly available on the market.

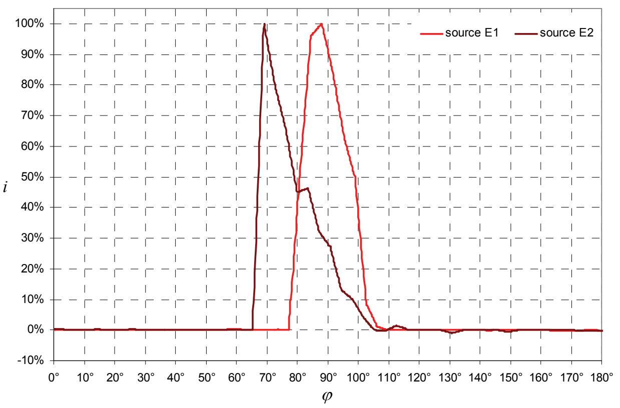

Fig. 12. Current runs in the first alternation for semiconductor light–sources E1 and E2.

Electronics feed systems integrated with the lamp underlie the high level of current distortion charged by the energy-saving light sources. In many cases, manufacturers implement the cheapest and the simplest technical solutions which enables them to lower the production costs. If the input member of such system contains a rectifier (usually it is a Graetz rectifier bridge) and just behind it there is an electrolytic capacitor which capacity equals several μF (it acts as a filter), then the current from the mains will have impulse nature. Its value will drastically increase until it reaches the peak and subsequently it will start to decline until the zero value. Charging current in a form of short impulses which characterize of significant peak current means low power factor for the unit; figures presented in table 1. confirm that.

Yet, if in terms of feeding, a passive filter is placed before a rectifier, then the emission of distortions generated by the electronics unit cooperating with the lamp will be significantly reduced. This kind of technical solution is present in high power light sources (power above 25 W F10÷F14, T2). The current run, on which these circuits are fed, is considerably less distorted, therefore the power factor is notably higher.

Analysis of measurement errors and uncertainty in measurement

The uncertainty in measurement is randomized and it is a geometric total of type A uncertainty related to the influence of external factors onto the measurement conditions and type B uncertainty related to the finite precision (error limit) of the equipment. In order to eliminate type A uncertainty a series of measurement of one parameter in reproducible conditions is required [5]. Its value is determined by the pattern (2)

(2) $$u_{Ax} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n(n-1)}}.$$

Type B uncertainty is defined on the basis of error limit contained in the technical specification of testing equipment. Assuming that the distribution of errors is uniform, the uncertainty equals

(3) $$u_{Bx} = \frac{\Delta grx}{\sqrt{3}}.$$

Having both components u_{Ax} and u_{Bx} we are able to determine the total uncertainty which is a geometrical sum of both elements. It constitutes a basis for defining the expanded uncertainty which is a product of total uncertainty and a coverage factor; the value of coverage factor is dependent on the applied level of confidence.

(4) $$U_x = k \cdot u_{\tau x}, \qquad u_{\tau x} = \sqrt{u_{Ax}^{\;2} + u_{Bx}^{\;2}}.$$

The presented results were obtained using Norma 4000 power analyzer made by Fluke. It characterizes of error limit Δ_{gr} = 0,1% X_n (measuring range) + 0,1% X (measurand). The results are burdened with expanded uncertainty which was determined in the following manner. Due to the fact that single measurements were conducted, type A uncertainty was assumed to be zero. Type B uncertainty was defined on the basis of analyzer's error limit.

For power measurement of a selected source F4, the total uncertainty equals

(5) $$u_{\tau u} = u_{bu} = \frac{\Delta_{gru}}{\sqrt{3}} = \frac{0{,}1\% \cdot 300 + 0{,}1\% \cdot 230{,}15}{100\sqrt{3}} = \frac{0{,}53}{\sqrt{3}}.$$

For the confidence level p = 0,95 the coverage factor k = 2 has been assumed. The expanded uncertainty in power measurement at this level of confidence is

(6) $$U_U = \pm k \cdot u_{\tau U} = \pm 2 \cdot 0{,}306 \approx \pm 0{,}6\ \text{V}.$$

This generated uncertainty applies to all measurements of lamps. Uncertainty in current measurement can be determined in a similar way

(7) $$U_I = \pm k \cdot u_{\tau I} = \pm 2 \cdot 0{,}499 \approx \pm 1{,}0\ \text{mA}.$$

For individual sources ((F1÷F16, E1, E2, T1, T2) the uncertainty falls in the 0,18÷1,6 mA range and in case of uncertainty in measurement of power components the values are:

for active power

(8) $$U_P = \pm k \cdot u_{\tau P} = \pm 2 \cdot 0{,}036 \approx \pm 0{,}07\ \text{W},$$

for reactive power

(9) $$U_Q = \pm k \cdot u_{\tau Q} = \pm 2 \cdot 0{,}048 \approx \pm 0{,}10\ \text{var},$$

for apparent power

(10) $$U_S = \pm k \cdot u_{\tau S} = \pm 2 \cdot 0{,}054 \approx \pm 0{,}11\ \text{VA}.$$

The uncertainty in defining the power factor is dependent on the uncertainty in calculation of components of active, reactive and apparent power, however it may be assumed that it is at 0,01.

Conclusions

Electric lighting is an integral element of our life, therefore manufactures keep modernizing electric light sources. Energy efficiency is one the most important parameters in terms of EU decrees [1] which call for restraint in energy consumption. It can be achieved inter alia by minimizing losses in electrical energy. In practice it involves using electronic switchstart units instead of conventional chokes – in case of fluorescent lamps, or electronic systems responsible for lowering voltage instead of traditional transformers – in case of semiconductor light sources and halogen light bulbs equipped with a low-voltage capsule.

As a result of progressive dissemination of electronic units in energy-saving light sources used in households, the problem of significant line-current distortion becomes substantial. On the basis of carried out measurements of different light sources, produced by different manufacturers, it is possible to conclude that the degree of line-current distortion in case of some lamps can be really high. Big number of such sources in the network (in combination with other nonlinear loads i.e. majority of devices operating in households) may lead to voltage distortion, which in turn lowers the quality of electric energy supplied to customers.

Manufacturers of energy-saving light sources generally are not interested in implementation of some solutions which would limit the content of higher harmonic in the current on which their lamps are fed. The reason for such attitude is the price but also regulations contained in standards. Manufacturing a low THD_I ballast is possible; high power light sources are a perfect example of that. Unfortunately, when a lamp is equipped with an electronic unit responsible for correction of power factor, it means price increase of compact fluorescent lamps, which are already more expensive than conventional incandescent light bulbs. Therefore such technical solutions are only introduced when the standard requires that i.e. in case of light sources whose active power exceeds 25 W. Another discouraging factor which stops consumers from buying compact fluorescent lamps above 25 W is the fact that their price was unjustifiably raised when the ban on sales of 100 W conventional incandescent light bulbs was enforced. The analysis of current time runs charged by the set of fluorescent lamps and incandescent light bulbs points out that the presence of conventional incandescent light bulb "moderates" current run. Thus, on the one hand disposal of conventional incandescent light bulbs means energy savings, but on the other hand it increases the level of current distortion.

LITERATURE

[1] DIRECTIVE 2005/32/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council

[2] PN-EN 61000-3-2 ELECTOMAGNETIC COMPATIBILITY, part 3-2: Limits for harmonic current emissions (equipment input current ‹= 16A per phase)

[3] PN-EN 50160 Voltage characteristics of electricity supplied by public distribution networks

[4] Tabaka P.: Badania porównawcze zamienników tradycyjnych żarówek (Comparative studies of conventional incandescent lamp substitutes), *Przegląd Elektrotechniczny* NR 9/2010, p. 315-321

[5] Guide to the Expression of Uncertainty In Measurement 1995 International Organization for Standardization Geneva. Polish edition: Wyrażanie niepewności pomiaru. Przewodnik. Główny Urząd Miar Warszawa 1999

Authors: *dr inż. Przemysław Tabaka, Technical University of Lodz, The institute of Electrical Power Engineering, 18/22 Stefanowskiego Street , 90-924 Łódź, E–mail: przemyslaw.tabaka@p.lodz.pl*

dr inż. Stanisław Derlecki, Technical University of Lodz, The Institute of Electrical Engineering Systems, 18/22 Stefanowskiego Street , 90-924 Łódź, E–mail: stanislaw.derlecki@p.lodz.pl