

SPECIFICS OF LIGHT-EMITTING DIODE LIGHT SOURCES USE FOR LIGHTING HOUSING AND COMMUNAL FACILITIES

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Abstract. *The article deals with the problems of developing systems for lighting housing and communal facilities, specifics of occurrence and the history of higher harmonics in lighting electric networks with light-emitting diode (LED) light sources, the level of distortion has been evaluated and distortion consequences caused by LED light sources into a supply network have been determined.*

Keywords: lighting network, higher harmonics, housing and communal facilities, light-emitting diode (LED) light sources

INTRODUCTION

The existing systems of lighting housing and communal facilities (lighting of staircases, house plates, fire hydrants, lifts) are mainly based on using filament lamps (FL) because of their simplicity and ease of use. But because of a low efficiency of FL-base illumination systems their use is connected with an excessive consumption of electric power. As calculations show Ukraine loses hundreds of millions of kilowatt-hour a year, suffers considerable material and social environmental losses.

As there are practically no investigations on the introduction of light-emitting diode lamps (LEDL) into housing and communal services in towns and cities, the authors of the article made technical and economic comparison of the variants of four kinds of the systems based on filament (F), fluorescent (Fl), compact fluorescent (CFL) and light-emitting diode (LED) lamps taking into account the quality of electric power and starting currents.

Efficiency of lighting plants with different kinds of light sources was estimated by the quantity of the expenditures spent on the development of a unit of light energy by the formulae:

$$Z_{\bar{n}} = \frac{1}{\eta_m} \left[\frac{\hat{E} \cdot \hat{A}}{E_{\text{inst}} \hat{O}} + q \cdot \left(1 + \frac{\delta}{100} \right) + \frac{\tilde{N}_l}{E_l \hat{O}_U} + \frac{\tilde{N}_{l.c}}{E_l \hat{O}_U} \right], \quad (1)$$

where K – capital expenditure on the development of a lighting plant, Ukrainian hryvnas; $E = E_H + E_a$ – a total coefficient equal to a standard factor of capital investment effectiveness and depreciation rates; δ – losses in starters and distributors, % of a lamp power; C_l – a lamp cost, hryvnas; $C_{l.c.}$ – a lamp changing cost, hryvnas; η_m – an average luminous efficiency during a light source lifetime, lumen/kilowatt; P_{inst} – total installed lamp capacity, kilowatt; T – duration of a lighting plant glowing in a year, hours; q – energy rate, hryvna/ kilowatt-hour; P_l – a lamp power, kilowatt; T_U – a lamp life utility, hours.

Results of the analyses are given in **Fig. 1-3**.

As the analysis showed the most energy-conserving systems for internal lighting are light-emitting diode light sources (LED LS). The payback period of LED lighting costs is 1,6 year, of FIL – 4,2 year, of CFL – 4,6 year (**Fig. 4**).

A comparative analysis showed that the use of LED lamps besides a considerable (up to 100 thousand hours) lifetime guarantees an

essential energy consumption reduction. But the use of LED LS is accompanied with some peculiarities conditioned by the presence of higher harmonics in the curve of the current consumed by them. The latter is connected with the fact that LED LSs represent a non-linear electrical load. A total effect of such loads is expressed in a distortion of the current consumed from the network and in higher harmonics flow into every element of the total network. This negatively influences the equipment supplying power from the common source.

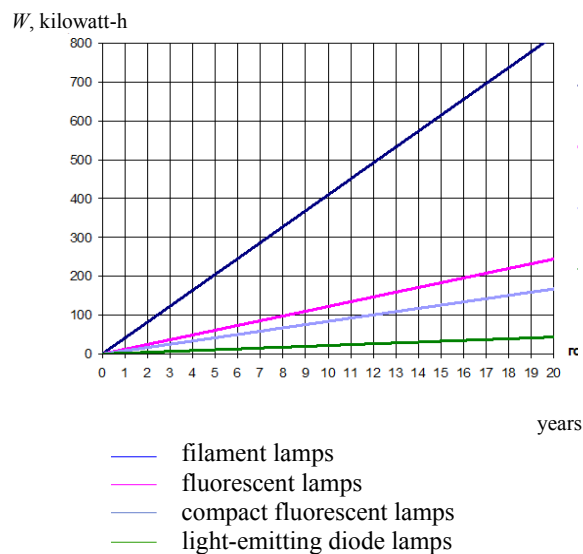


Fig. 1. Time dependence of energy consumption, $W = f(T)$

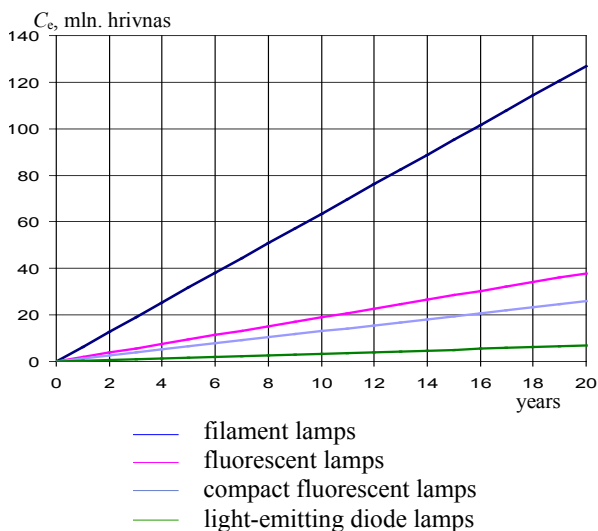


Fig. 2. Time dependence of energy cost $C_e = f(T)$
 C_i , mln. hryvnas

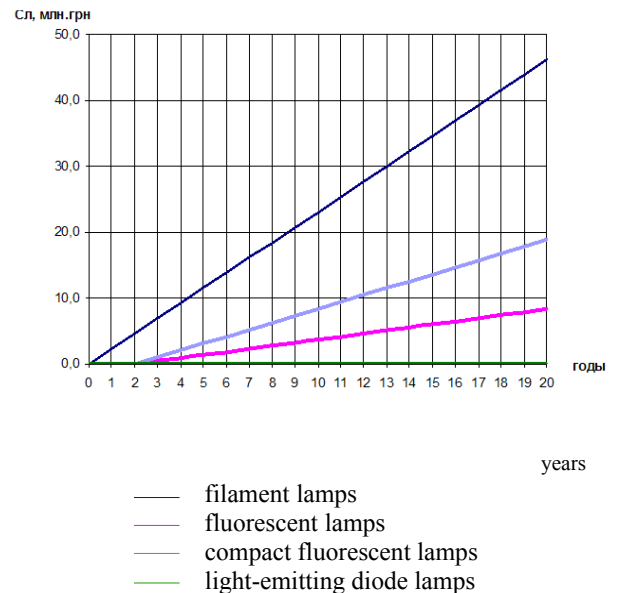


Fig. 3. Time dependence of lamp operation $C_l = f(T)$

Analysis of the works devoted to the problem under study [5–9] showed that the influence of lighting electrical receivers based on the LED light sources on a supply network is a new and little-investigated problem. Harmonic distortions and problems in electric networks caused by them are more and more urgent in the world [9] and in Ukraine, in particular, because of a poor study of the problem and a wide use of LED LSs.

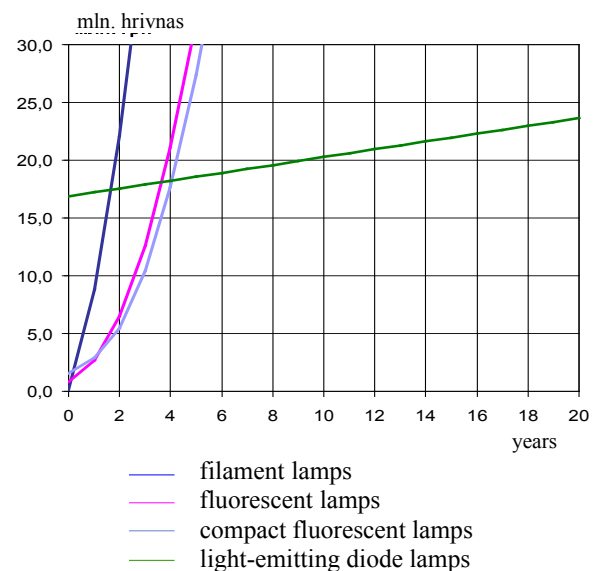


Fig. 4. Time dependence of the total cost of internal lighting lamp operation

A great number of scientists studied the problems of electromagnetic compatibility in the systems of housing and communal energy consumption. Among them the Ukrainian specialist academicians Kuznetsov V.G. and Shidlovsky A.K., professors Zhezhelenko I.V., Kurennoy E.G. and others [1-4] as well as the specialist of the near and far abroad [7, 8]. They evaluated and developed scientific and technical and methodical bases of improving energy quality in public networks for the most common, classical structure of consumers. At the same time an enlargement of the electrical receiver assortment and appearance of their new types and a nonlinear nature of their characteristics required additional investigations aimed at the estimation of modes and levels of electromagnetic compatibility of consumers and these electrical receivers.

The use of light-emitting diode light sources of high power performance, with better color and dynamic properties is connected with some specifics conditioned by a nonlinear nature of the behavior of the LED LSs themselves and by the use of light-emitting diodes of electronic transducers as a power source. The most important feature of such devices is an appearance of distortions both of the current consumed and voltage on a LED LS in the network. Side by side with some deterioration of a network energy data this is in a greater degree accompanied with the generation of disturbances which are transferred both across the network and over the atmosphere. Alongside with a reduction of the lifetime of the equipment and power lines supplying from the global buses, an increase of power and voltage losses in the networks, their presence, in the large, decreases the operation efficiency of the networks and consumers connected to them, impedes the operation of electronic, TV- and radio- and transmitting equipment, communication facilities. This is connected with the propagation of higher harmonics and current across the whole network which supplies light sources including transformers and even, at some definite conditions, further, into a higher-voltage network.

Among the consequences of current higher harmonics flow in electrical plants of 0,4 kV the following should be mentioned:

- overheating and damage of zero threads of cable line;
- additional losses in power transformers (including a failure);
- a false response of safety devices and automatic circuit breakers;
- an over-wear, swelling, and premature failure of condensers of the reactive power compensation devices;
- an accelerated ageing of wire and cable insulation ;
- deterioration of supplying voltage quality (non-harmonicity);
- operation failure and physical collapse of computer equipment ;
- a premature collapse of electric motors;
- resonance phenomena in electrical plants 0,4 kV;
- a reduction of electric plant power factor.

As evident, the task of limiting the level of harmonics in electrical networks has both a technical and economical aspects. A degree of a specific influence of a LED LSs on the processes in the public networks is determined by their joint participation in the total load of the network, if their part is small, the influence is insignificant, if the power of electrical receivers is large, their influence can mean much. That is why, an estimation of the electromagnetic compatibility of LED LSs and the network is a topical and urgent problem as in the period ahead there is expected a considerable increase of the electric power for LED lighting.

So, as the results of the analysis show the use of LED LSs in housing and communal services requires an investigation of some specifics connected with their high cost and availability of distortions in the supply network.

EXPOSITION

1. The problem of the LED LSs high cost

The cost of the available LED LS-based power systems is about \$0,1–0,05 for lumen. This is by a factor of a hundred higher than for filament lamps (**Table 1**) and this is a very serious drawback.

Table 1

Source	Luminous efficiency, lumen/Watt	Electrical power, Watt	Luminous power, lumen	Price 1 lumen, hrivnas
1	2	3	4	5
FL	12	60 (3 hrv.)	720	0.0042
FIL	80	11 (40 hrv.)	740	0.0541
CFIL	70	15 (30 hrv.)	750	0.0400
LEDL on low-power LED	60	10 (320 hrv.)	720	0.4444
LEDL on powerful LED	120	14 (320 hrv.)	770	0.4444

That is because in the routine fabrication of light items, light-emitting diodes have the largest share in the budget of manufacturing light-emitting diode devices.

The reason for that is that cases used for light-emitting diodes were developed rather long ago and in the automated packaging processes a minimum final cost of elements is secured.

But such a packaging was not designed for super-bright light-emitting diodes. The size of a component area for a crystal does not exceed 12 mm, the fit of a crystal is possible only by a classical scheme, a case structure does not provide with a necessary heat removing the absence of which results in a fast degradation of a quantum yield of a light-emitting diode chip. The use of heat-conducting packing materials causes an increase of final products cost.

Analysis of conditions of applying LED LSs in housing and communal services shows that the value of normalized lighting E is not large and there is a possibility of using low-powerful LEDs. That will allow cutting down the cost of light devices on the LED-base and will open up opportunities of their wide use in housing and communal services.

2. The problem of distortions caused by LED LSs in a network

According to the State Standard of Ukraine 61000-3-2:2005 (IEC 61000-3-2:2004, edito 2.2, IDT: Standards of harmonic flow emission [10], electromagnetic compatibility is a property of the equipment or systems to satisfactorily operate in the electromagnetic environment and not to generate objectionable electromagnetic interference to anything in this environment.

As said above, the source of electromagnetic interference in the networks is elements with non-linear behavior. Two main groups of such sources can be distinguished in the electromagnetic interference structure: electromagnetic interference (IMI) of power sources and IMI of consumers.

The reason of the occurrence of IMI of power sources is specified by a combination of circuit and operation conditions. The presence of IMI of consumers is conditioned by peculiarities of energy transformation in electrical receivers.

It should be noted that peculiarities of occurrence and the history of IMI of power sources have much in common and are well studied [11]. At the same time, peculiarities of occurrence and the character of influence of IMI of different consumers differ greatly. Most of them, especially traditional ones, are thoroughly and comprehensively studied. But for a lot of new consumers such investigations have not been carried out and this makes their operation inefficient and has a negative influence on allied consumers. Among such new and little-investigated, with regard to IMI, electrical receivers are illuminating electrical receivers made on the base of light-emitting diode light sources. Availability of an electronic transducer and a non-linear character of the light-emitting diodes cause a distortion of curves of voltage and current consumed from a network and, as a consequence, a flow of current higher harmonics along all network elements. As light-emitting diode sources and power sources are, as a rule, all-in-one-piece, then separation of interference on interference of power sources and interference of consumers is hardly reasonable within a problem under study, and recording of a feed circuit scheme can be done fully with regard to different types of light-emitting diode sources.

Standardization of harmonics. Values of distortions generated by electrical receivers of housing and communal services in a network are fixed nowadays by some documents, among them State standard of Ukraine IEC 61000-3-2:2005 (IEC 610003-3-2: 2004, editio 2.2, IDT) Standards of harmonic flow emission [10], State standard of Ukraine 4210:2003 (UT 55103-1:1996) Electromagnetic compatibility. Professional audio-, video- and audio-visual facilities and apparatus for controlling lighting facilities [12], State standard of Ukraine IEC 61000-6-2:2007 (IEC 61000-6-3: 2006, IDT) Electromagnetic compatibility. General Standards. Interference emission in housing and trade environment and in production areas with low energy consumption [13] etc. Every standard is adapted to specific operating conditions and specifies a permissible level of distortions caused by a definite type of electrical receivers.

For most electrical receivers in housing and communal services specific operating conditions a permissible level of distortions are known [1, 3, 5]. Modern electrical receivers of a non-linear behavior require standards of higher harmonics emission to be estimated and a degree of their compliance in specific operating conditions to be examined. For lighting electrical receivers based on light-emitting diode sources interference standardization is regulated by State standard of Ukraine IEC 61000-3-2:2005 depending on the power P_{LU} and a lighting unit power factor λ_{LU} . Numerical values of the harmonic current components of lighting units are given in **Table 2**.

Maximum allowed value of current harmonics for lighting units of more than 25 Watt* according to State standard of Ukraine 61000-3-2:2005 [10]

Table 2

Harmonic number, n	Maximum allowed value of current harmonics in % of the basic harmonic
1	2
3	$30 \cdot \lambda_{CII}$
5	10
7	7
9	5
11	3
$13 < n < 39$	3

* For lighting units of the power less than 25 Watt there are standardized only the values of 3rd and 5th harmonics which should not be higher than 86% and 61%, respectively, of the main harmonic current

3. Evaluation of electromagnetic compatibility of light-emitting diode light sources.

To evaluate a level of distortions caused by light-emitting diode light sources in a network and a necessity of their record in the construction of lighting units on the base of light-emitting diode light sources the authors performed the experimental research of curves of current consumed by light-emitting diode light sources out of a network. Root-mean-square voltage U_I and current I_I were measured with the help of the instrument of an electromagnetic system, and the form and a harmonic composition of a network current curve $i_C = i_L$ were investigated with the help of the instrument «Power monitor 3.3». The scheme of the experimental bedstead is given in **Fig. 5**.

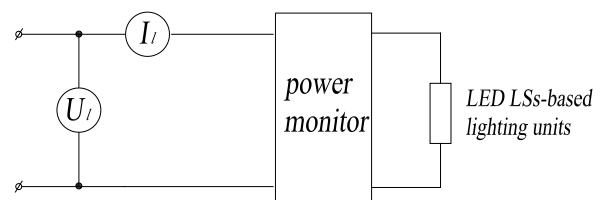


Fig. 5. The scheme of the experimental unit

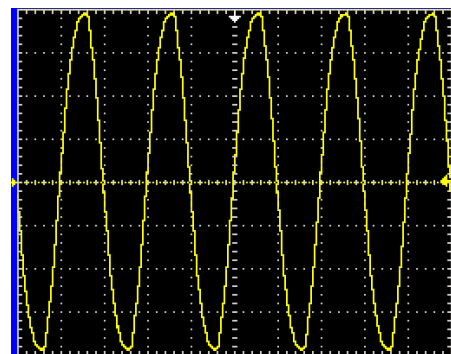
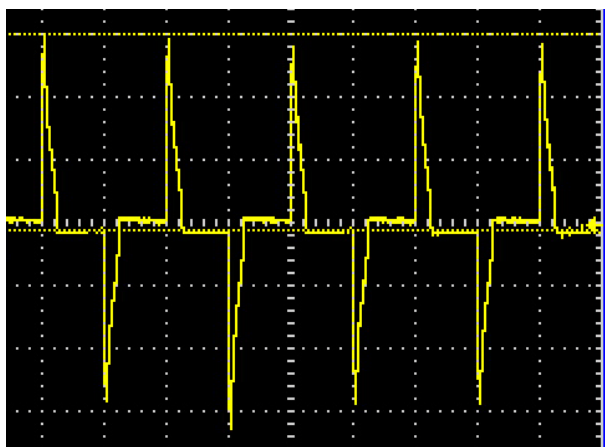


Fig. 6. The voltage curve of the LED LSs-based lighting units

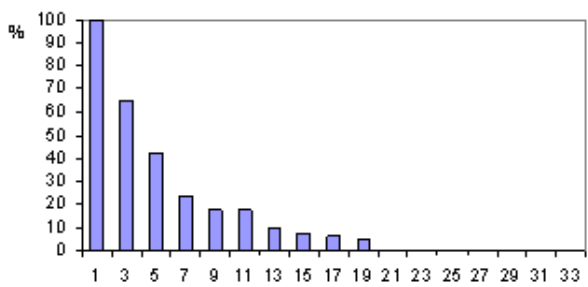
Light-emitting diode light sources SDK-27 and SDP-27 with pulse-duration modulation (PDM) and without it were used as light sources. Voltage curve $u_L = u_C$ is given in **Fig. 6** for both type of illuminating lamps. The forms of lamp current $i_L = i_C$ are given in **Fig. 7a–10a**, respectively, and their harmonic composition – in **Fig. 7b–10b**.

Analysis of the experimental research results shows that the level of higher harmonics of the curve of the current consumed out of a network of lighting units based on LED LSs is close to the levels specified the State standard of Ukraine. First of all this refers to

single lighting units like SDP-27, SDP-27-PDM and SDK-27-PDM provided that their power is not more than 25 Watt. If the total power of lighting units is more than 25 Watt, the specifications of the State standard of Ukraine are more severe and almost all lighting units do not meet them; the only exception is the lighting units SDK-27 whose data are at the breaking point.

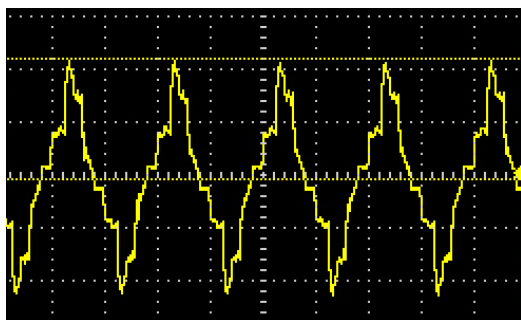


a)

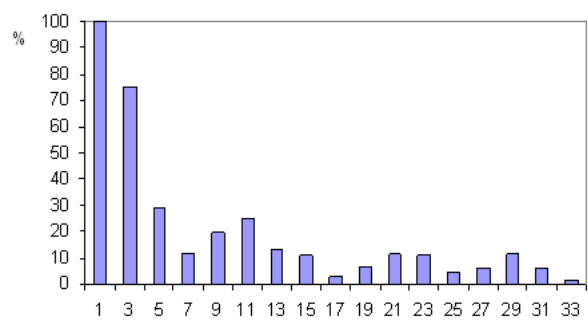


b) harmonic number

Fig. 7. Harmonic composition of the current curve of the lighting units like SDP-27-PDM with PDM ($K_{HC}=85.87\%$): a) a curve forve; b) levels of harmonics

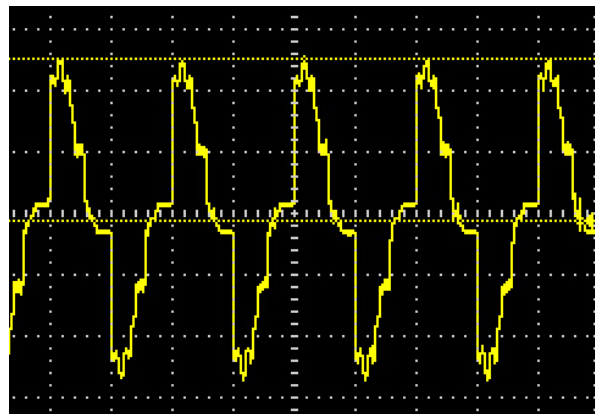


a)

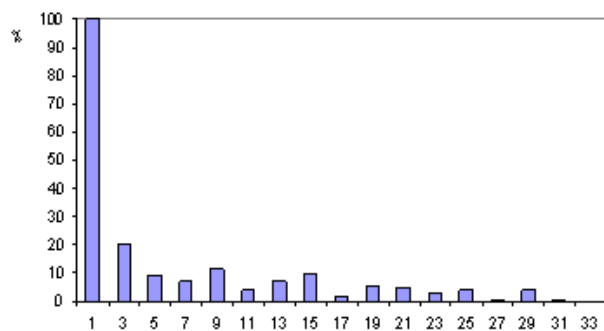


b) harmonic number

Fig. 8. Harmonic composition of the current curve of the lighting units like SDP-27 without PDM ($K_{HC}=91.9\%$): a) a curve forve; b) levels of harmonics



a)



b) harmonic number

Fig. 9. Harmonic composition of the current curve of the lighting units like SDK-27 without PDM ($K_{HC}=31.09\%$): a) a curve forve; b) levels of harmonics

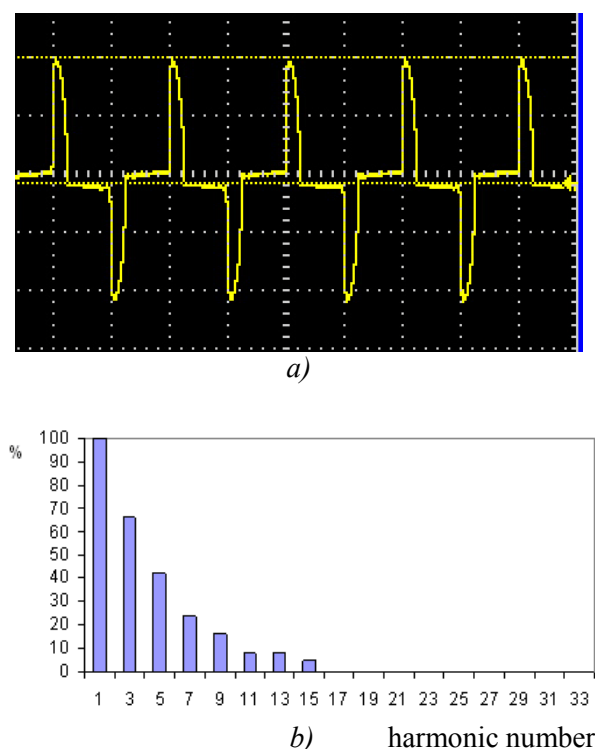


Fig. 10. Harmonic composition of the current curve of the lighting units like SDK-27-PDM with PDM ($K_{HC}=31,09\%$):
a) a curve forve; b) levels of harmonics

The above said requires the use of special measure to reduce the level of higher harmonics in the networks with light-emitting diode light sources, especially if their total power is more than 25 Watt.

4. Ways of reducing the level of higher harmonics in lighting networks

Harmonic distortions can be suppressed in lighting networks if harmonic filters are used. In its classical form a filter is a series of a condenser and inductance which are adjusted to a definite harmonic frequency. Theoretically a filter resistance is equal to zero at a resonant frequency, therefore harmonic current is absorbed by the filter. This effect together with a line resistance means that in such a way one can easily suppress harmonic in a network.

Types of filters

Any filter efficiency depends on its reactive power, tuning accuracy, and network impedance in a draw-off point. Harmonics which are lower than a filter resonant frequency will become stronger. A filter circuit design is important to be sure that distortions will not become stronger than normal levels. When some different series

of harmonics are present in a network, we can suppress some of them and intensify the others. The 7th harmonic filter draws an inverse resonance at the frequency of the 5th one and intensifies it, so the 7th harmonic filter should be complemented with the 5th harmonic filter. So, in actual conditions one should apply some filters each adjusted to its frequency (**Fig. 11**). As the results of the performed analysis showed, for the conditions under study these are the filters of the 3rd, 5th and 7th harmonics, at the minimum.

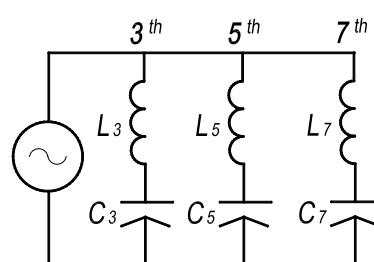


Fig 11. A shunt filter

Depending on the place of a filter placing compensation can be individual (performed on a single electrical receiver), group (performed on a group of electrical receivers) or centralized (performed on a central substation). Suitability of this or that method of compensation is evaluated on the base of a technical and economic comparison of the variants. The assessments done by the authors show that the most effective is an individual compensation of higher harmonics by installing filters of the 3rd, 5th and 7th harmonics straight into a lighting unit.

CONCLUSION

1. The result of a comprehensive investigation of the power-supply and lighting system of a building made it possible to determine a prospect of growth of the power consumers number on the base of LED LSs and the problems characteristic for them.

2. The analysis carried out made it possible to determine cause-and-effect relations of higher harmonic occurrence and the character of their flow in lighting electric networks with light-emitting diode light sources.

3. The experimental research performed let us find out that the values of higher harmonics in the networks with light-emitting diode light sources are at the limiting level and in

some case require the development of special measures to reduce them.

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