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Review and Results of Studies of the Harmonic Structure of the Current of Lighting and Household Electricity Consuming Devices and Their Negative Impact on the Distribution Networks of Electric Power Systems

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Key words: The highest harmonic components of current, compact fluorescent lamps, LED lamps, LED luminaries for street lighting, induction luminaries for street lighting, household non-linear electrical loads

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Abstract: Load in the utility network is predominantly non-linear and generating the highest harmonic components of current in the electrical power network, increases in the overall structure of electricity consumption. The results of experimental measurements and calculations for a number of household consumers as well as information from literature sources noted in the article indicate that the operation of modern appliances in electrical power networks generates sufficiently large currents of higher harmonic components of 3, 5, 7 and 9 orders of magnitude. The main share of emission of the current harmonic components in the city electrical power system networks is made by recreational and household appliances (computers, laptops, printers, TVs, etc.). Continuous growth of the specified capacity of nonlinear asymmetric and sharply variable loads in the electric power networks is not followed by timely implementation of solutions aimed to improve the quality of electrical energy, so, in recent years, the task of improving the quality of electricity associated with reducing the impact of higher harmonic components on the operation of electrical equipment is becoming more and more urgent and important. The listed measures and technical means of influence reduction of the higher harmonic components are considered in the article in details.

INTRODUCTION

Recent changes have taken place in electricity consumption related to the use of a wide range of different household electric devices using the DC voltage for it's functioning obtained by rectifying the AC voltage and smoothing it out with the help of a capacitive filter[1, 2]. The implementation of these kind of devices worsens the quality of electrical power in electrical networks[1].

Modern electronic equipment used in everyday life, in most cases, appears to be a non-linear electrical load for the electrical power system, therefore it consumes non-sinusoidal current that creates distortions in the

electric grid and as a consequence, distortion of voltage which affects other equipment that receives electricity from a common source[3, 4]. The issue with electricity consuming devices that distort the quality of electrical energy is continuously degrading[5]. The significant deterioration in the quality of electric power in the networks of non-industrial consumers-shopping malls, office buildings, educational institutions, residential buildings has been observed in recent years[6]. The load in the utility grid is predominantly non-linear and every year related share of such load which generates the highest harmonics of current in the electricity network, increases in the overall combination of electricity consumption[7]. The number and characteristics of nonlinear household electricity consuming devices change and consequently, the harmonic structure of currents and voltages[5]. Degradation in the quality of electricity in urban distribution networks is typical for most developed countries[8,9] because there are fewer and fewer electricity consuming devices with linear volt-ampere characteristics.

The origination of harmonic components of current and voltage is related with the use of electric devices with integrated pulse power supplies which are based on power semiconductor switches[10] and represent non-linear loads (computer equipment, consumer electronics, energy-saving lamps), the resistance of which varies over the time[11, 12]. The higher level of the highest harmonic components is typical for networks where a large number of household and office electronic devices are used, among which are actively introduced LED as well as energy-saving gas discharge compact fluorescent lamps, since in the modern balance of electricity consumption the lighting load reaches 20-23% and taking into account the architectural lighting 30%.

Continuous growth of the specified capacity of nonlinear asymmetrical and sharply variable loads is not accompanied by timely implementation of solutions intended to correct the quality of electrical energy[12]. Harmonic components of the current of various sources cause the corresponding harmonic components of voltage at the combined resistance of the electrical power network[13]. Each individual household electricity consuming device affects the network insignificantly but their combination has a significant impact on the electrical distribution network[14] because with the power of non-linear load, not exceeding 10-15% of the capacity of the electrical power system, significant changes in the operating mode of the system are not perceptible but with the share of non-linear load in the power networks exceeding 25% there are negative and sometimes even emergency conditions[15, 16].

MATERIALS AND METHODS

As the analysis indicates, there has been a recent tendency of predominance of the highest harmonic components of the current of small nonlinear electrical consumers over the highest harmonic components of high power consumers. In connection with the recent growth of the acting household appliances number, the expected trend is a gain of the highest harmonic components influence by consumers on operation of the grid up to 1000 V[17].

In consideration of the above, the interest is to analyze the regulatory documents governing the standards for the quality of electrical power in terms of harmonic components of voltage and current. USA codes such as IEEE 519 (Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems) and IEEE P1495 (Guide on Harmonic Limits for Single-Phase Equipment) do not impose specific limits on the content of the highest harmonic components for single-phase loads with currents >40 A. At the same time, the IEEE 519 code divides loads into two classes[8].

High-power non-linear loads such as pumps and chargers as well as low-power devices such as computers and electronic ballasts concentrated in large quantities in one room. The power factor of not <0.95, the total harmonic component coefficient of not >15%, the content of the 3rd harmonic component in the consumption current of not >10% are limited for such loads.

Low-power devices that are not concentrated in one place. The total harmonic component ratio of no >30% and the 3rd harmonic component in the consumption current of no >20% are limited for such loads.

The IEEE 519 also assumes limitation of the harmonic components of the grid voltage for the total harmonic component ratio to 5% and for the individual harmonic components to 3%[8].

The code of the European Committee for Standardization in the field of electrical engineering, in particular IEC 61000-3-2 (Electromagnetic compatibility (EMC)-Limits for Harmonic Current Emission (equipment input current <16 A per phase)), regulates the overall harmonic component ratio and power factor. The total harmonic component ratio for luminaires must be <33% as well as the power factor must be >0.95. There are no limits for devices with an active power of <25 W in the code. This means that there is no regulation of harmonic components for LED and compact fluorescent lamps with integrated electronic ballast controls just yet[18].

The regulation of harmonic components for devices with a current of 16-75 A per phase is specified in the code IEC/TS 61000-3-12. Parameters of the grid voltage supplied by public distribution networks are specified in EN 50160. At this time GOST 32144 (Electric power quality standards in general-purpose electrical power

systems) is in force in the Russian Federation[7]. The present code is intended for application at an determination and standardization of quality indicators of the electric energy related to characteristics of voltage of the electric power regarding frequency, values and the form of voltage and also to symmetry of voltage in three-phase electrical power systems.

Indicators of the electrical energy quality related to the harmonic components of the voltage are: values of coefficients of voltage harmonic components up to the 40th order (KU(n)) as a percentage of the voltage of main harmonic component (U1) at the point of transmission of electrical energy.

The value of the Total Harmonic Distortion (THDU) of the voltage (ratio of the RMS value of the sum of all harmonic components up to the 40th order to the RMS value of the main component) KU, % at the point of transmission of electric energy. Measurements of harmonic component voltage (U(n)) shall be performed in compliance with the requirements of Russian Federation codes (GOST) 30804.4.7.

Concerning the field of sinusoidal current curve distortion, Foreign producers focus on the general non-sinusoidal coefficient. In this case, it is undoubtedly cheaper to keep the total factor of harmonic components within the norm due to a general reduction in the level of other harmonic components in the presence of a sharp excess of current emission of one of the harmonic components[19]. In the Russian Federation norms such an approach is excluded due to the other arrangement of the requirements.

Norms of harmonic components emission of consumed current for various electrical equipment, including lighting equipment are regulated in the Russian Federation in compliance with GOST 30804.3.2 (Emission of current harmonic components by technical means with current consumption not exceeding 16 A in one phase)[2] and IEC 61000-3-12 (Norms of current harmonic components created by equipment connected to public low-voltage systems with an input current of >16 A but not >75 A in one phase).

GOST 30804.3.2 as well as the European code IEC 61000-3-2, applies to electrical, electronic and radio electronic equipment with current consumption not exceeding 16 A (in one phase), intended for connection to low-voltage distribution networks. Indicators of the quality of electrical energy related to the current harmonic components are.

Effective value of the higher harmonic components of the current: RMS value of the sum of the current harmonic components (In) of the order from 2-40. Total Harmonic Component Index (THDI): a ratio of the RMS value of the sum of all harmonic components of the current (In) of the order of 2-40 to the RMS value of the main component (I1).

In compliance with GOST 30804.3.2 the lighting equipment belongs to the class “C”. For this class, the code establishes standards for the current harmonic components which must not be exceeded in the operation of lighting equipment. For lighting equipment with power <25 W, the code gives slightly different standards of the current harmonic components[20]. Permissible levels of the power voltage interharmonic components which increase due to the use of frequency converters and other control equipment in electrical installations are under current consideration.

Thus, as the analysis of normative documents has revealed, in the Russian Federation only voltage harmonic components are regulated in electrical power systems, while the highest harmonic components of current are not regulated. However, their level needs to be controlled as they cause the following undesirable impacts.

Occurrence of overheating and destruction of neutral operating conductors of supply lines because multiple of the third harmonic components in three-phase circuits are coinciding in phase and create a null sequence[21]. Calculations for large public and industrial facilities power grids demonstrate that the current in the neutral conductor can be from 150-210% of the phase current.

Distortion of the supply voltage, due to the fact that the supply current was distorted by a nonlinear load, causes a distorted voltage drop in the electrical network. As a result, voltage with a distorted form is applied to all other loads included in the same electrical network which leads to the formation of harmonic components of currents flowing through them, even if they are linear. Origination of additional losses in transformers and motors from the flow of the highest harmonic component currents as well as their overheating towards to failure[22]. The current highest harmonic components originate additional losses in the windings of transformers and additional losses on vortex currents in the magnetic circuit. Additional losses also occur in rotating machines on the stator and in the rotor due to the difference in frequency between the harmonic rotating fields and the rotor. All of this leads to a reduction of the efficiency of the processes of transmission and use of electrical power.

Increased wear, swelling and premature destruction of capacitors of reactive power compensation units, because the non-sinusoidal current flowing through the capacitor batteries causes losses that cause their heating which can cause dielectric breakdown and then the capacitor failure. Reduced design life of electrical

equipment and networks from accelerated thermal and electrical aging of insulation, due to additional losses resulting in overheating.

False tripping of fuses, circuit breakers, RCDs, relays and electronic units, due to additional heating of the internal elements of protection devices and faulty operation of sensitive measuring and control devices in the event of non-sinusoidal currents.

The interference in telecommunication networks[23], if the power and telecommunication cables are laid close to each other because the flow of currents of the highest harmonic components can cause interference and noise in telecommunication networks. As a consequence, the operation of remote control systems is affected and there are observed malfunctions in operation and failures of computer hardware.

Resonance effects in 0.4 kV electrical equipment, appearing at increase of currents and voltages of harmonic components due to parallel and series resonances. Decrease of power factor of electrical equipment. Increase of resistance of grounding elements because when zero sequence currents flow through them they are dried. Increased acoustic noise in electromagnetic equipment, due to the occurrence of ferro-resonance associated with a high value of harmonic components of the current[15, 16].

The overestimation of the required power of electrical equipment at the design stage in order to overcome undesirable consequences, noted above associated with the appearance of additional losses from the flow of currents of the highest harmonic components. The increase of voltage drop in the supply wires due to the skin-effect that occurs for currents of the highest harmonic components.

These examples demonstrate the importance of considering the harmonic components of current in electrical networks. The risk of such troubles in the electrical power systems of buildings for various purposes (production, commercial, office, residential, etc.) in our country is much higher than in European countries. This is due to the fact that the problem of harmonic components is known in the West and technical means are used to solve it.

As mentioned earlier, up to 30% of the total amount of electricity produced is spent on electric lighting, so, the active use of new energy-saving technologies in lighting leads to a reduction in total energy consumption. According to FA-261, facilities and organizations are obliged to switch to new energy-saving technologies. Therefore, one of the main steps taken by the authorities in the field of energy saving is the replacement of Incandescent Lamps (ILs) with Compact Fluorescent Lamps or CFLs or they are also called Energy Saving Lamps (ESLs)[24].

A CFL is a lamp twisted in a spiral or snake shape in the base of which the electronic ballast is placed to enable it to start. Switching to energy-saving light emitters such as CFLs has resulted in significant energy savings, since, CFLs consume 25% of their electricity to produce light. However, energy-saving lamps (as opposed to incandescent lamps) are non-linear consumers of electricity producing the highest harmonic components of current in the network[22] which in its turn leads to the appearance of the highest harmonic components of voltage in the electrical network.

Nonlinearity of electric energy consumption of CFL is related to the fact that for its operation an electronic semiconductor circuit (electronic ballast) is used. Actually CFL can be divided into two parts. The first is the electronic ballast resistance and the second is the fluorescent tube. Nonlinearity of the CFL is also connected with the fact that the luminescent tube is a nonlinear load itself and the harmonic emission of electronic ballast with a luminescent tube is higher than that of electronic ballast with a linear active load.

According to the literature, the harmonic structure of CFLs represents an extremely nonlinear load. Especially distorted is the current curve which is characterized by clear peaks in each half-period. The harmonic structure of the current has the form of a modulated exponent with predominance of odd harmonic components. The spectral composition of the current demonstrates that in addition to the main one, the currents of the 3, 5, 7 and 9 harmonic components prevail. The other harmonic components can be neglected. The current of the 3rd harmonic component is predominant in the spectral composition.

To implement effective measures to improve the quality of electrical energy and increase the efficiency of electricity distribution in the networks of 0.38 kV it is necessary to study the harmonic structure of the consumed current. One of the effective ways to obtain such information is experimental research. Oscillograms obtained as a result of experimental studies allow to analyze the spectral composition. To analyze the spectral composition of the consumed current, the Fourier series decomposition is used which contains the first harmonic component ensuring normal consumption as well as the higher harmonic components. The results of the experimental measurements given below are obtained with the help of the electric energy quality analyzer from Metrel. The spectral composition calculated on the base on the obtained oscillograms and the results obtained by the electric energy quality analyzer are practically identical.

RESULTS AND DISCUSSION

The results of experimental measurements and calculations of emission of the highest harmonic

Table 1: The results of experimental measurements and calculations of emission of the highest harmonic components of the current by modern commercially produced CFLs

Sample No.	P_u, W	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the 3rd, 5th, 7th, 9th and 11th harmonic components of the current to the formation of THD_I (%)
1	13	88.6	69.7	44.4	29.5	25.7	**140.5**	90.6
2	15	28.2	27.6	16.2	16.1	10.5	**63.1**	74.0
3	15	78.1	50.9	26.7	21.8	19.2	106.4	95.2
4	15	82.4	57.3	34.5	24.6	20.4	118.8	93.3
5	20	62.1	33.3	32.3	15.2	6.4	84.1	94.2
6	20	64.8	37.8	31.3	13.2	7.4	86.2	95.9
7	20	76.6	47.9	25.1	21.1	18.4	103.9	94.2
8	20	83.6	56.4	31.7	21.6	19.9	115.2	95.3
9	23	77.3	45.6	24.5	21.3	16.5	102.6	94.4
10	25	74.1	45.0	24.2	21.1	16.1	101.1	92.9
11	30	64.4	35.5	29.2	12.3	6.6	83.3	96.4
12	30	71.5	43.0	36.7	27.5	13.2	98.2	97.9
13	30	87.4	61.9	35.7	22.9	20.4	122.8	95.3
14	125	76.2	49.9	42.4	38.4	26.4	114.4	96.8
Average values		72.5	47.3	31.1	21.9	16.2	102.9	93.3

Bold values are significant

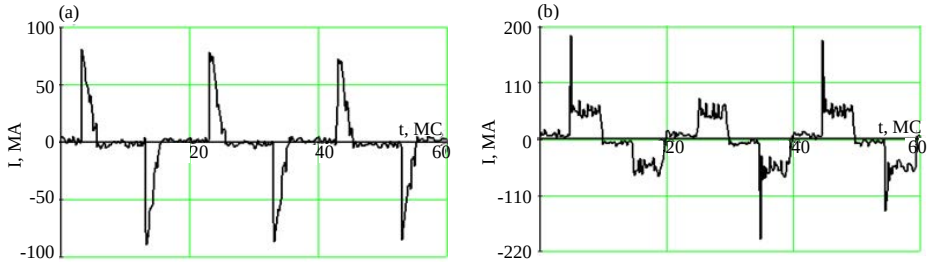

Fig. 1: Oscillogram of instantaneous values of the current of CFLs (Table 1), (a) Sample No. 1 and (b) Sample No. 2

components of the current by modern commercially produced CFLs are given in Table 1. As follows from Table 1, the largest THDI was obtained for the sample of CFL No. 1 with power of 13 W. Oscillogram of instantaneous values of this sample current is demonstrated on Fig. 1a. It also follows from Table 1 that the smallest THDI was obtained for CFL sample No. 2 with power of 15 W and the oscillogram of instantaneous current values of the sample is demonstrated on Fig. 1b.

In general, the results of the study of CFL samples correspond to the data given in the literature[7, 12, 13, 14, 21] earlier. However, we can add that the average value of the total harmonic components of the current of the studied CFLs is approximately 103% that indicates that the RMS value of the sum of all harmonic components up to the 50th order is equal to the value of the main component which is very significant. Also, in addition to the 3, 5, 7 and 9 harmonic components, the 11th harmonic component prevails which is not much inferior in value to the 9th harmonic component. On average, the sum of the contribution of the above mentioned dominant harmonic components in the formation of the THDI value is 93%.

Thus, the use of CFLs, despite their advantages, creates distortions with frequency components multiple of the basic harmonic component. Analysis of the modes of three-phase four-wire networks, the main loads of which are CLLs, demonstrates that a serious issue with such networks are the high values of the neutral wire currents, even under a symmetric load[20]. As mentioned above, this is due to the predominance of the 3rd harmonic component in the spectral composition of the current. In this connection, the growth of the use of CLLs as energy-saving light emitters, instead of incandescent lamps will have a huge negative effect on the electric power system and may lead to serious impact on the reliability of electric power.

The evolution of semiconductor technology has stimulated the transition to lighting systems using LED emitters[20, 25]. In this regard, recently CFLs have been gradually replaced by Light Emitting Diode lamps or LED lamps[26-28]. LED lamps are preferred to incandescent and CFL lamps because of their high fluorescent efficiency, durability, reliability, small size[29], lower power consumption and environmental friendliness in terms of mercury content[30]. With LED lamps, 80% of electricity

Table 2: The results of experimental measurements and calculations of emission of the highest harmonic components of the current by modern commercially produced LED lamps

Sample No.	P_n, W	Colour temperature K	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the 3rd, 5th, 7th, 9th and 11th harmonic components of the current to the formation of THD_I (%)
1	20	2700	86.6	64.3	44.9	35.4	30.3	133.7	94.1
2	12	2700	77.1	44.3	25.4	20.2	11.4	96.6	98.7
3	12	2700	87.4	65.6	47.4	37.2	31.0	138.9	92.6
4	12	4000	78.8	53.8	32.4	25.8	21.4	109.8	96.7
5	12	4000	80.4	59.6	37.8	23.8	21.2	118.2	94.4
6	12	6400	87.7	66.3	46.6	35.7	29.9	137.8	93.0
7	10	2700	87.6	64.3	39.3	20.9	17.2	121.5	97.6
8	10	2700	83.4	57.5	39.3	33.4	27.0	125.5	93.1
9	10	4000	90.0	70.1	47.3	27.7	18.7	132.7	96.5
10	9	6400	86.1	64.9	47.2	40.3	38.2	140.3	92.7
11	7	2700	46.9	18.3	18.9	11.3	8.9	57.2	97.3
12	7	2700	49.2	20.0	19.6	13.7	8.1	63.5	92.5
13	7	2700	90.2	70.6	51.8	39.6	35.9	**148.8**	91.8
14	7	2700	88.4	67.9	47.9	37.9	36.1	145.8	90.6
15	7	4000	85.0	60.7	41.0	34.4	31.6	131.1	92.7
16	7	4000	47.9	17.6	18.1	11.2	10.0	57.6	97.5
17	7	6400	90.1	70.1	50.4	36.1	29.8	139.9	95.2
18	7	6400	86.7	65.5	44.5	34.0	30.9	133.6	94.4
19	5	2700	43.4	20.2	16.4	7.9	11.7	56.6	92.9
20	5	4000	30.2	17.7	7.4	8.4	3.8	**39.7**	93.1
21	5	4000	41.9	20.3	14.6	9.2	11.6	53.5	95.4
Average values		73.6	50.5	35.2	25.9	22.1	108.8	94.4	

Bold values are significant

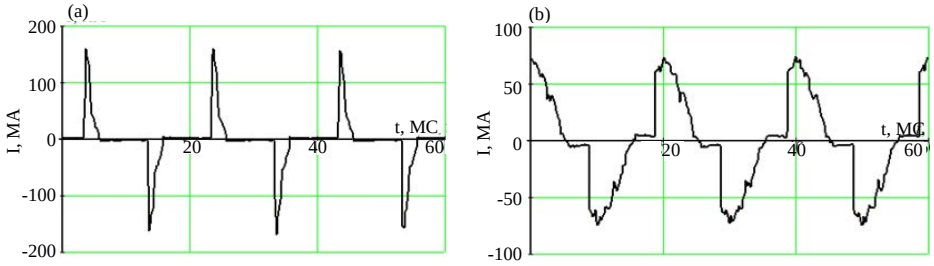

Fig. 2(a, b): Oscillograms of instantaneous values of the current of LED lambs (Table 2), (a) Sample No. 13 and (b) Sample No. 20

consumption is used to produce light. Also LED lamps, unlike CFLs, are characterized by all the attributes of devices capable of being controlled through computer interfaces including wireless cell-based technologies, i.e., address control. However, for address control of LED lamps it is necessary to use additional power supply units which increase the cost of products and are additional sources of harmonic components of current.

The LED lamp consists of light emitting diodes and an electronic driver. Its main purpose is to convert AC grid current into direct current required for the operation of light-emitting diodes[30]. And although LED lamps have low power consumption and provide high fluorescent efficiency[8], at the same time they have a pulse nature of power consumption, a wide range of harmonic components and low electromagnetic compatibility with the electric power network. In this regard, the connection of a large number of LED lamps can cause issues in the power system associated with a significant amount of harmonic components of their current consumption[30]. The amplitude spectrum of the LED lamp current is characterized by an extremely high level of the highest harmonic components. The dominant components are 3, 5, 7 and 9th harmonic components.

The results of experimental measurements and calculations of emission of the highest harmonic components of the current by modern commercially produced LED lamps are given below in Table 2.

As follows from Table 2, the largest THDI was obtained for the sample of LED lamp No. 13 with power of 7 W. Oscillogram of instantaneous values of this sample current is demonstrated on Fig. 2a. It also follows

from Table 2 that the smallest THDI was obtained for LED lamp sample No. 20 with power of 5 W and the oscillogram of instantaneous current values of this sample is demonstrated on Fig. 2b.

In general, the conclusion which might be made based on the results of the study of LED lamp samples is corresponding to the information given in the literature[6, 14, 20, 26, 30], mentioned earlier. However, we can add that the average value of the total harmonic components of the studied LED lamps current is about 109% which indicates that the RMS value of the sum of all harmonic components up to the 50th order is equal to the value of the main component that is very significant and slightly higher than the same indicator for CFL. Also in addition to the 3rd, 5th, 7th and 9th harmonic components, the 11th harmonic component is not much smaller than the 9th harmonic component. On average, the sum of the contribution of these dominant harmonic components in the formation of the THDI value is 94%. It should be noted that the THDI value of different LED lamp samples is significantly different and ranges from 40-150% while for CFLs it is less variable.

Nowadays CFL lamps are being replaced by LED lamps gradually and in many cases these lamps work together in the same luminaires in domestic, commercial and industrial environments all over the world[31]. The amplitude of harmonic distortion of CFLs differs significantly from that of LED lamps. However as indicated in the literature[26, 31], studies performed for various combinations of CFLs and LED lamps, demonstrate a significant reduction in the current of the third harmonic component due to the effect of intercompensation.

At the same time, the mass transition to energy-saving light emitters instead of incandescent lamps in addition to a significant reduction in power consumption for lighting, will further increase the deterioration of electrical power networks with the highest harmonic components of current.

With the evolution of semiconductor technology, it has become apparent that the reduction of electric energy consumption in outdoor lighting should be achieved not only by partially or completely turning off lights in lighting installations but also through the wider introduction of highly efficient light emitters and luminaries with a rational distribution of light. Such requirements are met by light emitting diode luminaires (LED luminaires).

High-pressure sodium lamps are now used in virtually all areas of modern lighting technology[32]. They are produced in a wide range of capacities with different levels of fluorescent efficiency. However, the possibility of using high-capacity Light Emitting Diode Luminaries (LEDL) for street lighting is growing continuously due to their higher energy efficiency, reliability, durability and ease of operation[33, 34].

A LEDL, like an LED lamp, consists of light-emitting diodes and a solid-state power supply (SSPS) called a driver or control unit. With all the apparent diversity the circuit solutions of modern drivers from leading world manufacturers, in general are the same. In fact, the differences in SSPS circuits are mainly in the control circuitry and in the type of high-frequency noise suppression filter used, since, the other components have been developed to a degree that they are practically unified.

The electrical parameters of SSPSs of different companies are almost identical: Efficiency-86-94 %; power factor as usual is not <0.95. The content of the higher harmonic components in the consumed current is usually not <15%. However, with the beginning of implementation of LEDL, it turned out that SSPS have exceeded the emission of components of the operating current in the range of higher harmonic components. And as a consequence, the main challenge in creating a system of street lighting with LEDLs has become the calculation of the electromagnetic condition of the electric power network of the illuminated area in terms of the harmonic components of the current generated by SSPSs of used luminaires, on the one hand and the presence of non-sinusoidal current in the electric power network-on the other[34].

Table 3 presents the results of experimental measurements and calculations of emission of the highest harmonic components of LEDL current with nominal power of 72 W, widely used for street lighting. The data given in Table 3, reflect the value of emission of the highest harmonic components of the current in the voltage range of 220 V±10% which meets the requirements of GOST 32144 for the voltage deviation. The oscillogram of instantaneous values of the LEDL current at 220 V is demonstrated on Fig. 3.

The following conclusion can be made based on the results of experimental measurements and calculations of emission of higher harmonic components of the LEDL current. The average value of the total value of the harmonic components of the LEDL current is approximately 21% which is significantly lower than the same indicator for household LED lamps and is explained by the use of SSPS in the design of LEDL. However, this value is higher than the maximum value of 15% stated in the literature. The spectral composition of the LEDL current shows that in addition to the main one, the currents of the 3, 5, 7 and 11 harmonic components prevail, so, the rest can be neglected. The current of the 3rd harmonic component is predominant in the spectral

Table 3: The results of experimental measurements and calculations of emission of the highest harmonic components of the current by LEDL, intended for street lighting with a rated power of 72 W

Sample No.	U, V	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the 3rd, 5th, 7th, 9th and 11th harmonic components of the current to the formation of THD_I (%)
1	246.9	16.3	11.7	5.30	0.4	4.4	22.1	95.9
2	244.8	15.9	12.1	5.70	0.9	4.1	21.9	96.7
3	240.2	14.2	11.5	6.20	1.6	3.9	20.6	95.4
4	240.1	13.4	11.6	7.30	2.7	4.7	20.9	94.3
5	239.6	14.4	11.4	6.04	1.6	4.3	20.6	95.8
6	222.8	14.8	10.8	7.40	2.6	4.8	21.4	94.9
7	222.4	14.8	11.0	6.80	1.8	4.6	21.2	95.3
8	220.6	14.6	11.2	7.00	1.7	5.0	21.2	95.8
9	220.5	14.1	10.7	6.70	1.9	4.6	20.4	95.5
10	220.0	15.1	11.6	6.30	1.4	3.9	21.3	95.8
11	207.0	14.7	10.7	7.20	1.8	4.6	21.1	95.2
12	202.6	14.9	10.3	7.20	2.5	5.0	21.4	93.9
13	200.7	15.2	10.5	6.80	1.8	4.8	21.5	94.2
14	199.8	16.6	10.6	5.90	1.6	4.4	21.9	95.7
Average values		14.9	11.1	6.60	1.7	4.5	21.3	95.3

Table 4: The results of experimental measurements and calculations of emission of the highest harmonic components of the current by IL, intended for street lighting with a rated power of 150 W

Sample No.	U, V	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the 3rd, 5th and 9th harmonic components of the current to the formation of THD_I (%)
1	242	4.02	3.04	0.64	1.69	0.29	5.75	92.50
2	220	3.15	2.74	0.77	0.86	0.43	4.90	87.04
3	198.2	3.29	2.65	0.40	1.30	0.70	4.92	89.98
Average values		3.49	2.81	0.60	1.28	0.47	5.19	89.84

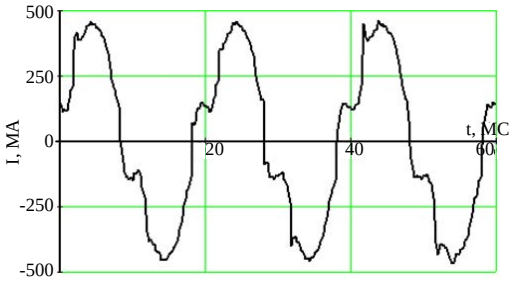

Fig. 3: Oscillogram of instantaneous values of the current of LEDLs with rated power of 72 W, intended for street lighting in the grid power of 220V AC

composition. Unlike for LED lamps, the current of the 9th harmonic component is insignificant. On average, the sum of the contribution of the specified dominant harmonic components in the formation of the THDI value is 95%. It should be noted that the THDI value of the LEDLs tested in the voltage range of 220 V±10% changes slightly.

In an effort to reduce the current harmonic component coefficient of the LEDL current, it is proposed to use the LLC resonant filter on board of the driver which is designed to ensure clear switch-over on two switches and rectifier diodes to reduce their switching losses. The proposed filter will allow to reduce the harmonic components and thus the value of total harmonic distortion to the value of THDI<10% as well as a high coefficient of reactive power at the level of 0.99[35].

As an alternative to the use of LEDL for street lighting, in terms of reducing the value of the harmonic component of current can be the use of luminaires with electrodeless discharge lamps in which the primary source of light is plasma, originated from the ionization of the gas with a high-frequency magnetic field, known as Induction Luminaires (ILs). Table 4 presents the results of experimental measurements and calculations of emission of the highest harmonic components of the IL current with nominal power of 150 W, used for street lighting. The information given in Table 4 reflects the value of emission of the highest harmonic components of the current in the voltage range of 220 V±10 %. Oscillogram of instantaneous values of IC current at 220 V is demonstrated on Fig. 4.

As follows from Table 4, the average value of the total value of the harmonic components of the IL current is approximately 5% which is 4 times less than the same value for LEDL. The spectral composition of the IL current demonstrates that in addition to the main, the currents of the 3, 5 and 9 harmonic components prevail,

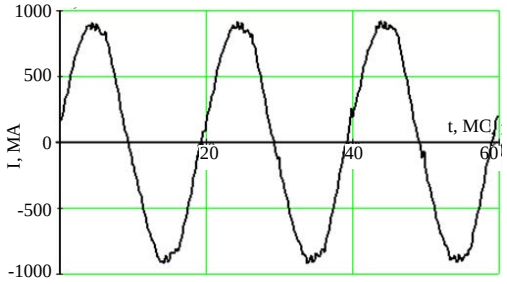

Fig. 4: Oscillogram of instantaneous values of the current of ELs with a rated power of 150 W, intended for street lighting in the grid power of 220V AC

so, the rest can be neglected. The current of the 3rd harmonic component is predominant in the spectral composition but slightly higher than the current of the 5th. Unlike for LEDL, the current of the 7th and 11th harmonic components is insignificant. On average, the sum of the contribution of the above mentioned dominant harmonic components in the formation of the THDI value is 90%. The THDI value of the IL as well as that one of the LEDL tested in the voltage range of 220 V±10%, changes insignificantly. All of the above points are in favour of an IC but two important factors prevent that: more power required for the IL to produce the same luminous flux and on average, double the price of the IL compared to LEDL. Therefore, ILs will not constitute a significant competition for LEDL in the near future.

Continuous application of new technologies in household appliances leads to rapid growth of household loads having non-linear volt-ampere characteristic and called nonlinear electricity consuming devices[36]. A significant part of such operating in residential buildings electricity consuming devices, are equipped with switching power supplies or have an electronic control mode[37]. In recent years, the use of non-linear loads has increased exponentially and is increasing day by day[38,39].

The power consumption of a single household device is low and does not cause any issues in the power system but a very large number of such devices will have a significant negative impact on the power system. Distortion of voltage and current form worsens the operation of equipment and devices connected to the distribution networks[40]. Also such household consumers are the cause of deterioration in terms of quality of electrical power the coefficient of distortion of the sine waveform of the voltage and the coefficient of n-th harmonic component of the current[41]. Therefore, when a large number of modern household appliances appear at present time in apartments, research is required to assess the level of emission of currents of higher harmonic components generated by them into the external electric power grid[42]. Residential electrical appliances can be divided into the following groups:

- Household appliances (washing machines, irons, vacuum cleaners, etc.)
- Appliances for food processing and storage (refrigerators, universal kitchen machines, mixers, etc.)
- Heating appliances for cooking (electric stoves, electric kettles, microwave ovens, etc.)
- Recreational appliances (TV sets, personal computers, audio systems, DVD players, etc.)
- Sanitary and hygienic appliances (fans, hairdryers, etc.)
- Appliances for air conditioning and space heating (climate control systems, electric heaters, etc.)

Among the group of household appliances, washing machines, vacuum cleaners and irons are the main ones in terms of duration of electricity consumption. Below is information only on washing machines and vacuum cleaners as the iron has a linear characteristic of the current consumption. According to the results of measurements and calculations, the total factor of harmonic components of the current for it is about 2%, so, it just slightly affects the harmonic distortion in the electric power network. Domestic electricity consuming devices such as washing machines, appear to be non-linear loads. With the evolution of electronic technologies and improvement of the household appliances design the so-called direct drive drum (Direct Drive-from English) began to apply in a number of washing machines. LG company was one of the first to produce a washing machine with direct drum drive. Today, direct drive is used in a number of washing machines of Samsung, Whirpool, Haier, etc. The main harmonic components of the current generated by washing machines to the network are: the 3rd, 5th, 7th and 9th. Collector motors included in the group of vacuum cleaners belonging to the group of household appliances, increase the portion of the harmonic components in the load current: the coefficient of the 3rd harmonic component of the current is within the range of 18.2-18.6%; the 5th-varies from 5.2-18.6%. In addition to the main harmonic component, the currents of the 3rd, 5th, 7th, 9th and 11th prevail.

The results of experimental measurements and calculations of emission of higher harmonic components of current by a washing machine at various operating modes and vacuum cleaner are presented in Table 5. An oscillogram of the instantaneous current values of the washing machine's current consumption in the turbo spin mode is presented on Fig. 5a and the vacuum cleaner's one is on Fig. 5b.

Table 5: The results of experimental measurements and calculations of emission of the highest harmonic components of the current by household appliances

Sample No.	Items	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the harmonic components of the current to the formation of THD_I (%) (order of the harmonic components)
1	Washing machine (water fill mode)	4.91	1.45	0.73	0.67	0.79	5.6	90.98 (3, 5)
2	Washing machine (stop mode)	0.45	0.96	0.47	0.77	0.31	1.8	73.06 (5, 7, 9)
3	Washing machine (running mode)	1.16	0.97	0.27	0.62	0.26	1.96	82.98 (3, 5, 9)
4	Washing machine (turbo-spin mode)	10.1	5.08	1.32	2.34	1.19	11.9	96.76 (3, 5, 9)
5	Washing machine (dryer mode)	0.40	1.02	0.33	0.04	0.15	1.7	66.50 (3, 5, 7)
6	Vacuum	18.4	2.78	1.26	1.12	0.97	18.8	98.885 (3, 5)

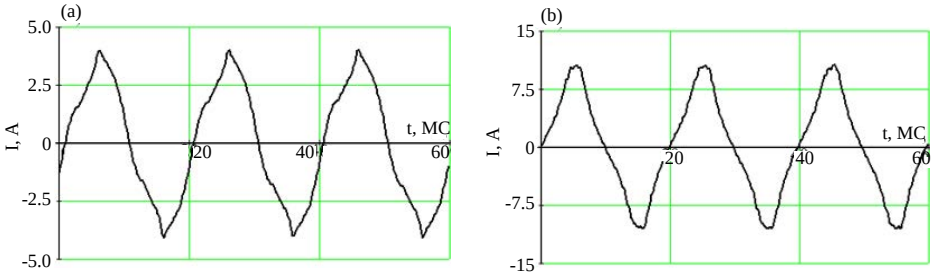

Fig. 5(a, b): Oscillograms of instantaneous values of the current of household appliances, (a) Washing machine in turbo-spin mode and (b) Vacuum

As follows from Table 5, the maximum value of the total harmonic components of the washing machine current is observed in the turbo spin mode and is approximately 12%. In the other modes of the washing machine operation, the harmonic component of the current is much lower. The main harmonic components of the current generated by the washing machines to the network are the 3rd, 5th and 9th while the 7th and 11th are approximately comparable and slightly less than the 9th. The current of the 3rd harmonic component in the spectral composition in most modes is predominant.

Regarding vacuum cleaners which are essentially collector machines, the obtained data on the value of the 3rd harmonic component are in the range given in the literature but the value of the 5th harmonic component is much smaller than the similar range. In addition to the main harmonic component, the currents of harmonic components indicated in the literature[42, 14] predominate, the only thing that can be added is that the current of the 3rd harmonic component prevails over the others by almost an order of magnitude in the spectral composition.

Among the group of electrical appliances for processing and storing products, refrigerators are the main ones in terms of the length of time they consume electricity. Universal kitchen machines, mixers, etc. exploited a small amount of time and have a small value

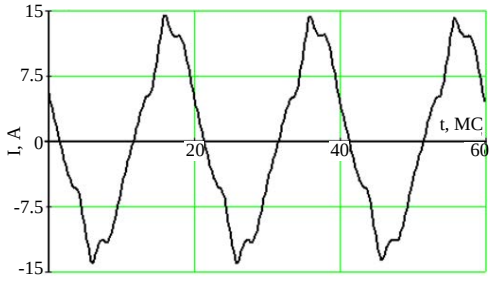

Fig. 6: Oscillogram of instantaneous values of current consumed by refrigerator

of the total coefficient of harmonic components of the current, ranging from 5-10%. The results of experimental measurements and calculations of the emission of a current higher harmonic components that apply only to refrigerators presented in the Table 6 and an oscillogram of the instantaneous values of the current consumed by the refrigerator is demonstrated on Fig. 6.

According to the results of experimental measurements and calculations of emission of the highest harmonic components of the current consumed by the refrigerator, it is possible to make a conclusion that the value of the total coefficient of harmonic components of the current is approximately 13%. The spectral

Table 6: The results of experimental measurements and calculations of the emission of the highest harmonic components of current by refrigerator

	The values of the particular coefficients of the current harmonic components (%)						Contribution of the 3rd, 5th and 7th harmonic components of the current to the formation
Items	3	5	7	9	11	THD_I (%)	of THD_I (%)
Refrigerator	8.94	5.49	6.39	2.24	0.49	12.7	96.7

Table 7: The results of experimental measurements and calculations of the emission of the highest harmonic components of current by microwave ovens

		The values of the particular coefficients of the current harmonic components (%)						Contribution of the 3rd and 5th harmonic components of the current to the formation
Sample No.	Items	3	5	7	9	11	THD_I (%)	of THD_I (%)
1	Microwave oven	30.9	14.1	3.4	2.39	1.36	34.6	98.1
2	Microwave oven	30.2	14.2	3.4	2.39	1.35	33.9	98.3

composition of the harmonic components of the current indicates that in addition to the main one, the currents of the 3rd, 5th and 7th harmonic components prevail, the other ones can be neglected. The current of the 3rd harmonic component is predominant in the spectral composition. On average, the sum of the contribution of the above mentioned dominant harmonic components in the formation of the THDI value is 97%. As for the data from the literature[14], they are identical to the results obtained.

Among the group of electric heating devices for cooking, microwave ovens stand out in terms of the emission of higher harmonic components of current. Electric stoves, electric kettles, etc., household appliances of this group have an insignificant indicator of the total factor of harmonic components of the current, not exceeding 5%. Therefore, the results of experimental measurements and calculations of emission of the higher harmonic components of current, related only to microwave ovens are presented in Table 7 and the oscillogram of instantaneous values of microwave oven current is demonstrated on Fig. 7.

The obtained results are consistent with the data from literature, indicating that the microwave oven generates high-frequency currents of the 3rd and 5th harmonic components during operation[14]. On average, the sum of the above mentioned dominant harmonic components in the formation of the THDI value is 98%. The value of the total current harmonic components for the microwave oven is approximately 35%.

Among household appliances, a special group can be accentuated in terms of the significant emission of higher harmonic components of current which includes recreational residential appliances. In this group it is possible to allocate electric devices for the entertaining purposes (TV sets, tape recorders, musical centers, DVD-players, etc.) and electronic-computer electric devices-office equipment (Personal Computers (PC), laptops, printers, Multifunctional Devices (MFDs), etc.).

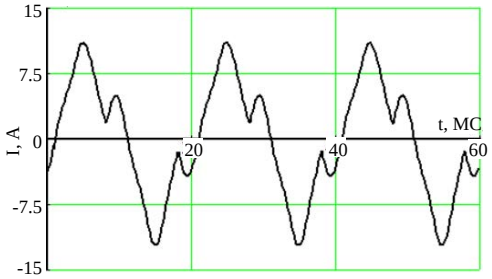

Fig. 7: Oscillogram of instantaneous values of current consumed by microwave oven

TV sets, regardless of the specified capacity, generate odd-order high-frequency currents such as the 3rd, 5th, 7th and 9th. The other harmonic components of the current have lower values. Negative influence on the electrical network in terms of emission of higher harmonic components of the current is also caused by tape recorders, music centers, DVD-players because in their design there are switching power supply units. Table 8 presents the results of experimental measurements and calculations of emission of higher harmonic current components related to TV sets, tape recorders and DVD players as they are used for a considerable time.

Oscillogram of instantaneous values of TV current is demonstrated on Fig. 8a, tape recorder on Fig. 8b and DVD-player on Fig. 8c. According to the results of the research on TV sets, a conclusion can be made that corresponds to the information given in the literature, mentioned earlier. However, it can be added that the value of the total coefficient of the current harmonic components for the TV is approximately 139% which indicates that the RMS value of the sum of all harmonic components up to the 50th order exceeds the value of the main component which is very significant. It can also be said that the value of the 9th harmonic component is insignificant in relation to the values of the 3rd, 5th and 7th harmonic component, the sum of their contribution to the formation of the THDI value is 93%.

Table 8: The results of experimental measurements and calculations of the highest harmonic components emission of the current of recreational household appliances belonging to the group of entertainment

Sample No.	Items	The values of the particular coefficients of the current harmonic components (%) 3	5	7	9	11	THD_I (%)	Contribution of the harmonic components of the current to the formation of the value THD_I (%) (order of harmonic components)
1	TV set	89.8	75.2	56.2	35.7	16.8	139.3	93.3 (3, 5, 7)
2	Tape-recorded	37.2	34.2	11.7	5.1	6.4	53.1	95.2 (3, 5)
3	Tape-recorded	44.8	33.7	8.2	5.3	6.6	57.5	97.4 (3, 5)
4	DVD player (reading mode)	91.9	81.1	65.6	48.6	34.2	176.9	83.2 (3, 5, 7, 9)
5	DVD-player (waiting mode)	91.9	81.9	72.5	59.6	46.1	168.8	91.7 (3, 5, 7, 9)

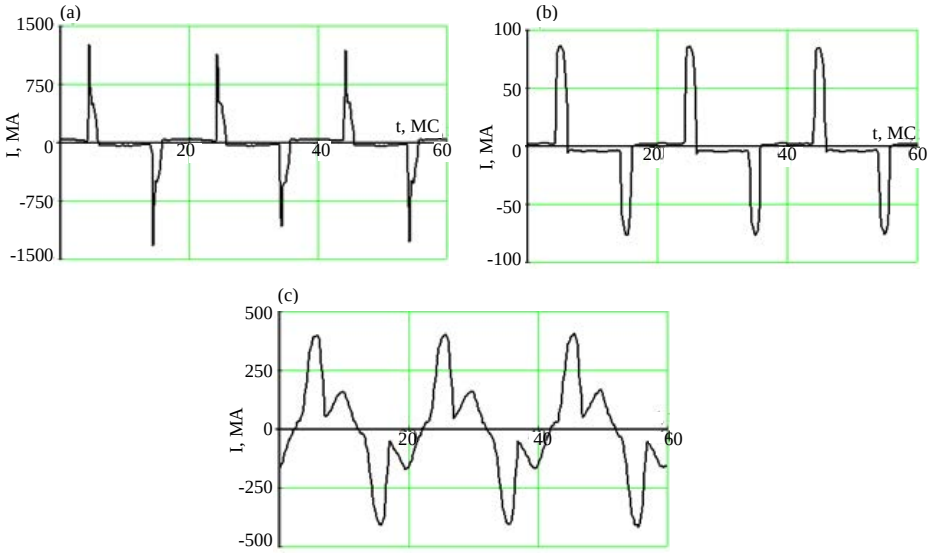

Fig. 8(a-c): Oscillograms of instantaneous values of the current of recreational residential appliances, (a) TV set (b) Tape recorder and (c) DVD player

It can also be noticed that the value of the 9th harmonic component is insignificant in relation to the values of the 3rd, 5th and 7th, whose total contribution to the formation of the THDI value is 93%. The total coefficient of the current harmonic components for DVD players is approximately 177% which indicates that the RMS sum of all harmonic components up to the 50th order is 1.7 times higher than the value of the main component which indicates their significant negative effect on the electric power network. Moreover, the value of the total harmonic current component of the DVD player in the reading mode is slightly different from the standby mode. The spectral composition of the current harmonic components indicates that in addition to the main currents, the currents of the 3rd, 5th, 7th and 9th harmonic components prevail, so, the rest can be neglected. The current of the 3rd harmonic component is predominant in the spectral composition. On average, the sum of the contribution of these predominant harmonic components in the formation of the THDI value is about 87%.

Tape recorders, unlike TVs and DVD-players have a significantly lower (2-3 times) value of the total harmonic component coefficient of the current equal to 55% on average. In addition to the main current in the spectral composition, currents of the 3rd and 5th harmonic components prevail. On average, the contribution of these predominant harmonic components to the formation of the THDI value is about 96%.

PC-type loads are characterized by the presence of all odd harmonic components of low order with very high levels of 3rd, 5th, 7th and 9th[43]. Non-linear loads which are PCs, can cause serious problems in electrical power systems such as an increase in voltage distortion, the thermal effect on rotating machines, a decrease in the power factor of devices[44, 45]. However, it is noticed that the harmonic attenuation coefficient is obvious when comparing the results of measurements and calculations of overall coefficient of harmonic current components of a single PC and a group of PCs connected

Table 9: Results of experimental measurements and calculations of emission of highest harmonic components of the current of recreational and household appliances belonging to the group of electronic-computing

Sample No.	Items	Values of the individual harmonic components of the current (%) 3	5	7	9	11	THD_I (%)	Contribution of the harmonic components of the current to the formation of the value THD_I (%) (order of harmonic components)
1	PC	90.2	65.3	38.8	16.1	10.7	121.5	97.0 (3, 5, 7)
2	PC	74.5	28.8	6.60	17.7	9.70	83.70	97.7 (3, 5, 9)
3	PC	85.4	59.6	34.5	21.0	20.0	117.0	93.7 (3, 5, 7)
4	PC	83.6	65.1	40.3	19.1	8.90	117.6	96.4 (3, 5, 7)
5	PC	84.2	62.4	36.7	17.3	13.4	116.0	95.6 (3, 5, 7)
6	PC	79.2	46.7	21.5	20.6	20.9	102.5	89.7 (3, 5)
7	Laptop (old model)	88.4	68.0	45.6	30.7	28.9	146.1	82.5 (3, 5, 7)
8	Laptop (old model)	36.1	5.70	3.70	1.50	3.30	37.20	98.3 (3)
9	MFD (old model)	88.9	65.5	39.4	17.8	11.9	122.2	95.9 (3, 5)
10	MFD (old model)	4.29	3.60	2.50	0.70	0.50	6.600	93.5 (3, 5, 7)

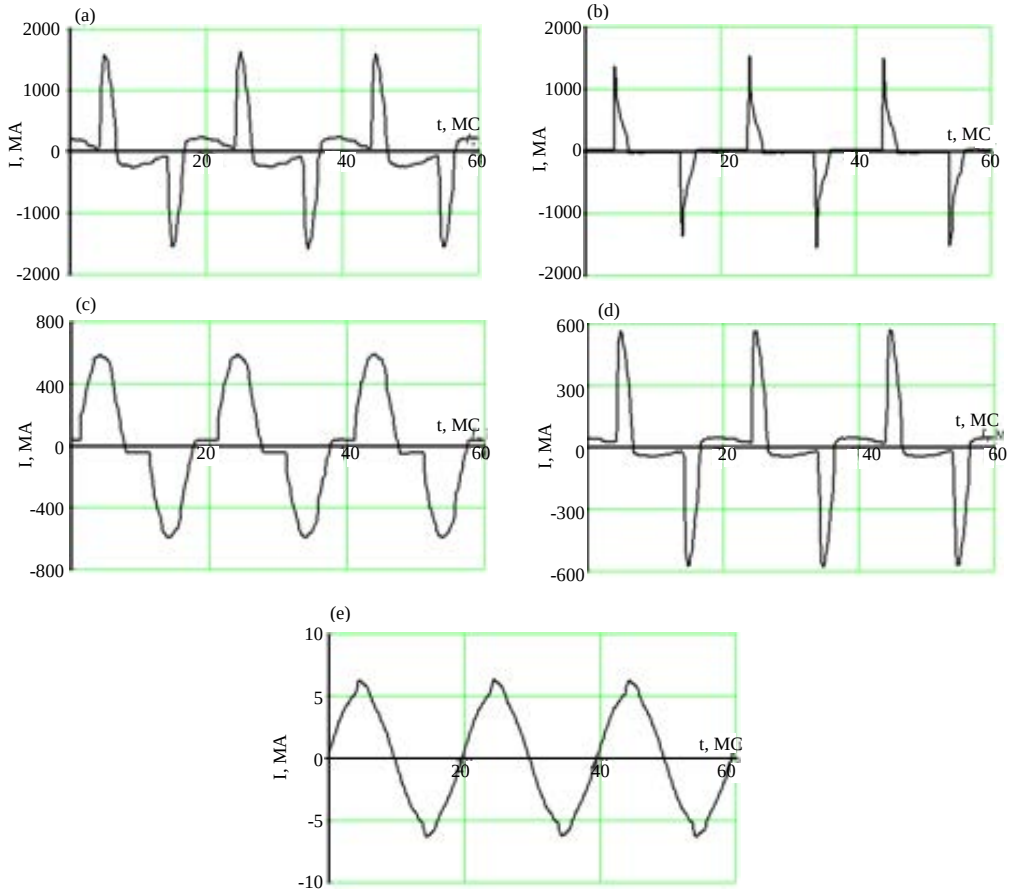

Fig. 9(a-e): Oscillograms of instantaneous values of the current of recreational residential appliancesbelonging to the group of electronic-computing, (a) Personal Computer (PC), (b) Old model laptop, (c) New model laptop (notebook), (d) Old model multifunction device (MFD) and (e) Old model MFD

to the same phase of the electric power network. However, this effect of attenuation is related to the diversity of emission of the current highest harmonic components by each PC and changes in the load which are random. Therefore, this effect is difficult to predict. The results of experimental measurements and calculations of emission of the current highest harmonic components, related to PCs, laptops and MFDs are given in Table 9.

The oscillogram of instantaneous PC current values is demonstrated on Fig. 9 and the laptop of the old and new models, respectively. Figure 9b and 9c, MFDs of the

Table 10: Results of experimental measurements and calculations of emission of the current highest harmonic components by fans

Sample No.	Items	Values of the individual harmonic components of the current (%) 3	5	7	9	11	THD_I (%)	Contribution of the 3rd and 5th harmonic components of the current to the formation of the value THD_I (%)
1	Fan	15.0	1.73	0.54	0.32	0.02	15.15	99.8
2	Fan	11.6	1.20	0.48	0.09	0.35	11.69	99.4
3	Fan	12.9	1.87	0.44	0.38	0.22	13.06	99.5

old and new models, respectively Fig. 9d and 9e. The average value of the total harmonic component of the PC current is approximately 110 % which indicates that the Root-Mean-Square (RMS) value of the sum of all harmonic components up to 50th order exceeds the value of the main component which is significant. The spectral composition of the current shows that in addition to the basic one, the currents of the 3rd, 5th and 7th harmonic components prevail. The current of the 3rd harmonic component is predominant in the spectral composition, the rest can be neglected. In contrast to the data given in the literature, the current of the 9th harmonic component in most cases is insignificant in comparison with the value of the dominant harmonic components. On the average, the sum of the contribution of the above mentioned dominant harmonic components in the formation of the THDI value is 95%. It should also be noted that there is a significant diversity in the emission of the highest harmonic components of the current by each PC.

It should be noted here, that for laptops there is a significant (4-fold) decrease in the total harmonic current component coefficient for new models which is reflected on Fig. 9b and 9c. However, it is still high and is about 37%. The spectral composition of the current indicates that in addition to the main component, the current of the 3rd harmonic component is predominant.

It is an order of magnitude higher than the value of all other harmonic components of the spectrum and its contribution to the formation of the THDI value is 98%. But, it should be noted that a significant number of laptops of old models are still in operation with a significant value of the total harmonic current component, comparable in magnitude to that for a PC.

The same pattern is observed for MFPs as for laptops, related with a decrease in the total coefficient of harmonic components of the current for the new models which is reflected on Fig. 9d and 9e. The spectral composition of the current indicates that in addition to the main one, the currents of the 3rd, 5th and 7th harmonic components prevail. On average, the sum of the contribution of these dominant harmonic components to the formation of the THDI value is 93%.

Electricity consuming devices of the group of sanitary-hygienic electrical devices (fans, hairdryers, etc.) have an insignificant indicator of the total coefficient of harmonic components of the current, not exceeding 5%.

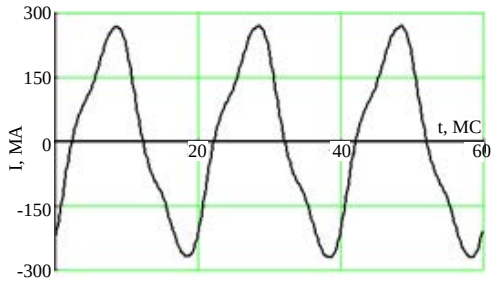

Fig. 10: Oscillogram of instantaneous values of current consumed by fan

Fans can be selected from this group and the results of experimental measurements and calculations of emission of the current highest harmonic components of which are presented in Table 10 and the oscillogram of instantaneous values of fan current is demonstrated on Fig. 10.

The average value of the total factor of the harmonic components of the fan's current is approximately 13%. The spectral composition of the current indicates that in addition to the main, the 3rd and 5th harmonic components prevail. On average, the sum of the contribution of these dominant harmonic components in the formation of the THDI value is 99%.

Electrical devices belonging to the group of air-conditioning and heating of facilities, produce emission of harmonic components of current into the electrical power system, however, they have an insignificant index of the total coefficient of harmonic components of current which does not exceed 6% according to the results of measurements and calculations for electric heaters and 13% for split-systems.

The given results of experimental measurements and calculations as well as data from literary indicate that at work of modern home appliances in electric networks there are rather big currents of the highest harmonic components. The main share of the emission of a current harmonic components in city networks of electrical power systems are brought by recreation and household appliances. The main share of the emission of a current harmonic components in all characteristic periods of consumption of household consumers is mainly on the 3rd and 5th harmonic components and to a lesser extent on the 7th and 9th harmonic components, the rest can be neglected.

In connection with all of the above as well as regard the intensive spread of semiconductor converting technology which creates non-sinusoidal currents in its operation in recent years, the task of improving the quality of electricity is becoming more and more important associated with reducing the influence of highest harmonic components on the operation of electrical equipment[46].

In general, an unbalanced load affects the voltage, causing its distortion. Therefore, one of the ways to reduce the negative influence of the highest harmonic components of current and voltage is to provide a symmetrical mode of operation of three-phase power transmission system. In order to achieve a balance of loads by phases and at the same time to provide the minimum current in the neutral conductor and the minimum content of harmonic components in the output voltage, appropriate monitoring and control circuits are required. It is also known that the harmonic components of the current of different electrical consumers differ in phase and as a result, when they work together in one network, the total harmonic components in it can be mutually suppressed. This effect is weakly expressed and difficult to control, so, it can only be welcomed but not quantified.

Another way to reduce the value of the highest harmonic components of current and voltage is to include a delta-star separating transformer in the electrical power system. Balanced harmonic components, multiple of the 3rd, induce corresponding magnetic fluxes in the core of transformer, so, if they are equal in size and synchronised in phase, than the voltage induced in the primary winding will be compensated.

But still the main tool of weakening the highest harmonic components in electrical power systems are harmonic filters. One of the most effective examples of such equipment is filter-compensating devices. Thereat, passive, active and hybrid filters are differed by the presence of active elements. It is necessary to have an information about the harmonic structure of the inline current for the set up filter-compensating devices. For this purpose, it is necessary to possess information about the levels of the main harmonic components present in them before the introduction of filter-compensating devices in operating electrical power systems[47].

LC or RC filters are widely used as passive filters. It is worth noting that passive filters of harmonic components are effective for compensation of harmonic distortions created by nonlinear electricity consuming devices with practically unchanged operating mode. Therefore, applications of LC-filters are considered as the most promising in lighting networks. However, passive filters have a number of deficiencies: the possibility of overcompensation and undercompensation, high power consumption and high mass and dimensions. At the same time, the use of resonant LC-filters in lighting devices that prevent the penetration of highest harmonic components into the network is an effective tool but here is a hidden danger. If the electricity consuming devices that create harmonic components in the network which the filters devices are set for will be connected to the same grid, than the interaction of filters with those harmonic components can cause their overheating and failure.

LLCL and LCL filters are recommended for use in order to eliminate these deficiencies. LLCL-filter is based on the principle of active resonance damping control. The advantage of LLCL-filters is that in such a scheme the capacitance of the capacitor can be reduced by 40 times compared to conventional LC-filter[48]. LCL-filters consist of a capacitor battery with a damping resistor as well as input and output chokes. Advantages of LCL-filters in comparison with LC-filters are lower losses as well as dimensions and weight. However, they are not devoid of the resonance phenomena in the process of their work[49]. In three-phase networks four-beam passive filters of harmonic components also can be used as passive filters with the help of which it is also possible to effectively suppress the highest harmonic components of non-sinusoidal voltages and currents. They allow both filtration of highest harmonic components and power factor correction at the same time.

The use of active power filters, sometimes called Active Power Filters (APFs) is very promising. Unlike passive filters, active power filters contain controls that allow changing the filter's frequency response. Development of power electronics: GTO-thyristors and IGBT-transistors has determined the element base which is the basis for the construction of active harmonic filters. Broad opportunities of operational characteristics of the active filter allow to apply it not only for reduction of harmonic components level but also for compensation of reactive power.

The improvement of APF characteristics is connected with the increase of the control system reaction speed which is possible with the use of neuronal networks. As a result, a low value of the current total harmonic distortion coefficient and the best efficiency of APF is achieved[50, 51].

The operation of the Shunt Active Power Filter (SAPF) essentially depends on the accuracy of harmonic component selection and synchronization[52]. The SAPF module is more efficient than conventional APF due to the high amplitude factor of the compensating current and the rapid dynamic response. However, when using SAPF, there are problems such as resonance and stability associated with the modular design of SAPF.

Hybrid Active Power Filters (HAPF) combine active and passive filters that are either in series or in parallel. HAPF is an improved form of harmonic filter combining the advantages of both active and passive

components[53-56]. Hybrid filters include static thyristor compensators (STATCOM)-devices made on the principle of voltage conversion when using high-frequency pulse-width control[11]. Compared to static thyristor compensators (STC), STATCOM has a number of advantages such as: better dynamic characteristics, active filtration of harmonic components of currents, reduced size and active losses. However, STATCOM has one significant disadvantage that constrains their widespread use the high cost.

The hybrid three-level SAPF modular filters are the less expensive and consist of two types of modules with different current carrying capacities. The proposed hybrid system provides a wider bandwidth and faster dynamic performance than existing SAPF modular modules. This filter also effectively suppresses resonance phenomena.

CONCLUSION

Load in the utility network is predominantly non-linear and each year related share of such load which generates the highest harmonic components of current in the electricity network, increases in the overall structure of electricity consumption. This leads to a deterioration in the quality of electrical energy and as an impact, to negative and sometimes even emergency consequences. Just the harmonic components of the voltage are regulated in compliance with GOST 32144 in the Russian Federation while the highest harmonic components of the current are not regulated. However, their level should be controlled as they cause a number of undesirable consequences.

Replacement of incandescent bulbs with CFL allowed to switch to energy-saving light emitters in accordance with FA-261 which significantly saved energy resources. However, despite their advantages, CFLs are non-linear consumers of electric energy and create harmonic components of current of 3, 5, 7, 9 and 11 orders of magnitude. In this regard, the growing use of CFLs as energy-saving light emitters, instead of incandescent lamps has a huge negative effect on the electrical power system and may lead to serious problems in electricity networks.

The development of semiconductor technologies has stimulated the transition to lighting systems using LED emitters. That is why CFL lamps are being replaced with LED lamps. However, they have a pulsed nature of electricity consumption, a wide range of harmonic components 3, 5, 7, 9 and 11 orders of magnitude and low electromagnetic compatibility with the power grid. Therefore, the connection of a large number of LED lamps can cause problems in electrical power systems associated with a significant amount of harmonic components of their current consumption.

With the development of semiconductor technology, it has become apparent that the reduction of electric energy consumption in outdoor lighting should be achieved through the wider introduction of highly efficient light emitters and luminaires with a rational light distribution such as LEDL. The average value of the total value of the harmonic components of the LEDL current is much lower than that of household LED lamps and is explained by the use of LEDL SSPS in the design. However, the spectral composition of the LEDL current shows that in addition to the main one, the currents of 3, 5, 7 and 11 harmonic components prevail which negatively affects the operation of electrical networks. An alternative to the use of LEDLs for street lighting, in terms of reducing the harmonic component of the current can be the use of an IL. The average value of the total harmonic component of the IL current is 4 times less than the same value for LEDL. However, the wide use of ILs is hindered by the higher power of ILs required to produce the same luminous flux and, on average, double the price of IL compared to LEDLs. Therefore, in the near future, IL will not constitute a significant competition for LEDL.

Continuous implementation of new technologies in household appliances leads to a rapid growth of household loads with non-linear volt-ampere characteristic. Household electricity consumers are the reason for the deterioration of the quality of electricity in the following indicators the coefficient of sinusoidal voltage curve distortion and the coefficient of n-th harmonic component of the current. The results of experimental measurements and calculations for a number of household consumers as well as information from literature show that when modern household appliances work in electrical networks there are rather high currents of higher harmonic components of 3, 5, 7 and 9 orders of magnitude. The main share of the emission of harmonic components of current in the city networks of electrical power systems is made by cultural and household appliances.

Continuous growth of the specified capacity of nonlinear asymmetric and sharply variable loads in the electric networks of the Russian Federation is not accompanied by timely implementation of solutions aimed at correcting the quality of electrical energy, so in recent years the task of improving the quality of electricity is becoming more and more relevant and important, associated with reducing the impact of highest harmonic components on the operation of electrical equipment.

The current condition of electric power networks requires further research aimed at improving the methods of assessing the impact of non-sinusoidal electrical parameters on the losses of active power and electricity in the equipment of electric power networks. As an

implication, it is necessary to develop new methods and standards related to the analysis of the influence of the highest harmonic components of current on the electrical network and ways to eliminate them.

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