Light & Engineering
Vol. 28, No. 4, pp. 84–90, 2020
https://doi.org/10.33383/2019-083
Svetotekhnika #2, 2020, pp. 63–66

STUDY OF OPERATING MODES OF A CONTROLLABLE LIGHTING SYSTEM CONSISTING OF A TRIAC DIMMER AND A LED LIGHT SOURCE WITH A CONTROLLABLE DRIVER

Nadezhda P. Kondratieva[1], Dmitry A. Filatov[2], and Pavel V. Terentiev[2]

[1] *Izhevsk State Agricultural Academy*
[2] *Nizhny Novgorod State Agricultural Academy*
E-mail: filatov_da@inbox.ru

ABSTRACT

The article covers the study of the effect of a dimmer on operation of a light source and electromagnetic compatibility of a controllable lighting system. It is found that with reduction of active power $\boldsymbol{P}$ of a light source its luminous flux and bulb heating temperature decrease, the power factor of the lighting system decreases too with increasing of the total harmonic distortion current factor of the lighting system. The changes are non-linear. Mathematical expressions related to changes of luminous flux, heating temperature, power factor and total harmonic distortion caused by change of active power of a light source are obtained. A conclusion is made that together with an opportunity to save energy and to increase the operating life of the controllable lighting system application of a dimmer leads to reduction of electric power quality and electromagnetic compatibility of this system. The study also demonstrated that changes in supply voltage also affect operation of the controllable lighting system. Reduced supply voltage causes the highest effect on characteristics of the lighting system. Change in the supply voltage strongly affects the luminous flux and the heating temperature of the light source and the power factor of the lighting system in operating modes at 0.25 of $\boldsymbol{P_{nom}}$ and 0.5 of $\boldsymbol{P_{nom}}$ and the total harmonic distortion in operating modes at 0.75 of $\boldsymbol{P_{nom}}$ and $\boldsymbol{P_{nom}}$.

Keywords: TRIAC dimmer, LED light source, controllable driver

1. INTRODUCTION

In Russia, 10 % of all annual electric power generation is used for lighting purposes [1]. The electricity tariffs growth makes the issue of energy saving and transfer to more energy-efficient technologies in lighting system still relevant. Nowadays light sources based on light emitting diodes (LED) are being introduced in different industries more actively. One of the advantages of LEDs is capability to control them. The control is based on such parameters as operating time and illuminance level. The operating time is controlled by means of a timing relay and the illuminance level is controlled by a dimmer. Analysis of works on controllable lighting systems [2–7] has shown that they aim at development of configurations or particular elements of such systems as well as their cost-efficiency. There are virtually no studies of the influence of dimmers on operation of light sources and electromagnetic compatibility (EMC) of a controllable lighting system. EMC of a technical device is its capability to function with a set quality level in the set electromagnetic environment and not to generate unacceptable electromagnetic interference (EMI) into operation of other technical means [8]. Level of electromagnetic compatibility of a power supply system: standardised level of conductive EMI used as reference for coordination between the acceptable level of interference caused by technical means of electric power network users and the level of interference received by technical means con-

Table 1. The Results of Studying the Characteristics in Absolute Values

P, W	K_m, per unit	*THDi*, %	*E*, lx	*Kn*,%	*T*, °C
Supply voltage 220V					
3	0.84	92.7	50.2	25.6	41.9
6	0.94	91.3	65.4	26.7	47.1
9	0.99	82.3	171.3	28.8	70
12	1	34.8	266	21.4	81.9
Supply voltage 198V					
3	0.66	91.9	20.9	22	40.2
6	0.88	90.9	47.9	25.2	46.2
9	0.99	78.3	150.7	27.5	69.3
12	1	29.2	266	20.9	81.9
Supply voltage 242V					
3	0.9	93	63.5	26.7	43.6
6	0.97	92.1	80	27.2	48.1
9	0.99	86.7	187	29.7	70.7
12	0.9	40	266	21.1	82

nected to an electric power network without prevention of their normal functioning. Conductive EMI is electromagnetic interference propagating via electric power network conductors [9]. Conductive EMI may reduce quality of functioning of devices, electric installations or systems, or damage them [10, 11]. That is why the problem of the determination of dimmer effect on operation of light sources and electromagnetic compatibility of a controllable lighting system is relevant.

2. MATERIALS AND METHODS

The controllable lighting system consisting of a LED light source and a dimmer was studied in the Lighting Engineering laboratory of the Nizhny Novgorod State Agricultural Academy. The study was conducted with the electric system (Fig. 1) consisting of: RNO-250–2-M regulating linear autotransformer –1, *Circutor* AR-6 electric power quality analyser – 2, IEK BCP-10–1–0 dimmer – 3, voltmeter – 4, TKA-PKM 08 flicker and illuminance meter, JazzWay PLED-DIM A60 LED light source with dimming functionality. Dimmer power regulation is up to 400 W. Dimming range of the LED light source is (25–100)%. The regulation of the active power was four-step: 0.25 $\boldsymbol{P_{nom}}$; 0.5 $\boldsymbol{P_{nom}}$; 0.75 $\boldsymbol{P_{nom}}$ and $\boldsymbol{P_{nom}}$. Each step was measured 3 times.

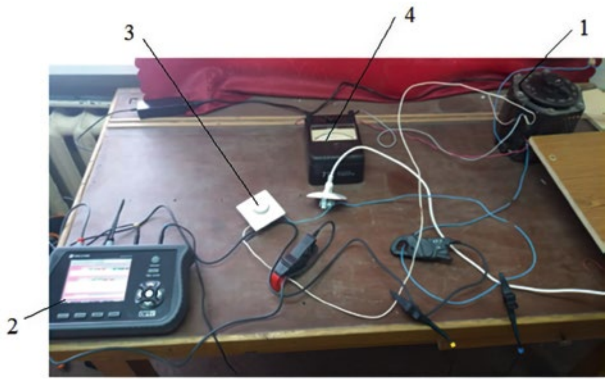

Fig. 1. The electric system for studying the controllable lighting system consisting of a LED light source and a dimmer

3. RESULTS AND DISCUSSION

The studied characteristics of the controllable lighting system included luminous flux of the light source, heating temperature of the light source, power factor and total harmonic distortion. The results of studying these characteristics at nominal points are shown in Table 1 in absolute values.

The results of the study of the light source luminous flux Φ_v dependence on active power consumption P are shown in Fig. 2.

It is found that luminous flux of the light source decreases with decrease in active power. With decrease in active power of 25 %, luminous flux decreases by 36 %. With decrease in active power of

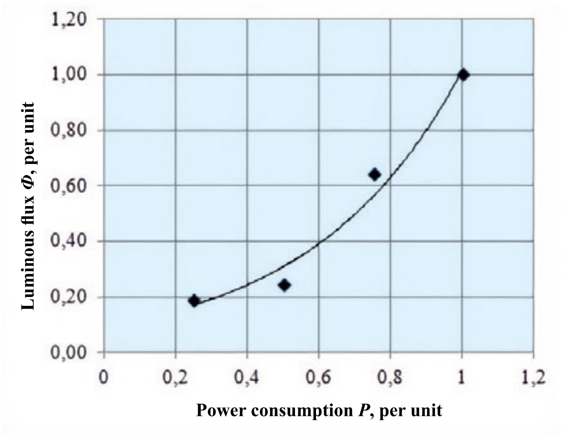

Fig. 2. The luminous flux dependence on active power consumption change

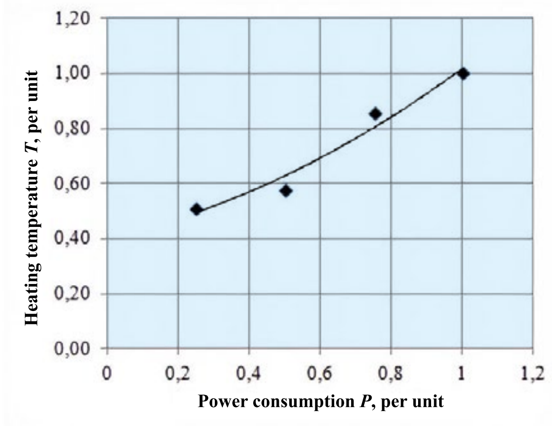

Fig. 3. Heating temperature dependence on active power consumption change

50 %, luminous flux decreases by 75 %. With decrease in active power of 75 %, luminous flux decreases by 81 %. The dependence of change of luminous flux and change of active power is non-linear and may be described by means of a mathematical expression derived using MS Excel:

$$\Phi_{\upsilon} = \Phi_{\upsilon nom} \cdot (\alpha \cdot \exp^{\beta \cdot K_P}), \quad (1)$$

where $\Phi_{\upsilon nom}$ is the nominal luminous flux, lm; α, β are constant factors depending on the manufacturer of a given light source (for the studies light source, α=0.095; β=2.3689); $K_p = \frac{P_\Phi}{P_{nom}}$ is the change of the level of active power of the light source, per unit; P_Φ is the actual active power consumption, W; P_{nom} is the nominal active power consumption, W.

The results of studying the dependence of the light source heating temperature T change and active power consumption P change are shown in Fig. 3.

It is found that heating temperature of the light source decreases with decrease in active power. With decrease in active power of 25 %, heating temperature decreases by 15 %. With decrease in active power of 50 %, heating temperature decreases by 42 %. With decrease in active power of 75 %, heating temperature decreases by 49 %. The dependence of heating temperature change and change of active power is non-linear and may be described by means of a mathematical expression derived using MS Excel:

$$T = T_{nom} \cdot (a \cdot K_p{}^2 + b \cdot K_p + c), \quad (2)$$

where T_{nom} is the heating temperature at nominal power consumption, °C; a, b, c are the constant

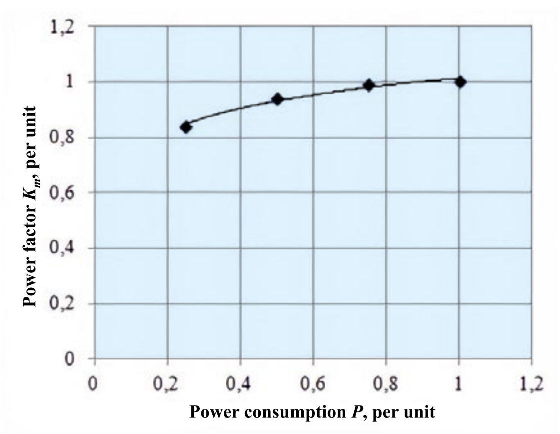

Fig. 4. Dependence of power factor change on active power consumption change

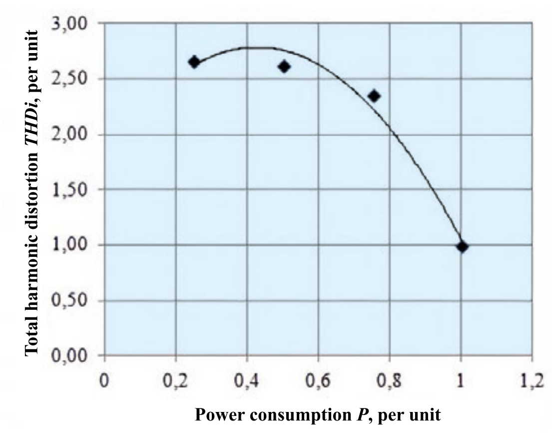

Fig. 5. Dependence of total harmonic distortion change on active power consumption change

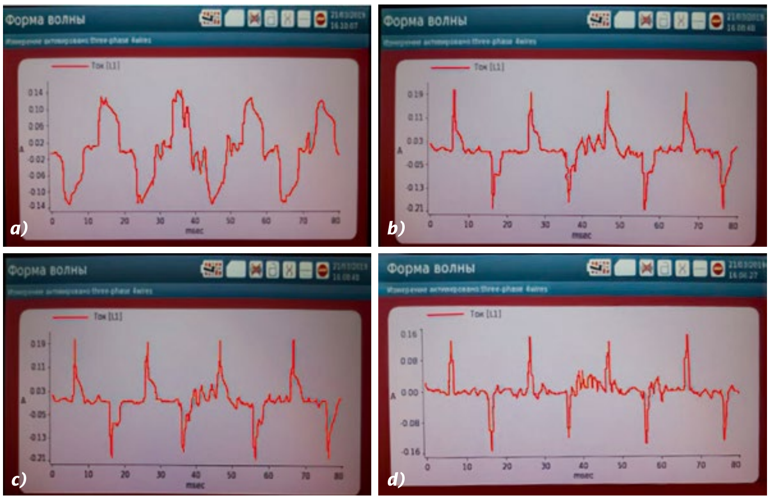

Fig. 6. The current's waveforms of the lighting system at: a) P_{nom}, b) 0.75 P_{nom}, c) 0.5 P_{nom}, d) 0.25 P_{nom}

factors depending on the manufacturer of a given light source (for the studied LED light source, *a* = 0.3272; *b* = 0.2889; *c* = 0.4014).

The results of studying the dependence of power factor K_m change and active power consumption *P* change are shown in Fig. 4.

It is found that power factor of the light source decreases with decrease in active power. With decrease in active power of 25 %, power factor decreases by 1 %. With decrease in active power of 50 %, power factor decreases by 6 %. With decrease in active power of 75 %, power factor decreases by 16 %. The dependence of power factor change and change of active power is non-linear and may be described by means of a mathematical expression derived using MS Excel:

$$K_M = K_{nom} \cdot (a \cdot \ln(K_p) + b), \qquad (3)$$

where K_{nom} is the nominal power factor, per unit; a, b are the constant factors depending on the manufacturer of a given light source (for the studied LED light source, a = 0.1201; b = 1.0135).

The results of studying the dependence of total harmonic distortion *THDi* change and active power consumption *P* change are shown in Fig. 5.

It is found that total harmonic distortion increases with active power decrease. With decrease in active power of 25 %, total harmonic distortion increases by 2.36 times. With decrease in active power of 50 %, total harmonic distortion increases by 2.62 times. With decrease in active power of 75 %, total harmonic distortion increases by 2.66 times. The effect of total harmonic distortion change on active power is non-linear and may be described by means of a mathematical expression derived using MS Excel:

$$THDi = THDi_{nom} \cdot (a \cdot K_P^{\;2} + b \cdot K_P + c), \qquad (4)$$

where $THDi_{nom}$ is the nominal total harmonic distortion, per unit; a, b, c are the constant factors depending on the manufacturer of a given light source (for the studied LED light source, a = –5.2989; b = 4.5236; c = 1.8197).

Increase in total harmonic distortion negatively affects electric power quality. The oscillograph records (waveforms) of the current (Fig. 6) confirm it.

The results of studying the dependence of flicker index K_p change and active power consumption *P* change are shown in Fig. 7.

It is found that, generally, with decrease in active power, flicker index of luminous flux increases as compared to the nominal mode. With active power decrease by 25 %, flicker index of luminous

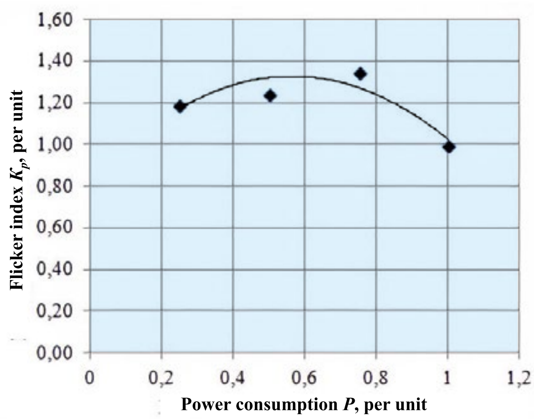

Fig. 7. Dependence of luminous flux flicker index change on active power consumption change

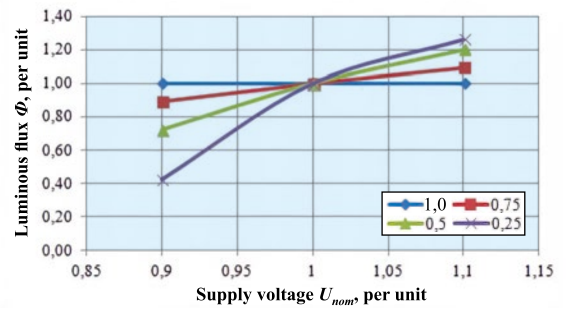

Fig. 8. The effect of supply voltage change on luminous flux of the light source with change of active power

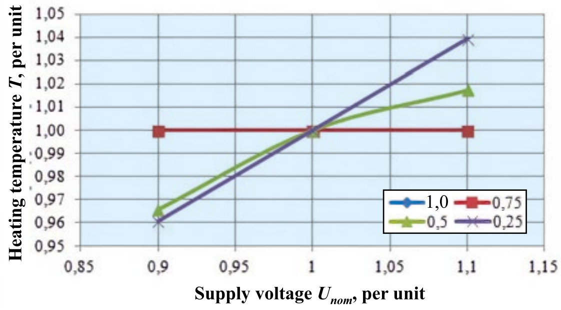

Fig. 9. The effect of supply voltage change on heating temperature of the light source with change of active power

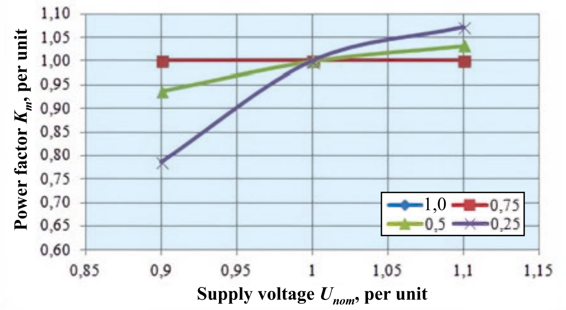

Fig. 10. The effect of supply voltage change on power factor of the light source with change of active power

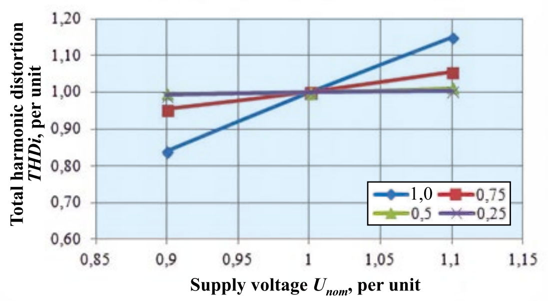

Fig. 11 The effect of supply voltage change on total harmonic distortion of the light source with change of active power

flux increases by 35 %. With active power decrease by 50 %, flicker index of luminous flux increases by 25 %. With decrease in active power of 75 %, flicker index of luminous flux increases by 20 %. The dependence of luminous flux flicker index change and change of active power is non-linear and may be described by means of a mathematical expression derived using MS Excel:

$$K_p = K_{Pnom} \cdot (a \cdot K_p{}^2 + b \cdot K_p + c), \qquad (5)$$

where K_{Pnom} is the nominal luminous flux flicker index,%; a, b, c are the constant factors depending on the manufacturer of a given light source (for the studied LED light source, a = –1.5888; b = 1.7897; c = 0.8236).

Slow change of supply voltage is one of the main characteristics of electric power quality characterising EMI. According to [9], voltage fluctuations at balance sheet attribution border of $\pm U_{nom}$ are acceptable.

The study of the effects of supply voltage changes on a light source without a dimmer has shown that, irrespective of voltage level, luminous flux, heating temperature, and power factor remain constant.

The effect of supply voltage change on operation of a controllable lighting system (with a dimmer) is studied. The results of the study are presented below.

Fig. 8 shows the effect of supply voltage change on luminous flux of the light source with change of active power.

It is found that change of supply voltage affects luminous flux of the light source with change of active power. The most significant effect is caused by reduction of supply voltage. At 0.9 U_{nom} and with decrease in active power of 25 %, luminous flux decreases by 11 %, with decrease in active power of 50 %, luminous flux decreases by 28 %, with decrease in active power of 75 %, luminous flux decreases by 58 % as compared to the nominal mode. Increase in supply voltage causes less effect. At 1.1 U_{nom} and with decrease in active power of 25 %, luminous flux increases by 9 %, with decrease in active power of 50 %, luminous flux increases by 20 %, with decrease in active power of 75 %, luminous flux increases by 26 % as compared to the nominal mode.

Fig. 9 shows the effect of supply voltage change on heating temperature of the light source with change of active power.

It is found that change of supply voltage does not affect heating temperature of the light source with change of active power from P_{nom} down to $0.75P_{nom}$

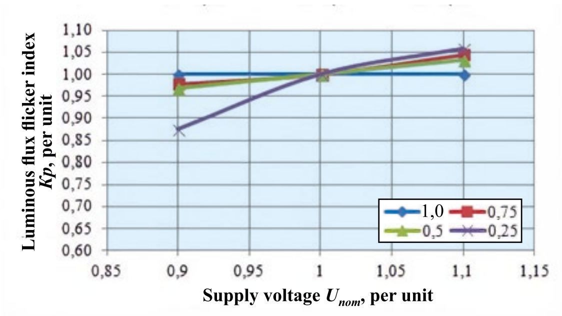

Fig. 12 The effect of supply voltage change on luminous flux flicker index of the light source with change of active power

and insignificantly affects heating temperature of the light source with change of active power from $0.5P_{nom}$ down to $0.25P_{nom}$. At $0.9U_{nom}$ and with decrease in active power of 50 %, heating temperature decreases by 3 %, with decrease in active power of 75 %, heating temperature decreases by 4 % as compared to the nominal mode. At $1.1U_{nom}$ and with decrease in active power of 50 %, heating temperature increases by 2 %, with decrease in active power of 75 %, heating temperature increases by 4 % as compared to the nominal mode.

Fig. 10 shows the effect of supply voltage change on power factor of the light source with change of active power.

It is found that change of supply voltage does not affect power factor of the lighting system with change of active power from P_{nom} down to $0.75P_{nom}$ and affects power factor of the lighting system with change of active power from $0.5P_{nom}$ down to $0.25P_{nom}$. At $0.9U_{nom}$ and with decrease in active power of 50 %, power factor decreases by 6 %, with decrease in active power of 75 %, power factor decreases by 21 % as compared to the nominal mode. At $1.1U_{nom}$ and with decrease in active power of 50 %, power factor increases by 3 %, with decrease in active power of 75 %, power factor increases by 7 % as compared to the nominal mode.

Fig. 11 shows the effect of supply voltage change on total harmonic distortion of the light source with change of active power.

It is found that changing supply voltage does not affect total harmonic distortion of the lighting system at active power of $0.25P_{nom}$ and $0.5P_{nom}$ and affects total harmonic distortion of the lighting system at active power of P_{nom} and $0.75P_{nom}$. At $0.9U_{nom}$ and with decrease in active power of 25 %, total harmonic distortion decreases by 5 %, at 100 % of active power, total harmonic distortion decreases by 16 % as compared to the nominal mode. At $1.1U_{nom}$ and with decrease in active power of 25 %, total harmonic distortion increases by 6 %, at 100 % of active power, total harmonic distortion decreases by 16 % as compared to the nominal mode.

Fig. 12 shows the effect of supply voltage change on luminous flux flicker index of the light source with change of active power.

It is found that changing supply voltage affects luminous flux flicker index of the light source with change of active power. The most significant effect is caused by reduction of supply voltage. At $0.9U_{nom}$ and with decrease in active power of 25 %, luminous flux flicker index decreases by 2 %, with decrease in active power of 50 %, luminous flux flicker index decreases by 3 %, with decrease in active power of 75 %, luminous flux flicker index decreases by 12 % as compared to the nominal mode. Increase in supply voltage causes less effect. At $1.1U_{nom}$ and with decrease in active power of 25 %, luminous flux flicker index increases by 4 %, with decrease in active power of 50 %, luminous flux flicker index increases by 3 %, with decrease in active power of 75 %, luminous flux flicker index increases by 6 % as compared to the nominal mode.

4. CONCLUSION

The conducted study has shown that TRIAC affects operation of light sources and the power supply system.

It is found that, with reduction of active power of a light source, its luminous flux decreases, its heating temperature decreases, power factor of the lighting system decreases and total harmonic distortion of the lighting system and luminous flux flicker index of the light source increase. The changes are non-linear. Mathematical expressions related to changes of luminous flux, heating temperature, power factor, total harmonic distortion and flicker index caused by change of active power of a light source are obtained. It is possible to make a conclusion that together with an opportunity to save energy and to increase the operating life of a controllable lighting system application of a dimmer leads to reduction of electric power quality and luminous flux flicker index.

The study also demonstrated that changes in supply voltage also affect operation of the controllable lighting system. Reduced supply voltage causes the highest effect on characteristics of the lighting system. Changing supply voltage strongly affects luminous flux and heating temperature of the light source, power factor of the lighting system and luminous flux flicker index in operating modes at $0.25P_{nom}$ and $0.5P_{nom}$ and total harmonic distortion in operating modes at $0.75P_{nom}$ and P_{nom}.

REFERENCES

1. Bagin G. Ya., SolNtsev E.B., Malafeev O. Yu. Evaluation of Characteristics of Russian Lighting Systems [Otsenka kharakteristik sistem osvescheniya v Rossii] // Bulletin of the Samara State Technical University. Technical Sciences, 2016, Vol. 3 (51), pp. 78–86.
2. Nikolaev P.L. Architecture of a Smart House Control System Integrated in a Cloud Environment [Arkhitektura integrirovannoy v oblachnuyu sredu sistemy upravleniya umnym domom] // Programmnyie produkty i sistemy, 2015, Vol. 2 (110), pp. 65–69.
3. Galliulin R.R., Karimov I.I. Efficiency of LED Luminaires Application in Greenhouse Facilities [Effektivnost ispolzovaniya svetodiodnykh svetilnikov v teplichnykh khozyaystvakh] // Elektrotekhnicheskiye i informatsionnyye kompleksy i sistemy, 2016, Vol. 1, pp. 34–39.
4. Stepanchuk G.V., Yudaev I.V., Zharkov A.V. Energy-efficient Greenhouse Irradiating System [Energoeffektivnaya sistema oblucheniya v teplitse] // Tekhnologii, sredstva mekhanizatsii i energeticheskoye oborudovaniye, 2016, Vol. 1 (33), pp. 5–12.
5. Minaev I.G., Molchanov A.G., Samoilenko V.V. Energy-saving Greenhouse Optical Radiation Control System [Energosberegayuschaya sistema upravleniya istochnikami opticheskogo oblucheniya v teplitsakh] // Innovative Developments of Young Scientists of Southern Russia: abstracts of the scientific and practice conference, 2012, pp. 37–40.
6. Assonova M.L., Olkhovoy A.A., Iliin S.V. Energy-saving Technologies for Industrial Greenhouse Lighting Systems [Energosberegayuschiye tekhnologii dlya sistem osvescheniya promyshlennykh teplits] // Novyye informatsionnyye tekhnologii v avtomatizirovannykh sistemakh, 2014, Vol. 17, pp. 456–459.
7. Plotnikov V.V., Kuramshina L.F., Vakhitov A.R. Some Aspects of Design of Light Control Systems [Nekotoryye aspekty proektirovaniya sistem upravleniya svetom] // Bulletin of Kazan Techological University, 2013, Issue 4, Vol. 16, pp. 235–239.
8. GOST R50397–2011. Electromagnetic compatibility of technical equipment. Terms and definitions. Moscow: STANDARTINFORM, 2014, 57 p.
9. GOST 32144–2013. Electromagnetic compatibility of technical equipment. Power quality limits in the public power supply systems. Moscow: STANDARTINFORM, 2014, 16 p.
10. Kondratieva, N.P., Terentiev, P.V., Filatov, D.A. Comparative Experimental Analysis of Electromagnetic Compatibility of Discharge and LED Artificial Light Sources for Plant-Growing [Sravnitelnyy experimentalnyy analiz po elektromagnitnoy sovmestimosti razryadnykh i svetodiodnykh iskusstvennykh istochnikov sveta dlya rasteniyevodstva] // Bulletin of NGIEI, 2018, Vol. 12 (91), pp. 39–49.
11. Kondratieva N.P., Filatov, D.A., Terentiev, P.V. Selection of 0.4kV Cable Lines for Greenhouse Facilities [Vybor kabelnykh liniy 0.4 kV dlya teplichnykh kombinatov] // Elektrotekhnologii i elektrooborudovaniye v APK, 2019, Vol. 2 (35), pp. 17–25.

Nadezhda P. Kondratieva, Prof., Dr. of Tech. Sc. In 1978, she graduated from Chelyabinsk Institute of Mechanization and Electrification of Agriculture. At present, she is a Head of the Chair of Automated Electric Drive Izhevsk State Agricultural Academy (IzhGSHA). She has its own science school in the field of agricultural lighting and developing of energy saving lighting technologies for agricultural enterprises is her field of interests. Also, she has got the title of "Honorary Worker of Higher Vocational Education of Russian Federation"

Dmitry A. Filatov, Ph.D. of Tech. Sc., Associate Prof. In 2009, he graduated from R.E. Alekseev Nizhny Novgorod State Technical University. Currently, he is docent of the Chair of mechanization of livestock and rural agricultural electrification economy at Nizhny Novgorod State Agricultural Academy. His scientific interests are light sources, electromagnetic compatibility, and quality of electricity

Pavel V. Terentiev, Ph.D., Associate Prof. In 2009, he graduated from R.E. Alekseev Nizhny Novgorod State Technical University. At present time, he is docent of the Chair of mechanization of livestock and rural agricultural electrification economy at Nizhny Novgorod State Agricultural Academy. His scientific interests are light sources, electromagnetic compatibility, and quality of electricity