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The effect of greenhouse irradiators on the load factor of step-down transformers

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Abstract. The aim of the work is to determine the permissible load factors of step-down transformers when powering various types of greenhouse irradiators. All examined irradiators have nonlinear volt-ampere characteristic and generate upper current harmonics. The object of research are greenhouse illuminators with high pressure sodium lamps, induction and light-emitting diodes greenhouse illuminators (LED) with active and passive power factor. The permissible load factors of transformers are calculated using obtained data: for high-pressure sodium lamp light is 0.95 max; for LED lamps with active power factor corrector – 0.76 max; for LED lamps with passive power factor correction – 0.59 max; for electrodeless lamp light – 0.98 max. To reduce current harmonics in systems with LED lamps and to increase the load factor of transformers, it is necessary to apply special devices – active or passive harmonic filters. For greenhouse irradiators with sodium lamps and induction irradiators, the use of harmonic filters is not required.

1. Introduction

The choice of reducing transformers load factors has an impact on energy efficiency, reliability and performance of power supply systems, the cost of transformer substations of greenhouse facilities. Design of power supply systems is generally carried out at the initial stage, so to minimize the equipment calculating error it is necessary to take into account its operation affecting factors.

Greenhouse vegetable production is one of the most energy-intensive areas of agriculture. The main electric consumers at greenhouse facilities are plants artificial irradiation (lighting) systems. Total one-time power consumption of radiation sources is 1-1.5 MW per a hectare of greenhouses.

Currently, the main source of radiation in greenhouse vegetable growing is high-pressure sodium lamp (HPS) lights. They have high light efficiency at low cost and emit in a wide range of spectrum, meeting the requirements of many plant species. However, the maximum radiation in the range of photosynthetic active radiation (PAR) for HPSL lights falls at the yellow spectrum (589 nm), that is, their spectrum is relatively poor in the blue and far-red range compared to solar radiation [1].

Light-emitting diodes (LED) and electrodeless (fluorescent electrodeless) irradiators are promising for greenhouse vegetable growing. Their radiation spectrum can be set by the composition of LEDs and luminescent material, respectively. When growing plants in photoculture, it is possible to control and manage the physiological processes in plants.

The analysis of scientific work on the stated research topic. In [2-6], the results of studies of the effect of the red, blue and green spectrum of LED irradiators on the development of lettuce are presented. Comparative tests of the influence of the emission spectrum of LED irradiators and irradiators with sodium lamps on the productivity of salad crops were carried out in [7-9]. In [10,11], the results of studies of the effect of various radiation spectra on the photosynthesis of potatoes and lettuce are shown. The influence of the operating modes of LED irradiators on plant productivity was studied in [12,13]. In [14], comparative tests of the influence of the radiation spectrum of irradiators with sodium lamps and irradiators with induction lamps during the vegetative propagation of water hyacinth were carried out. The estimation of load factors of workshop transformers in the power supply of industrial power receivers is devoted to the work [15-16]. Of scientific and practical interest is the effect of greenhouse irradiators on step-down transformers of power supply systems. Greenhouse irradiators are electric receivers with a non-linear current-voltage characteristic that generate higher harmonics of the current Total Harmonic Distortion (THD_I). The flow of higher harmonics currents through transformers causes an increase in losses due to an increase in the active resistance of the windings with increasing frequency, as well as an increase in hysteresis and eddy current losses in the transformer magnetic circuit. These losses can cause transformer failure due to overheating. The purpose of the work is to determine the permissible load factors of step-down transformers when powering various types of greenhouse irradiators.

2. Materials and methods

The European Committee for Standardization in the Field of Electrical Engineering (CENELEC) recommends, when determining the load capacity of the transformer, additionally take into account the power reserve factor:

$$K = \sqrt{1 + \frac{e}{1+e} \cdot \left(\frac{I_1}{I_{RMS}}\right)^2 \cdot \sum_{n=2}^{40} n^q \cdot \left(\frac{I_n}{I_1}\right)^2} \quad (1)$$

where, I_n – n harmonic current; I_1 – first harmonic current; e,q – coefficients depending on losses in copper and steel of the transformer; and I_{RMS} – true rms current:

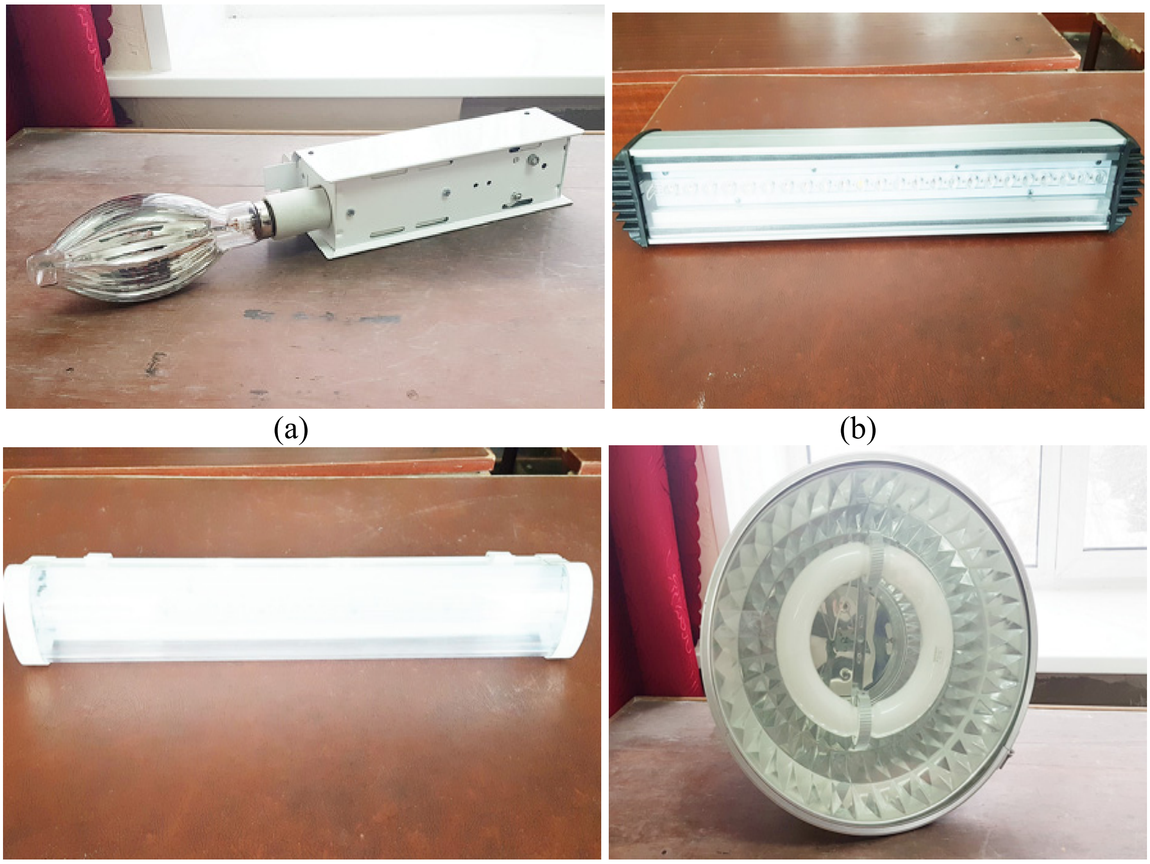
$$I_{RMS} = \sqrt{\sum_{n=1}^{40} I_n{}^2} \quad (2)$$

The inversely proportional value of the transformer power factor is the long-term allowable load factor of the transformer, which can be determined by a simplified expression [17]:

$$K_{3.T.} = \sqrt{1 + 0.1 \cdot \sum_{n=2}^{40} n^{1.6} \cdot \left(\frac{I_n}{I_1}\right)^2} \quad (3)$$

To achieve this goal, the work solved the problem of determining the higher harmonics currents of existing and prospective greenhouse irradiators experimentally.

The object of research - high-pressure sodium lamp (HPS) lights of the ZhTZ brand of KETZ company (figure 1a), LED lamps of the DSO brand OKB Luch company (figure 1b) and Flora brand of the ProfSvet Company (figure 1c), electrodeless lamps (EL) of the LVD brand S&O company (figure 1d).



(a) (b) (c) (d)

Figure 1. Photo appearance of HPSL irradiators KETZ company (a), LED lamps with active PFC OKB Luch company (b), LED lamps with passive PFC Profsvet company (c), electrodeless lamp S&O Company (d).

In the LL pulse converters of electric energy use a bridge rectifier with a storage capacitor to obtain a constant voltage from the sinusoidal voltage. In this case, the rectifying circuit consumes current from the electric system at a time when the instantaneous value of the mains voltage exceeds the voltage of the storage capacitor in modulus. As a result, the current consumed from the electric system has a non-sinusoidal form and contains high harmonics, which leads to the reactive power component. The power factor of such devices is usually below 0.6. In addition to inefficient power consumption, there is a distortion of the mains voltage form, and other electricity consumers are forced to apply measures to protect against line interference. Active or passive power factor correctors, PFC (power Factor Correction), are used to reduce the influence of the current consumer on the line. The main objectives of the PFC include the reduction of harmonic distortion, output power limitation, short circuit protection, and the protection against changes in the supply voltage level. In fact, the PFC can be considered as a buffer stage that reduces the mutual influence of the supply line and the power supply. Passive PFC are ordinary chokes. Active PFCs are boost pulse voltage converters consisting of a choke, a key element (e.g. power MOSFET), a rectifier diode. A storage capacitor [18] is connected to the terminals of the active PFC converter. Active PFC is more effective in reducing current harmonics, however, significantly increases the cost of the lamp. Therefore, we studied LED lamps with active PFC (LL_{APFC}) and with passive PFC (LL_{PPFC}) for a more objective assessment in this paper.

The appearance of the measuring electrical complex is shown in figure 2.

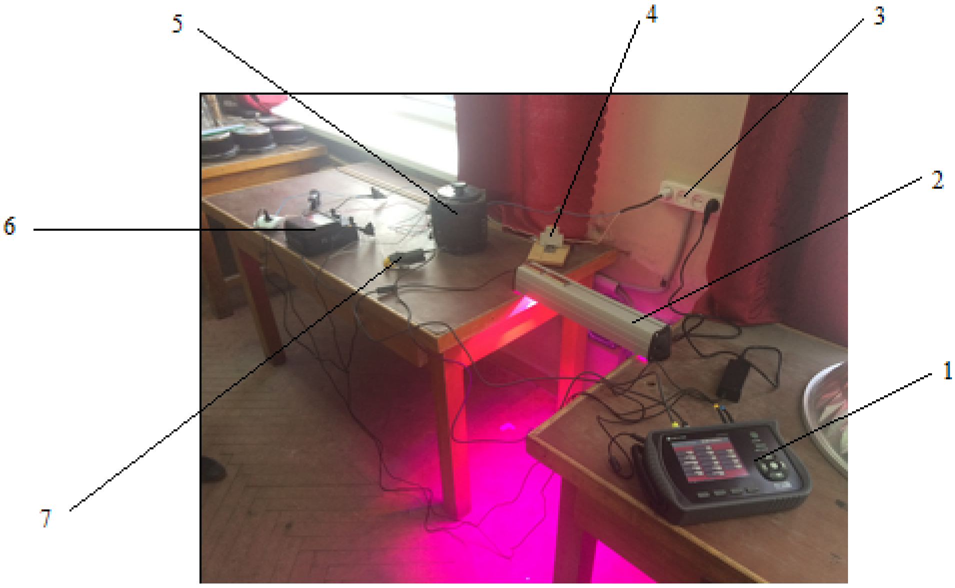


Figure 2. Experimental electrical complex for measuring higher harmonics of the current of greenhouse irradiators. The measuring electrotechnical complex includes 1 – Circutor AR-6 power quality analyzer, 2 – greenhouse irradiator, 3 – power supply ~ 220 V, 4 – circuit breaker, 5 – RNO-250-2-M control autotransformer 6 – ammeter; 7 – current measuring clamps at 5 A.

The supply voltage for the light (figure 2, point 2) source was adjusted by a linear autotransformer (figure 2, point 5). The readings of electrical parameters were taken by an electric power quality analyzer (figure 2, point 1). The measurements were carried out on 2 light sources of each type, 3 measurements of each current harmonic. During the first hour after switching on, the irradiators reached the nominal operating mode, measurements were not performed. Then, measurements were made of the harmonic composition of the irradiator currents in nominal mode.

3. Results and discussion

Based on the experimental studies, spectrograms of the higher harmonics currents of irradiators with sodium lamps (figure 3a), LED irradiators with an active power factor corrector (figure 3b), LED irradiators with a passive power factor corrector (figure 3c), irradiators with induction lamps (figure 3d) were obtained.

LED irradiators with a passive power factor corrector have the greatest current harmonics (THD_I=65.9%, figure 3c). The lowest harmonics (THD_I=4.9%) of the current are irradiators with induction lamps (figure 3d).

On the basis of the results of experimental studies on higher current harmonics, the authors obtained permissible load factors of transformers when supplying a large number of different types of lamps for greenhouse plants using the formula (3): for HPSL lamps (figure 3a) – 0.95 max; for LED with active power factor correction (figure 3b) – 0.76 max; for LED with passive power factor correction (figure 3c) – 0.59 max; EL lamps (figure 3d) – 0.98 max.

The most promising power supply systems when replacing HPSL lights in the greenhouse industry are electrodeless fluorescent lamps lights in comparison with LED. Experimental studies have shown that the current levels of the higher harmonics of the first orders (THD_I=4.9%, figure 3d) are much lower than the second (THD_I=43,8% and THD_I=65,9%, figure 3b and figure 3c). This will increase the load factor of transformers (0.98 vs. 0.76...0.59), and as a result, reduce their power and cost.

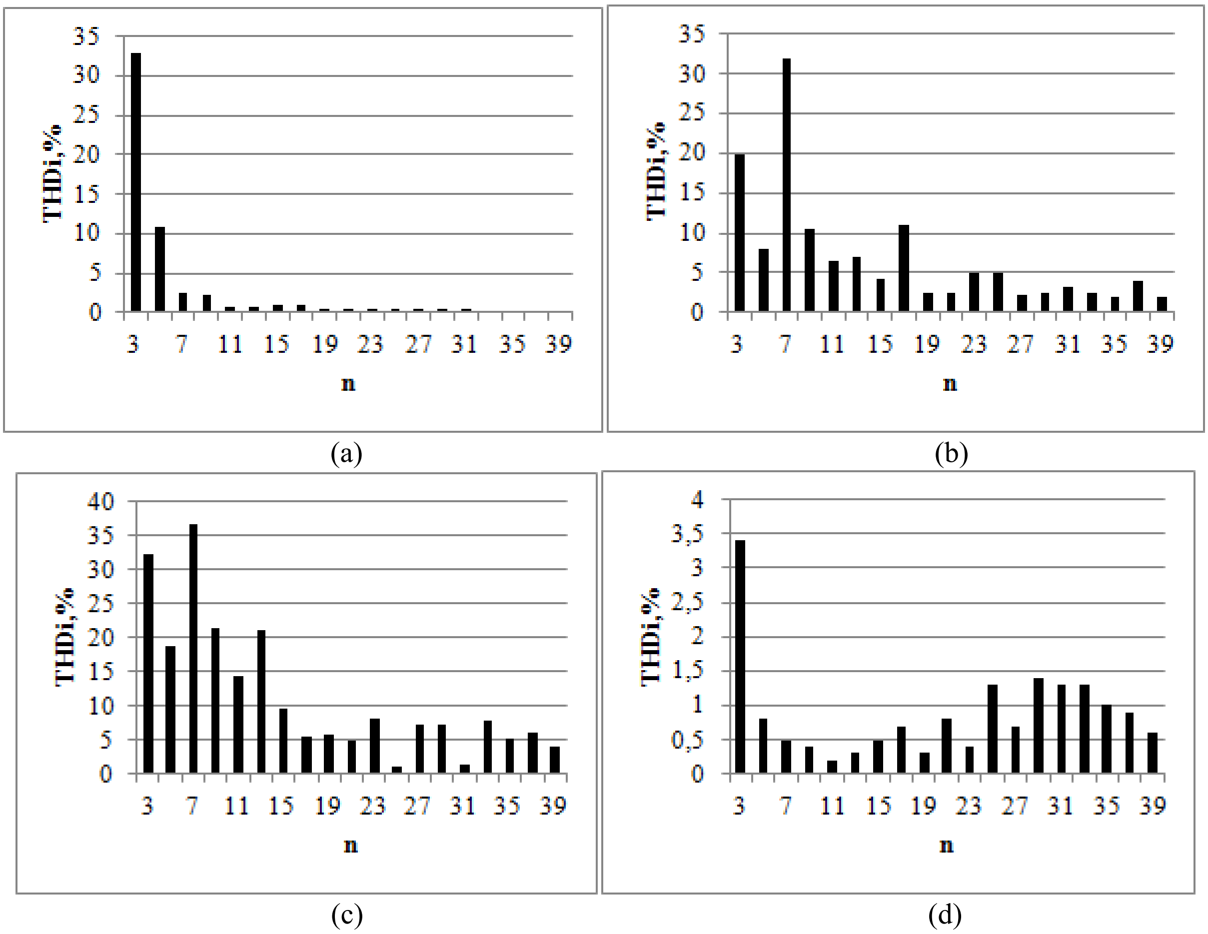


Figure 3. Spectrograms of currents of higher harmonics of greenhouse irradiators.

On the basis of the results obtained, the authors believe that it is necessary to know and take into account the harmonic composition of the radiation sources currents when designing and reconstructing irradiation systems of plants and transformer substations for greenhouse plants using LED lamps for irradiation of plants for the correct choice of power supply transformers for reliable and high-quality power supply.

4. Conclusion

Greenhouse irradiators affect the load factor of step-down transformers. Based on the results of experimental studies of the higher harmonics of the current of greenhouse irradiators, the permissible transformer load factors are obtained: for luminaires with HPS lamps no more than 0.95, for LEDs with an active power factor corrector no more than 0.76, for LEDs with a passive power factor corrector no more than 0.59, for luminaires with induction lamps not more than 0.98. To reduce current harmonics in systems with LED lamps in order to increase the load factor of transformers, it is necessary to use special devices - active or passive harmonic filters. For greenhouse irradiators with sodium lamps and induction irradiators, the use of harmonic filters is not required.

References

[1] Rakutko S A, Rakutko E N and Vaskin A N 2016 Comparative evaluation of energoecological properties of lettuce photoculture (Lactuca Sativa L.) under sodium and electrodeless lamps. *Bulletin of Saint-Petersburg State Agrarian University* **43** 331

[2] Johkan M, Shoji K, Goto F, Hahida S and Yoshihara T 2012 Effect of green light wavelength and intensity on photomorphogenesis and photosynthesis in Lactuca sativa. *Environ. Exp. Bot.* **75** 128 https://doi.org/10.1016/j.envexpbot.2011.08.010

[3] Fan X X, Xu Z G, Liu X Y, Tang C M, Wang L W and Han X L 2013 Effects of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. *Scientia Horticulturae* **153** 50 https://doi.org/10.1016/j.scienta.2013.01.017Get rights and content

[4] Lin K H, Huang M Y, Huang W D, Hsu M H, Yang Z W and Yang C M 2013 The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (*Lactuca sativa L. var. capitata*). *Scientia Horticulturae* **150** 86 https://doi.org/10.1016/j.scienta.2012.10.002

[5] Pardo G P, Aguilar C H, Martínez F R and Canseco M M 2014 Effects of light emitting diode high intensity on growth of lettuce (*Lactuca sativa L.*) and broccoli (*Brassica oleracea L.*) seedlings. *Annual Research & Review in Biology* **19** 2983

[6] Mishanov A P, Markov A E, Rakutko S A, Browzin V N and Rakutko E N 2015 The effect of the ratio of the share of green and red radiation on biometrics of lettuce. *Technologies and Means* **87** 264

[7] Sase S, Mito C, Okushima L, Fukuda N, Kanesaka N, Sekiguchi K and Odawara N 2012 Effect of overnight supplemental lighting with different spectral LEDs on the growth of some leafy vegetables. *Acta Hortic.* **956** 327 DOI: 10.17660/ActaHortic.2012.956.37

[8] Lee J S, Lim T G and Kim Y H 2014 Growth and phytochemicals in lettuce as affected by different ratios of blue to red radiation. *Acta Hortic.* **1037** 843 DOI: 10.17660/ActaHortic.2014.1037.112

[9] Prikupets L B, Emelin A A and Tarakanov I G 2015 Led phyto-irradiators: from the phytotron to the greenhouse? *Greenhouses of Russia* **2** 52 doi:10.1088/1757-899X/156/1/012045

[10] Martirosyan Yu, Polyakova M N, Dilovarov T A and Kosobryukhov AA 2013 Photosynthesis and productivity of potato plants under different spectral irradiation. *Agricultural Biology* **1** 107

[11] Muneer S, Kim E J, Park J S and Lee J H 2014 Influence of green, red and blue light emitting diodes on multiprotein complex proteins and photosynthetic activity under different light intensities in lettuce leaves (*Lactuca sativa L.*). *Int. J. Mol. Sci.* **15** 4657 doi: 10.3390/ijms15034657

[12] Kondrateva N P, Korepanov R I, Ilyasov I R, Bolshin R G, Krasnolutskaya M G, Somova E N and Markova M G 2018 The efficiency of microprocessor systems of automated control of LED irradiators. *Agricultural Machinery and Technologies* **3** 32

[13] Kondrateva N P, Obolensky N V, Bolshin R G, Baturin A I and Krasnoluckaya M G 2018 Power- and resource-saving electric lighting technologies in agricultural engineering for protected soil. *Advances in Engineering Research* **151** 364

[14] *Test Report of HPSL-400 and Electrodeless Fluorescent Lamps 250W M-S and Bi-S*, available at: http://growlife.ru/otchet-po-ispytaniyu-lamp-dnat-400-i-indukcionnyx-lyuminescentnyx-lamp-250w-m-s-i-bi-s/

[15] Shishkin S 2013 Optimization of the operation of transformers of shop substations with non-linear load. *Power Electronics* **1** 46

[16] Vagin G Ya, Sevostyanov A A and Petritsky S A 2017 On the issue of choosing the number, power and load factor of workshop step-down transformers. *Energy Security and Energy Saving* **2** 33

[17] UTE C15-112-2000. *Protection Against Electric Shock. Current Effects on Human Beings and Animals* (Cheboksary: GSHA)

[18] Gasanov S 2012 The structure and function of the power factor correction on semiconductor. *Solid State Lighting* **4** 28