ENERGY EFFICIENCY IN ELECTRICAL LIGHTING NETWORKS WITH LED LUMINAIRES

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Abstract: *This article examines the issue of energy saving in electrical lighting networks equipped with LED luminaires powered by solar panels based on monocrystalline silicon material with automatically controlled operating modes, and develops technical solutions to increase economic efficiency based on the results of experimental research.*

Methods and Materials. In this research, lighting engineering and electrical engineering theoretical calculations, experimental measurements, and comparative analysis methods were applied. The electrical lighting network was analyzed using lighting and electrical calculations based on the conventional luminous flux method and the power loss coefficient method.

Results. The article scientifically substantiates the improvement in energy efficiency and economic performance of the system when LED lighting fixtures equipped with motion and photo sensors and powered autonomously by solar panels are used in electrical lighting networks, compared to the initial condition where gas-discharge lighting fixtures were installed.

Conclusion. Based on the results of experimental studies and theoretical calculations, the authors developed recommendations for the use of energy-efficient LED lighting fixtures in electrical lighting networks.

Keywords: *gas-discharge lighting fixtures, LED lighting fixtures, motion and photo sensors, solar panels, automatic control device, energy efficiency, economic performance indicators, lighting and electrical parameters.*

INTRODUCTION

In developed countries, approximately 17–18% of the total annual electricity production is consumed by electrical lighting networks. This necessitates the effective application of energy-efficient lighting devices and innovative technologies with high economic efficiency in this sector. In this context, the efficient use of energy-saving LED lighting fixtures powered autonomously by solar panels made of monocrystalline silicon in industrial electrical lighting networks is currently one of the most pressing issues. Evaluating the amount of electrical energy consumed in modern lighting systems and the environmental characteristics of the lighting devices used against current requirements highlights the significant scientific and practical importance of this research.

A detailed analysis of scientific research conducted by specialists worldwide shows that improving energy efficiency and economic performance in electrical lighting networks depends on several interrelated factors: the correct selection of lighting equipment types, ensuring uninterrupted energy supply through renewable alternative energy sources, and the implementation of automatic control of system operating modes. At present, there remain unresolved and insufficiently studied issues in this field [1–5].

Based on the above-mentioned sources, the external electrical lighting networks of a highway were selected as the object of this research.

The purpose, objectives, and methodology of the research.

In this research work, the main objective was to scientifically substantiate—based on the results of experimental studies and theoretical calculations—the improvement of energy efficiency and economic performance indicators of a highway electrical lighting network. This was achieved by ensuring standard-compliant and high-quality illumination in each specific case, selecting appropriate light sources, and implementing automatic control of the operating modes of lighting fixtures.

Practical experience shows that the significant applied importance of electrical lighting lies in the fact that, in every field, providing standard and high-quality illumination in accordance with the regulations of the “Rules for Electrical Installations” ensures not only an increase in labor productivity and the quality of industrial output, but also prevents various technical failures or accidents [6–10].

Based on the above considerations, this scientific article presents technically grounded solutions demonstrating that the application of energy-efficient LED lighting fixtures - powered continuously by solar panels and equipped with motion and photo sensors - in the electrical lighting network of a selected main street (research object) leads to an increase in the system’s energy efficiency and economic performance indicators.

In this study, the theoretical calculations of the electrical lighting network were carried out in the following stages:

1. Lighting and electrotechnical calculations of the electrical lighting network were carried out in cases where gas-discharge electric lamps were installed and energy-saving LED luminaires were used, and the installed power of the electric luminaires $P_{1.o'r}$ and $P_{2.o'r}$ were determined, respectively;

2. Minimum illuminated working points A of the surface illuminated by electric luminaires were selected, the numerical illuminance values at these points were determined using a luxmeter (Fig. 1), and the electricity consumed by consumers was calculated.

3. The main parameters characterizing the energy efficiency and efficiency indicators of the electric lighting network have been determined.

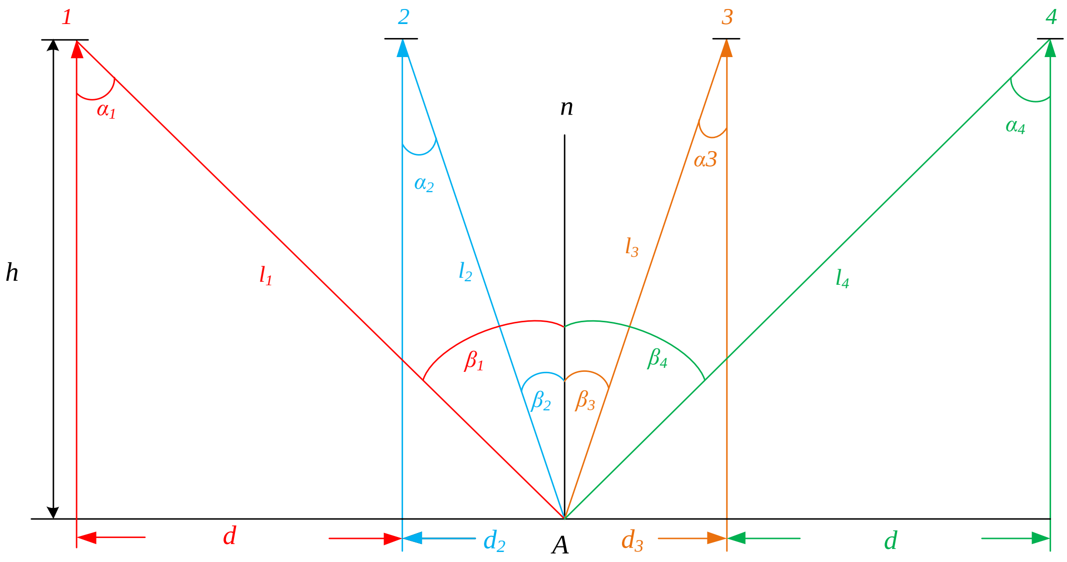

Figure 1. Minimum illuminance of the illuminated area surface

Results of the experiment. The main parameters characterizing high-pressure gas-discharge DRL and energy-saving LED electric luminaires with motion sensors, powered by autonomous solar photovoltaic batteries, are presented in Table 1.

Table 1.

Main parameters of electrical lighting network consumers.

№	Model and main parameters of electric lighting	
1.	Model	DRL 250
	Nominal voltage and frequency	220 V, 50 Hz
	Power	250 W
	Base type	E40
	Service life	10,000 hours
	Luminous flux	1200 Lm
	Color rendering	60 Lm/W
2.	Model	ZGSM 100
	Nominal voltage	DC 12/24V
	Power	100 W
	Luminous flux	7,500 Lm
	Color rendering	115 Lm/W
	Control type	Motion sensor
	Motion sensor detection range	11-12 meters
	Average battery charging time	4-5 hours
	Average battery discharging time	24-hour

Since the object under study in the research work is an urban-type highway, according to the "Construction Norms and Rules," the standard illuminance is set at E_M≈10 Lk for the roadway width of motor vehicles and E_M≈4 Lk for pedestrian paths [11-14].

The results of determining the illuminance of the pavement surface using the point method at the selected working point A, as shown in Figure 1 above, are presented in Table 2 below.

Table 2

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№	Electric lighting model	The power of the electric lamp is W.	Maximum and minimum illuminance values of the field surface Lk.	Average illuminance of the field surface Lk.	Required standard llluminance of the field surface Lk
Main road area for vehicle traffic					
1	DRL 250	250 W	E_{max}=10,2 Lk E_{min}=9,7 Lk	$E_{o'rt}$=9,95 Lk	10 Lk
2	ZGSM 100	100 W	E_{max}=10,5 Lk E_{min}=9,8 Lk	$E_{o'rt}$=10,2 Lk	

Data on the number of luminaires, the height of their installation on supports, and voltage losses occurring during operation, determined based on the results of experimental and theoretical calculations for main roads in a single section of the electric lighting network, are presented in Table 3 below.

Table 3 Lighting and electrical technical parameters of electrical lighting in the network.

Lighting model	Number of lights	Installation height of the luminaires (m).	Distance between lights	ΔU - is the voltage loss in the electrical lighting network;
DRL 250	30	11	30	2,1 %
ZGSM 100	30	11	30	1,5 %

Table 4 presents the calculated numerical values for the number of luminaires required to achieve standard illumination of the area across the width of highways, along with their installed power $P_{o'r}$, daily operating time, and electricity consumption under maximum load conditions for a single lighting section.

$$P_{1.o'r} = 30 \cdot 0{,}25 = 7{,}5 \text{ kW}; \qquad P_{2.o'r} = 30 \cdot 0{,}10 = 3 \text{ kW}.$$

Table 4

Parameters of the luminaires and the electrical energy consumed in a single section of the lighting network.

Model of electric lighting	Number of electric lights	Installed power (kW)	Average operating time per day (hours)	Amount of electricity consumed (kWh)
DRL 250	30	7,5	9 соат	67,5 кW·соат
ZGSM 100	30	3	9 соат	27 кW·соат

The electrical energy consumed in one section of the highway lighting network, with average usage time $W_{1.EE}$, $W_{2.EE}$ for a 24-hour period and $W_{1.Y}$, $W_{2.Y}$ for one year, was determined using the following equations.

For a 24-hour period:

$$W_{1.EE} = 7{,}5\text{кW} \cdot 9 \text{ соат} = 67{,}5 \text{ кW} \cdot \text{hour};$$
$$W_{2.EE} = 3 \text{ кW} \cdot 9 \text{ соат} = 27 \text{ кW} \cdot \text{hour}.$$

During the year:

$$W_{1.Y} = W_{1.EE} \cdot N = 67{,}5 \text{ kW} \cdot \text{soat.} \cdot 365 \approx 24{,}6 \text{ MW} \cdot \text{hour};$$
$$W_{2.Y} = W_{2.EE} \cdot N = 27 \text{ kW} \cdot \text{soat.} \cdot 365 \approx 9{,}85 \text{ MW} \cdot \text{hour};$$

An in-depth analysis of the research results revealed that for a single section of a highway lighting network, the initial scenario utilized high-pressure gas-discharge DRL-type lamps. In this case, the installed power required to provide the standard illuminance of E_m=10 lx, as specified by the "Construction Norms and Rules," was $P_{1.o'r} = 7{,}5$ kW. In the second scenario, which involved the use of energy-efficient LED-type lamps, the installed power was $P_{2.o'r} = 3$ kW. These research findings indicate that over one year of operation, the lighting network consumes 24.6 MWh of electricity in the first scenario and 9.85 MWh in the second.

Conclusion.

➢ Based on the results of the experimental study, it was determined that the lamps selected to ensure standard illuminance for the research object in each specific case fully meet the requirements of the "Electrical Installation Rules" in terms of their type and quantity;

➢ Electrical luminaires that fully meet the lighting and electrical technical requirements for the research object were selected, the main parameters characterizing one section of the electrical lighting network were determined, and an in-depth analysis was conducted based on comparison;

➢ As a result of replacing gas-discharge luminaires, which are still used in electric lighting networks, with energy-saving LED luminaires, a scientifically grounded technical solution has been developed to increase the energy efficiency and efficiency of the system.

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