Analysis of Outdoor Lighting Control Systems and Devices for the Creation of Outdoor Lighting Automatic Control System Using the Traffic Flow Value

Nikolai Pavlov[1], Andrei Bachurin[1] and Eduard Siemens[2]
[1]*Electrical Engineering Faculty, Perm National Research Polytechnic University, Komsomolskiy Prospect 29, Perm, Russia*
[2]*Anhalt University of Applied Sciences - Future Internet Lab Anhalt, Bernburger Str. 55, 06366 Koethen, Germany*
pavlov_v94@mail.ru, bachurin@ellips.ru, e.siemens@emw.hs-anhalt.de

Keywords: Lighting Automatic Control, Control System, Outdoor Lighting, Energy Efficiency, Quality Lighting, Traffic Flow.

Abstract: This article describes various automatic light control systems. The aim is to analyze existing luminous flux lighting installations with automatic control systems and propose some invention, which is able to eliminate some of their shortcomings. Disadvantages of existing systems are the increased power consumption due to the lack of the luminous flux flexible regulation depending on the traffic on the objects requiring illumination. The aim of invention is to optimize the power consumption by reducing its consumption in moments of significant traffic reduction. The known control systems are supplemented with a counter number of vehicles per unit of time and the controller of functional dependence, which controls the lighting installation luminous flux. The control signal for the lighting system is automatically generated depending on the intensity of vehicles, and sets the light amount as a percentage of the nominal value. The technical result is a significant reduction of power consumption of public lighting systems, the economic result - a reduction of electricity costs.

1 INTRODUCTION

About 14% of all generated electricity is spent on public illumination (Klykov, 2011), therefore increasing the lighting systems energy efficiency plays an important role in energy savings.

The application of the electronic ballasts and lighting control systems makes it possible to bring savings up to 60%.

The main contribution to this effect is created by light management systems (40%), while the share of electronic ballasts in the magnitude of this effect does not exceed 20% (Liping Guo, 2008).

Components of a lighting installation, determine its energy efficiency are shown in Table 1.

Table 1: Components of lighting installations and their functions.

Components of the lighting system	Functions
Lighting sources	Luminous flux generation
Lighting appliances	Luminous flux distribution
Ballasts	Performs supply electrical energy to light sources
Lighting control systems	Lighting Mode Control

2 ANALYSIS OF AUTOMATIC LIGHTING CONTROL

We know that economic efficiency during operation of lighting installations is inversely proportional to their power consumption, power consumption, in turn, is determined by the nominal value of the luminous flux produced by the lighting installation.

It is also known that different situations require different quantities of illumination and, under otherwise identical lighting installations parameters, different luminous flux quantities.

Generally, these situations are divided depending on the work complexity performed by the operator and the irritant (distractions) factors intensity.

Lighting systems project in a specific location (room, area, street section) is calculated on the operation for a long time (at least 5 years) (GOST, 2013).

Usually, the situation in the illuminated spot changes over the lifetime of the lighting system: the intensity of the movement throughout the day and over the year is changing, etc.

There are many technical solutions with automatic lighting control systems application.

Lighting load control is carried in two main ways: disconnection of all or of part of luminaires or change in the lamp luminous flux (for all the group of lamps or individually) (Branislav, 2016).

There are cases where the project specifications for the illuminated object is selected initially overestimated (excessive light flux, increased operation of lighting installations time limits) from various reasons (historical city center, theoretical streets capacity, movement of public transport, etc.) that additionally increases electric power consumed in the absence of regulation in real time.

The moment of illumination mode change in known systems is determined by signals from a light barrier, timers, motion sensors. Classification of outdoor lighting control system is shown in Figure 1.

Disadvantage of the existing control systems with motion sensors is reduction of lamp life due to switching on and off and the lack of luminous flux regulation.

Disadvantage of other control systems is the inability of automatic lighting control in real time depending on lighting needs in a specific situation (Boyce, 2009).

3 POWER CONTROL DEPENDING ON THE TRAFFIC FLOW

The aim of new lighting control system is to optimize the power consumption by reducing its consumption in the moments of a significant reduction in traffic on the objects which require illumination.

The control system taken as a basis is able to adjust the light flux of lighting installations in groups, depending on the time of a day according to the formula:

$$J = f(T), \tag{1}$$

where J - is the light flux level in the percentage of its nominal value, %; T - a variable indicating the current time, take one of four values: "Day", "Night", "Morning" or "Evening"; f - control function.

But it lacks switching of the lighting on and off due to flexible schedule. It is necessary that the schedule does not have only three states during the day - when the light is switched on, when light is switched on not at full power and when the light is switched off, but allows adjustments according to the traffic intensity within a few minutes.

This objective is achieved by the fact to be considered as a prototype of the control system with fixed time zones, the principle of which is shown in Figure 2, supplemented by: the number of vehicles per unit of time counter and the controller, which in turn controls the lighting system luminous flux by functional dependency:

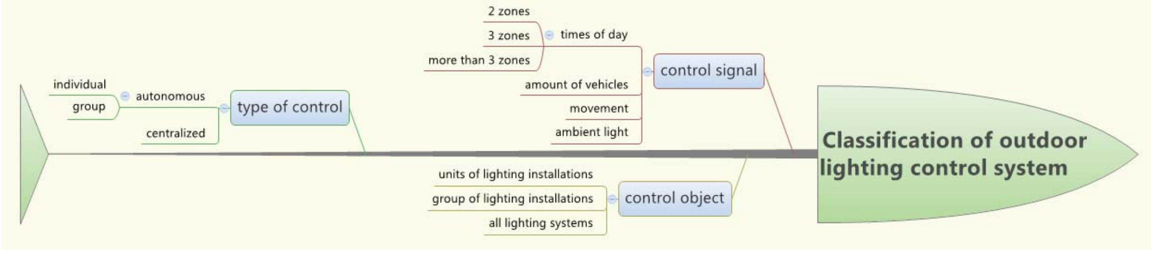

Figure 1: Classification of outdoor lighting control system.

$$J = f(N), \tag{2}$$

where J - is the light flux level in the percentage of its nominal value, %; N - number of vehicles in the percentage of the maximum average annual value, %; f - control function.

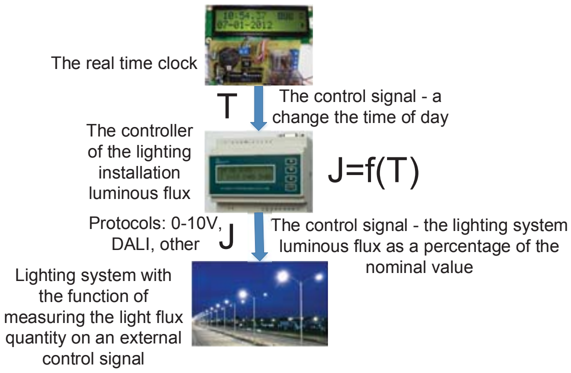

Figure 2: The operating principle of the control system with fixed time zones.

To develop the control algorithm, were calculated traffic flows on several typical streets of the city. The calculation was performed manually by counting the number of vehicles over one day per every 5 minutes on the site of interest. Counting was carried out on the previously recorded video.

For operation in the proposed control system can be applied automatic counters (based on infrared, ultrasonic or video technology). Figure 3 shows the operating principle of the new control system.

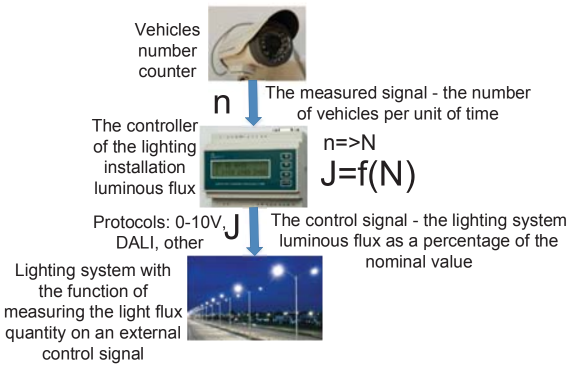

Figure 3: The operating principle of the new control system.

Features of the proposed operating principle - control signal for the lighting installation is automatically generated depending on the traffic of vehicles per unit of time.

The control signal sets the light amount as a percentage of the luminous flux nominal value. The dependence can be determined in tabular form or as a continuous function.

The application effectiveness of electronic ballasts with a hard regulation within 8 range shown in Figure 4 (Bachurin, 2016).

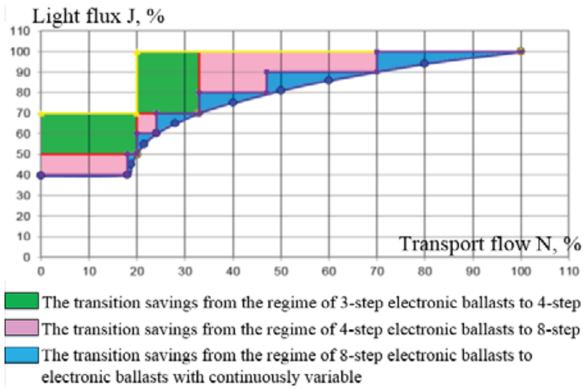

Figure 4: The application efficiency of electronic ballasts.

Specific functional dependencies must be consistent with the technical possibilities of lighting systems and applicable regulatory documents (GOST, 2013).

Example timetable of vehicles in conjunction with the operating schedule of the existing lighting system and the operating schedule of the system with an 8-step control principle is shown in Figure 6. The luminous flux is directly proportional to the traffic flow, so these values on the graph shown in the same coordinate axis.

In the daytime artificial lighting is not required. The principle of signal shaping in the form of tabular dependence is shown in Table 2.

Table 2: Example of control by 8-step tabular function.

№ step	Amount of light flux J, %	The boundaries of the traffic flow changes N, %
1	100	100-70
2	90	70-47
3	80	47-33
4	70	33-24
5	60	24-20
6	50	20-18
7	40	18-1

Values for the function are calculated in proportion to the value of the traffic flow - 100% of the light flux corresponds to 100% annual average movement intensity of vehicles, while reducing traffic volume - decreases the value of lighting installations luminous flux. Figure 5 shows the operation of this principle.

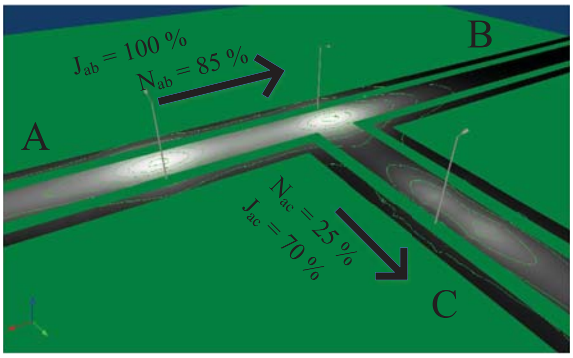

Figure 5: Operating of the new control system.

The dependence can be determined 2nd order function so as to fit in key points of standard documents (GOST, 2013).

These tables can be represented as a continuous function as shown in Figure 4. The coefficients in this case is calculated by method of least squares:

$$J = -0{,}0052N^2 + 1{,}208N + 31{,}522 \qquad (3)$$

where N - is the traffic flow, %; J - the luminous flux, %.

Schedule automatic control system is shown in Figure 7. The figure also schematically marked energy savings by using functional and table control functions. Next, to evaluate the effectiveness of the lighting control proposed method is necessary to perform a quantitative assessment to save electricity.

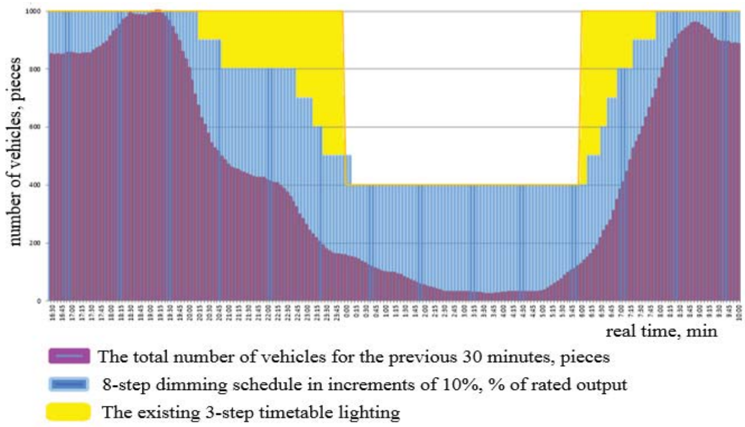

Figure 6: Vehicles movement schedule in conjunction with the operating schedule of the existing lighting system and the operating schedule of the system with 8-step regulation principle presented in tabular form.

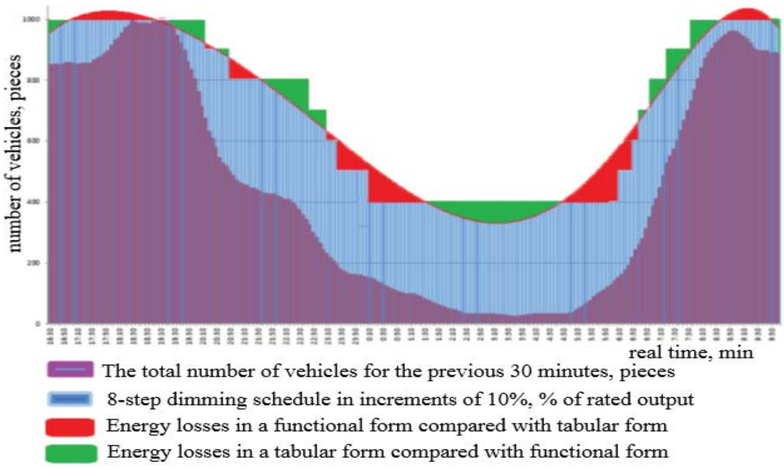

Figure 7: Vehicles Movement schedule in conjunction with the operating schedule of the existing lighting system and the operating schedule of the system with 8-step regulation principle presented in tabular form and continuous function form.

4 CALCULATION OF ELECTRIC ENERGY CONSUMPTION WITH OUTDOOR LIGHTING SYSTEM

To evaluate the effectiveness of the proposed lighting energy control system must calculate power consumption before and after its application. The estimation is made for Perm's outdoor lighting systems.

The integration of power consumption carried out for the year, since it is the smallest time interval at which the outdoor lighting power schedule more accurately shows the change in energy consumption, therefore, the annual consumption of outdoor lighting installations should be calculated according to the formula:

$$W_{year} = \int_{year} P \cdot dt \quad (4)$$

Schedule of power consumed by the outdoor lighting installation with the existing control system is shown in Figure 8.

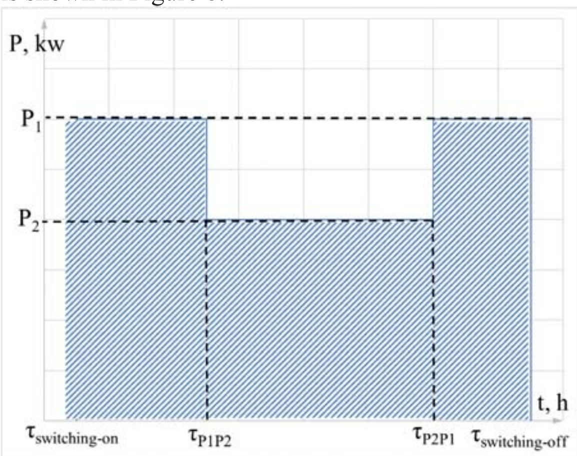

Figure 8: Schedule of power consumed by installations with the existing outdoor lighting control system.

Having defined time limits, you can count the number of inclusion hours by the formulas:

$$\tau_{P_1} = \sum_{i=1}^{m} ((\tau_{P_1P_2} - \tau_{switching-on}) + (\tau_{switching-off} - \tau_{P_2P_1}) \quad , (5)$$

$$\tau_{P_2} = \sum_{i=1}^{m} ((\tau_{P_2P_1} - \tau_{P_1P_2}), \quad (6)$$

The results of the annual outdoor lighting operating time calculation are presented in Table 3.

Table 3: Annual operating time for the existing regime of outdoor lighting.

№ step	Site length τ, h	Power consumption on site P, kW
1	1856,04	6970
2	1928,38	4879

Schedule of power consumed by outdoor lighting installations with a new control system with 8-step operating schedule is shown in Figure 9.

The inclusion hours number of each of the 8 new control regimes, at certain time intervals, is analogous to the existing control system calculation.

The results of the annual outdoor lighting operating time calculation are presented in Table 4.

Table 4: Annual operating time for the new 8-step regime of outdoor lighting.

№ step	Site length τ, h	Power consumption on site P, kW
1	1960,03	1600
2	308,4	3485
3	146,93	4182
4	163,25	4879
5	561,7	5576
6	237,4	6273
7	406,7	6970

The total values of energy consumed by the outdoor lighting installations shown in Table 5.

Table 5: Annual energy consumption of the existing and the new control system.

The control system	Energy consumption per year, GW per h
existing	22,345
new 8-step	8,841

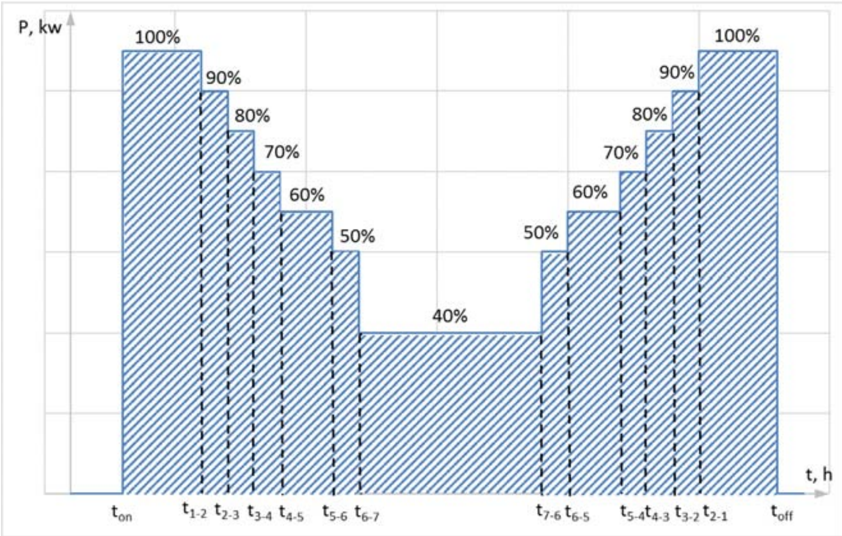

Figure 9: Schedule of power consumed by outdoor lighting installations with 8-step control.

5 CONCLUSION

The proposed automatic control system of lighting installation differs from the existing ones, that is provided with number of vehicles per unit of time counter, transmitting the measured signal in the luminous flux controller.

The controller, in turn, generates a control signal based on the functional dependence of the illumination level of the intensity of vehicle traffic, and then transmits the control signal to lighting system as a percentage of its nominal value in accordance with the one of standard interfaces (0-10V, the DALI, etc).

Implemented control principle allows to provide reduction in the value of the power consumption, reduce electricity costs and improve illumination uniformity of urban spaces and eliminate the need to switch off the lighting at night.

The estimated efficiency of the proposed new control system is 60%, compared to existing lighting systems.

It should be noted that the proposed control system will also improve the efficiency of modern lighting systems based on LED-lamps, the efficiency will not be less than 10%.

The next steps in this direction should be devoted to features of the technical implementation, the development of techniques and accurate energy calculation with system application for a particular facility, the development of control functions with maximum energy efficiency.

REFERENCES

Klykov M.E., Ju.B. Ajzenberga, 2011. Electronic ballasts for discharge lamps and automatic lighting control systems. PROON.

Liping Guo, Marjukka Eloholma DSc & Liisa Halonen D.Sc, 2008 Lighting Control Strategies for Telemanagement Road Lighting Control Systems, LEUKOS, 4:3, 157-171

GOST R 55706-2013, 2013 Outdoor lighting utilitarian. Classification and standards

Branislav M. Todorović, Dragan Samardžija, 2016. Road lighting energy-saving system based on wireless sensor network. Springer Science+Business Media Dordrecht

Boyce PR, Fotios S, Richards M, 2009. Road lighting and energy saving. Lighting Research and Technology; 41: 245–260.

Bachurin A, 2016, Improving the energy efficiency of outdoor lighting systems using the SmartLight technology Proceedings of the 4th International Conference on Applied Innovations in IT (2016). Jg. IV. Koethen : Hochschule Anhalt, pp. 9-13