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IMPROVING THE RELIABILITY OF OUTDOOR LIGHTING SYSTEMS

O. Iegorova[1], A. Iegorov[2], A. Gaunt [1]

[1]*Kharkiv Petro Vasylenko National Technical University of Agriculture*
[2]*O. M. Beketov National University of Urban Economy in Kharkiv*

The article examines the reliability of outdoor lighting systems operation considering the nature of failure flow. The author formulated and set a problem of multi-criteria optimization with identified parameters and optimization criteria. The key parameters of quality and reliable grid operation were identified. The detailed analysis of the elements and principles of the outdoor lighting grid make-up established that it is a complex structure, constantly evolving in time and space. The degree of its reliability depends on a set of conditions, especially the efficiency and reliability of its individual elements (light sources, lighting devices, wiring, security features, etc.).

The posing of problems The worsening energy crisis due to a limited supply of energy resources and increasing demand for them is one of the most important problems of our time. The rational use of light energy for lightning open spaces involves not only the functional and material resources, but, in a sense, a moral aspect, since it is used as criterion of the urban improvement and comfort**.**

Analysis of recent research and publications The outdoor lighting units make integral part of modern urban landscape and their importance is largely determined by the fact that they determine the number of road traffic accidents (RTA) in the hours of darkness. Increasing number of road accidents clearly indicates the poor quality of the lighting in urban roads. The accidents are most often in the areas with no lightning at all. The reasons for the lack of lighting can be different, usually it is the energy efficiency savings. Other reasons include light source outage, wire breakage, damaged transmission towers, damaged control lines, short-circuits in overhead lines, cable lines and power points, "false" and true responses of fuses. The last group is the most numerous. The recovery of the disconnected line takes at least 24 hours. The number of failures of lighting units (LU) comparing to the number of their recoveries defines one of the most important features of the LU – reliability. Besides the problems with the energy supply, which can partly explain the decrease in the length of the illuminated streets, this value is also influenced by the features of outdoor lighting systems. Since such systems are built on the cascade principle [1-3], the emergency in one area de-energizes the following areas. The disconnections take place when the fuse is tripped. However, besides truly emergencies activating the protection, there is a problem of so-called "false" positives. They occur when the lightning line is disconnected by the fuse burnout after the lighting unit was set to operation or the operating mode changed, i.e. during the transient processes [1-3].

Under adverse weather conditions, this type of failure can occur immediately after it was addressed (by replacement of the fuse link). Thus, the protection devices, particularly the fuses, are obviously in need for improvement. It should be highlighted that the reliability of the lighting unit as a whole largely depends on the "false" responses of the fuses caused by their design flaws and inadequate coherence between the features of existing fuses and the properties of the start-up modes for the light sources [4].

Purpose of the article - enhancement of the efficiency of the outdoor lighting grids with regard to how fuses false positives affect the grids operational reliability and economic efficiency..

The main research material. The reliability evaluation of any facilities and systems implies researching of the failure flow. The recent methods of reliability evaluation can be divided into elemental and functional [5].

The majority of elements used in outdoor lighting systems and exposed to severe conditions of external and internal factors are more likely to experience sudden failures which embrace the "false" positives, too. Taking into account that the lifespan of these elements often exceeds the operational life of the equipment for a certain period, the sudden failures become predominant. In the outdoor lighting units, the probability of short circuits is reported at the level of 37%, and of wire breakage – at the level of 24%. However, the main recovery flow in the elements of the lightning grids falls within 15-25 hours of the time to failure [5].

Due to criteria of high-quality lighting, the analysis of the outdoor lighting units functioning enables to identify the following groups of system parameters: I – illuminating parameters; II – reliability parameters; III – technical parameters; IV – economic parameters. The ranking of the optimized functions reduces the problem of multi-criteria optimization to the following form:

1. maximize - f1; f1= f (x1 - x10);
2. maximize - f2; f2= f (x4 - x10);
3. maximize - f3; f3= f (x4, x6 - x10);
4. minimize - f4; f4= f (x5 - x10).

The linear combination of criteria is as follows:

$$F = \acute{a}1f1 + \acute{a}2f2 + \acute{a}3f3 - \acute{a}4f4, \qquad (1)$$

where the operators of the summands are selected according to whether the criterion is to be maximized or minimized, άi coefficient (to be changed later) should be selected based on the priority of the criteria. The criteria in the ascending priority will go as follows f4,f3;f2;f1.

The blank cell in Table1 means that the criterion correlating with the column where this cell belongs, does not depend on the respective parameter. Up and down arrows mean the monotonous increase (decrease) of the criterion when the parameter increases.

Table 1 - Characteristics of the criteria

Symbol	Parameter name	Type of variables	Parametric constraints
x_1	Indicator blindness	Quantitative	$x_1 < 40$
x_2	The average brightness of the road surface	Quantitative	$x_2<1,6$ [cd/m^2]
x_3	The average horizontal illuminance	Quantitative	$x_3< 20$ [lx]
x_4	Deviations voltage	Quantitative	$-10\%<x_4<+10\%$
x_5	Plant capacity	Quantitative	$0<x_5<\infty$
x_6	Operation without failure	Quantitative	$0<x_6<\infty$
x_7	Downtime	Quantitative	$0<x_7<\infty$
x_8	The number of refusals (including "false" responses)	Quantitative	$0<x_8<\infty$
x_9	The number of maintenance teams	Quantitative	$3<x_9<5$
x_{10}	The service life of the elements	Quantitative	$0<x_{10}<\infty$

To find an optimal solution with the remaining parameters, we suggest reducing the problem to a one-criterion one and have it adjusted by a decision-maker [3].

As an indicator of cost efficiency of capital investments for the compared alternatives, the minimum reduced costs are taken. The economic outcome of accounting reliability is expressed in the following main points: improving the quality of one element, thereby increasing its reliability; backup of each element, thereby increasing the reliability of its operation, without increasing reliability of a single element; defining the damage depending on the probability of one element failure and the whole backup of the object under consideration. Therefore, when choosing the optimal level of electricity supply and lighting control reliability, it is necessary to compare the expenditures required to improve the reliability and the probable damage from the malfunctioning of the outdoor lighting grid.

Conclusions: 1. The author formulated and set a problem of multi-criteria optimization with identified parameters and optimization criteria. The key parameters of quality and reliable grid operation were identified.

2. The detailed analysis of the elements and principles of the outdoor lighting grid make-up established that it is a complex structure, constantly evolving in time and space. The degree of its reliability depends on a set of conditions, especially the efficiency and reliability of its individual elements (light sources, lighting devices, wiring, security features, etc.).

3. It was found that most of the failures of the LU can be explained by the protection device response (fuse). Considering the specifics of the grid structure, such responses thus de-energize a fairly large portion of the network.

4. It was determined that the increase in the number of the fuses “false” positives responses fuses is mostly driven by the grid overload and short-circuit modes. Among them, the most important is the parameter that determines the number of failures for a certain period of time. Optimization of the protection device design would increase the reliability and reduce the non-refundable damage caused by low-quality outdoor lighting.

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Аннотация

ПОВЫШЕНИЕ НАДЕЖНОСТИ ФУНКЦИОНИРОВАНИЯ СИСТЕМ НАРУЖНОГО ОСВЕЩЕНИЯ

Егорова О. Ю., Егоров А. Б., Гонт А. В.

В статье рассматриваются вопросы надежности функционирования системы наружного освещения с учетом характера потока отказов. Автором сформулирована и поставлена задача многокритериальной оптимизации в которой определены параметры и критерии оптимизации. Выявлено параметры, которые играют определяющую роль для обеспечения качественного и надежного функционирования сети.

Анотація

ПІДВИЩЕННЯ НАДІЙНОСТІ ФУНКЦІОНУВАННЯ СИСТЕМ ЗОВНІШНЬОГО ОСВІТЛЕННЯ

Єгорова О. Ю., Єгоров О. Б., Гонт Г. В.

У статті розглядаються питання надійності функціонування системи зовнішнього освітлення з урахуванням характеру потоку відмов. Автором сформульована і поставлена задача багатокритеріальної оптимізації в якій визначені параметри і критерії оптимізації. Виявлено параметри, які грають визначальну роль для забезпечення якісного і надійного функціонування мережі.