A modern way of outdoor lighting maintenance

P A Slivnitsin\textsuperscript{1} and A A Bachurin\textsuperscript{2}

\textsuperscript{1} Department of microprocessor means of automation, Perm National Research Polytechnic University, Perm, Russia
\textsuperscript{2} Department of microprocessor means of automation, Perm National Research Polytechnic University, Perm, Russia

slivnitsin1997@mail.ru, a.bachurin@pstu.ru

Abstract. This paper considers the existing method of outdoor lighting maintenance, its disadvantages and advantages of well-known modern, but not used methods. Modern service methods using a new connector are introduced. The requirements for the connector are defined, its structural and parametric synthesis is made and for this an integrated digital model is developed. The economic justification for using the new service method is presented.

1. Introduction

Modern production systems are characterized by a high level of automation, robotization and digitalization of the main technological processes. However, supporting (service) technological processes often remain implemented in an outdated form, despite the fact that they occupy a significant part in the total cost of production [1, 2]. A similar analysis of grid companies (like water supply, power supply, lighting, etc.) shows an even lower level of use of well-known modern technologies, in the main and supporting technological processes [3]. The introduction of modern technologies in the technological processes of grid companies is necessary to reduce the cost of services, increase the profitability and investor attractiveness of these companies. The implementation of the proposed innovations is complicated by their high cost and low organizational and technical readiness of grid companies. Outdoor lighting companies stand out as the most ready to use innovative technologies like IoT, robotics and digitalization of technological processes.

The aim of this research is to propose the most useful and simple innovative technologies for outdoor lighting technological processes. The research is also aimed at implementation of a new Master’s program "Conceptual design and engineering to improve energy efficiency" for preparing engineering and administrative skills for new generation master’s students [4].

2. The current status and new way of outdoor lighting maintenance

The main technological process in an outdoor lighting company is the maintenance of lighting network. This process includes diagnosis and repair of lighting installations. Currently, the diagnosis and repair of lighting installations are performed using a lifting platform car, in an uncomfortable position in all weather conditions, with minimum repair parts and tools. Account for such works is more than 40\% of the total volume of outdoor lighting maintenance works.

Methods of mounting luminaires are currently implemented by directly fixing the luminaire on the pipe bracket using fasteners (clamp, bolt, etc.). Not all luminaire types are compatible with all bracket
types. The luminaire electrical connection to the supply grid is performed by the use of a wire passing through the support pipe of the lighting system using bolted contacts.

The most significant shortcomings of the repair performed can be identified as follows:

- Work is performed at a height of 8 to 15;
- Repair can be made under voltage;
- Work can be performed in the presence of precipitation, wind, low temperature;
- Work is performed in conditions of congestion of city highways and leads to deterioration of the road situation;
- Incomplete diagnostics of malfunctions due to lack of time and complexity of diagnostics;
- As a result of the repair, only the obvious identified malfunctions are eliminated, and only if they were able to be repaired.

The consequence of the above-mentioned shortcomings of the existing repair technology using existing luminaires mountings and the lifting platform car is the large total time for diagnostics and repair of luminaires and the low repair quality.

A large-node replacement method for outdoor lighting maintenance is proposed. A luminaire can be considered as a large unit in the field of outdoor lighting, since it is the most frequently repaired part of outdoor lighting. This method involves the repair of nodes in a specially-equipped workshop and a quick procedure for replacing repaired node, therefore, the node (luminaire) must be replaced quickly. For this it is proposed to use a special connector that will complement the luminaire and allow quick replacement of it [5].

The algorithms of the existing and proposed methods of outdoor lighting maintenance are presented in Figure 1.

![Figure 1. Algorithms for outdoor lighting maintenance: existing and proposed](image)

The maintenance costs of outdoor lighting with both methods can be calculated by formulae (1).
The Table 1 presents the calculated costs of maintaining outdoor lighting installations.

Table 1. Cost calculation for outdoor lighting maintenance.

| Parameter                                                      | Value   |
|----------------------------------------------------------------|---------|
| The current maintenance cost of one lighting installation per year, rubles | 243,45  |
| The maintenance cost of one lighting installation using the proposed method, rubles | 14,60   |

3. Development of the connector for the quick replacement of outdoor luminaires

3.1. The connector requirements

To develop the connector, it is necessary to identify a number of requirements for it.

The connector must provide mechanical mount for the outdoor lighting fixture to the bracket on the support, must comply with the range and size of the used brackets and outdoor lighting luminaires.

The connector should consist of two parts: the stationary part of the outdoor lighting support mounted on the tubular bracket and the part of the outdoor lighting mounted in the luminaire.

According to the safety requirements for the maintenance of installations, three electric poles L, N, PE are required.

The connector must meet the requirements for mechanical strength, resistance to external influences, electrical characteristics and safety [6; 7].

The presence or absence of the connector under development should not affect the lighting, electrical and other parameters of the installation. Thus, it is allowed to use luminaires on the adjacent supports, both with or without the connector.

The connector should solve the existing problems of servicing outdoor lighting (the difficulty of servicing outdoor installations; poor repair quality).

3.2. Synthesis of the connector based on the methodology of structural-parametric synthesis

The development and design of a new device requires its quantitative and qualitative description, the scientific approach to the design of the new devices involves the use of structural and parametric research methods.

The structure of the new device provides a qualitative description. The parameters of this structure give a quantitative description of the device. When designing new devices, the method of structural-parametric synthesis can be used.

The structural and parametric synthesis is a process by which the structure of an object and the values of the parameters of its elements are determined, so that the conditions of the synthesis problem (technical specification) are satisfied. If at the same time the synthesized object is obtained optimal by some criterion, then the synthesis is optimal.

The structural and parametric synthesis is represented by the following algorithm (Figure 2), it is iterative and currently does not have software implementation that allows you to synthesize the optimal structure and parameters of the new device automatically. Therefore, the structural synthesis was carried out manually, and to perform the parametric synthesis, a specialized integrated digital model was developed. The algorithm consists of three main stages: setting the objective function, structure synthesis, and parameter synthesis.

The objective function is the minimum connector production cost, Formula 2:
\[ f(\text{connector cost}) \rightarrow \text{min} \] (2)

**Figure 2.** Structural-parametric synthesis algorithm

In the synthesis of the structure, a decomposition approach is used. Next, the structural elements are detailed to the level of the finite elements of the device for which it is necessary to synthesize the parameters.

The desired synthesis parameters include:
- geometric elements dimensions of all connector blocks;
- materials for elements of all connector blocks;
- construction of all connector elements.

**Figure 3.** The integrated digital model for calculating the connector parameters

To implement the synthesis of structure parameters elements, the integrated digital model was developed. It was divided into several functional models (Figure 3) [8].

Figure 4 shows the synthesized structure of the electrical circuit of the device and the structure of the mechanical elements that provide mounting.
Figure 4. Synthesized structure model of the connector

Input values for the connector electrical-circuit calculation: maximum operating current, conductor material, their geometry and types of contacts and the main parameters of standard (typical) parts (springs for contacts).

The electrical circuit resistance calculation is performed according to the Formula 3.

$$R_{\text{c,c}} = \sum_{i=1}^{n} \frac{\rho_{\text{material,i}} \cdot L_{\text{conductor,i}}}{S_{\text{conductor,i}}} + \sum_{i=1}^{m} \frac{a_i}{F_{\text{cont},i}};$$  \hspace{1cm} (3)

$n$ – number of conductors; $m$ – number of contacts; $\rho_{\text{material}}$ – resistivity of the material; $L_{\text{conductor}}$ – conductor length; $S_{\text{conductor}}$ – section of the conductor; $a$ – coefficient for the resistance calculation; $F_{\text{cont}}$ – contact pressing force; $k$ – coefficient considering the type of connection (point, linear, planar).

The conductors heating calculation is performed according to the Formula (4) [9].

$$\theta_{\text{max}} = \theta_{\text{env}} + \frac{2 \cdot I^2 \cdot k \cdot \rho_{\theta}}{S \cdot P \cdot k_{he}} + \frac{4I^2R_{\text{cont}}}{\lambda \cdot k_{he} \cdot S_{\text{cont}} \cdot P_{\text{cont}}};$$  \hspace{1cm} (4)

$k_{he}$ – heat exchange coefficient; $S$ – cross-sectional area of the conductor; $P$ – perimeter of the conductor section; $k$ – coefficient of additional losses, taken as 1; $\rho_{\theta}$ – specific resistance of the material of the conductor, considering heating; $I$ – current through the contact; $R_{\text{cont}}$ – resistance of the contact.

Considering the heating temperature of the connector conductors, the case material is selected. For the selected material, the minimum cross-section of the inserted part is considered. According to the requirements devices used to mount luminaires must withstand five times the luminaire weight without deformation for 10 minutes. The average weight of the luminaire is taken equal to 5 kg, therefore $P = 250$ N, $L$ is taken equal to 0.5 m.

$$d = \sqrt[3]{\frac{32 \cdot M_{\text{max}}}{\pi \cdot [\sigma]}};$$  \hspace{1cm} (5)

$M_{\text{max}}$ – the largest absolute value of the bending moment; $[\sigma]$ – permissible value of the normal stress for selected material.

Support reactions are determined in accordance with the equilibrium equations (6)
After checking the entered parameters for compliance with the requirements and restrictions, the
cost of each element of the connector is calculated and summed to calculate the cost of creating a
connector with such parameters. Also, the cost of creation takes into account the assembly cost of the
connector. The calculation of the cost is made according to the formula (7).

$$
C_{\text{connector}} = \sum_{i=1}^{n} (C_{m.c} \cdot V_{c,i} + C_{m.el.c} \cdot V_{el.c,i}) + \sum_{j=1}^{m} (C_{\text{type.el.c.j}} \cdot K_{\text{type.el.c.j}}); \tag{7}
$$

\( n \) – number of connector elements; \( C_{m.c} \) – the cost of one cubic meter of case material; \( V_{c} \) – element
case volume in cubic meters; \( C_{m.el.c} \) – the cost of one cubic meter of electrical part material; \( V_{el.c} \) –
volume of the electrical part in cubic meters; \( m \) – number of different standard parts; \( C_{\text{type.el}} \) – the cost
of the standard element as part of the connector element; \( K_{\text{type.el}} \) – the number of the standard elements
as part of the connector element.

The above given calculation models form the integrated model of parametric synthesis. Its
implementation is performed using a mathematical package.

The optimal parameters of the connector (which are presented in Table 2) were obtained using the
integrated digital model.

| Parameter                                          | Value          |
|----------------------------------------------------|----------------|
| Conductor Material                                 | Brass          |
| Type of main contact connection                    | Linear         |
| The force of pressing the spring of the main contact connection, N | 2,2            |
| Type of contact connection with external conductors | Linear         |
| The force of pressing the spring contact connection with external conductors, N | 20             |
| Case material                                      | ABS plastic    |
| Minimum section of the inserted part, mm²          | 570,71         |
| Payload, kg                                        | 20             |
| Minimum conductor cross-section according to emergency conditions mm² | 0,92           |
| Dimensions of the connector, mm                    | 211×48×48      |
| Current, A                                         | 3              |
| The connector electrical circuit resistance, Ohm    | 0,0215         |
| Maximum heating temperature of conductors or contact joints, ° C | 64,74         |
| Conductor cross section, mm²                       | 1,05           |
| The cost of production, rub                         | 287            |
3.3. Feasibility study of the proposed solution

Based on the previously determined structure and the results of calculating the optimal parameters of the connector with the integrated digital model, a prototype of the connector using 3D printing was implemented.

Prototype electrical, mechanical and thermal characteristics research tests were performed. The test results showed an approximate compliance with the results of calculations of the integrated digital model.

Figure 5. Calculated connector geometric model

Figure 6. Prototype of the connector

Figure 7. Connector thermal snapshots under test current overload
The efficiency of using the connector for the implementation of large-node repair of outdoor lighting luminaires can characterize the payback period calculated by formula (8). The payback period will be 1.7 years with the connector cost of 400 rubles per unit.

4. Conclusion

The new method for outdoor lighting maintenance is proposed. The connector for quick luminaire replacement has been designed in accordance with the requirements and restrictions, and patented [10]. While designing, modern methods of structural-parametric synthesis and the construction of integrated digital models were applied. Based on the integrated digital model using additive manufacturing, prototypes were made, the tests of which confirmed their compliance with the requirements of the standards and restrictions set previously.

The proposed method of outdoor lighting maintenance using the developed connector has high economic efficiency. It has a complex effect, which consists of the reduction of time and labor costs for outdoor lighting maintenance, saving financial resources due to the simplified process of replacing the luminaire and improving the quality due to diagnostics and repairs in the specially-equipped workshops.

5. Acknowledgements

Research is supported by JSC ELLIPS and also supported by educational and research grant 573879-EPP-1-2016-1-FR-EPPKA2-CBHE-JP by European program Erasmus+ (Project INSPIRE).

References

[1] Innovation in the business enterprise sector report 2017 (Statistics Norway)
[2] Innovation in New Zealand report 2009 (Stats NZ)
[3] EUR 25650 - Innovation Union Competitiveness report 2013 (Luxembourg: Publications Office of the European Union) 332 pp
[4] Lyakhomskii A, Perfilieva E, Petrochenkov A, Bochkarev S 2015 Conceptual design and engineering strategies to increase energy efficiency at enterprises: Research, technologies and personnel Proc. of 2015 IV Forum Strategic Partnership of Universities and Enterprises of Hi-Tech Branches (Science. Education. Innovations) pp 44–47
[5] Bachurin A A, Pavlov N V and Slivnitsin P A 2018 Designing a resource-saving connector-mount for an outdoor lighting fixture Scientific and Technical Bulletin of the Volga Region 4 pp 75–77
[6] 17516.1–90 Electrotechnical products. General requirements in terms of resistance to mechanical external factors (Russian national standards)
[7] IEC 60598–1 - 2011 Lamps. Part 1. General requirements and test methods (Russian national standards)
[8] Petrochenkov A B 2014 An energy-information model of industrial electrotechnical complexes Russian Electrical Engineering 85 pp 692-696
[9] Sipailova N Yu 2014 Issues of designing electrical apparatus: a training manual (Publishing house of Tomsk Polytechnic University)
[10] Bachurin A A and Slivnitsin P A 2019 Connecting device for mounting and connecting an outdoor lighting lamp 2695631 (Russian patent for invention)