The use of light filters in the photovoltaic solar power station to improve economic efficiency

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Abstract. The agriculture and forestry sector require a solution to the problem of energy supply to autonomous consumers. The use of renewable energy sources is relevant worldwide in accordance with environmental requirements. The paper considers the project of a photovoltaic solar power station using light filters to reduce the number of solar panels to provide the required power. The Krasnoyarsk State Agrarian University has developed an experimental setup for studying the characteristics of solar panels using light filters. The aim of the study is to develop a technology for the use of light filters in photovoltaic solar power station and to optimize their operation modes in order to increase the economic efficiency of using autonomous sources for power supply to agricultural consumers. The objectives of the study are the selection and analysis of light filter materials to increase the generated power, substantiate the application of the photovoltaic solar power station for autonomous objects of agriculture and forestry and prove the economic efficiency of the proposed installation. The paper presents the results of a study of the characteristics of solar modules using filters, the main economic indicators are calculated, the economic efficiency of the use of filters is proved. The use of photovoltaic solar power station will ensure a reduction in the cost of electricity generation by 7% compared to existing plants.

On September 23, 2019, Prime Minister of the Russian Federation D. A. Medvedev signed a decree of the Government of the Russian Federation (No. 1228 dated September 21, 2019) on ratification of the Paris Agreement to Combat Global Climate Change, which should replace the Kyoto Agreement.

The main requirement of the Paris Agreement is the reduction of harmful greenhouse gas emissions. Power plants that generate electricity using carbon fuel are sources of greenhouse gases, so replacing the generation of electricity with renewable sources is a promising area.

The use of renewable sources energy (RSE) including photovoltaic solar power stations (PSPS) for energy supply of industrial and agricultural enterprises for today is relevant enough for the developed direction energy in the world, Russia, including Krasnoyarsk Territory.

One of actively developing RES areas is solar energy (SE).

In addition, the rapid development of the industry was facilitated by a decrease in the cost of production of solar panels and an increase in their efficiency. On January 20, 2009, Vladimir Putin (at that time the Prime Minister) signed a decree approving the main directions of state policy in the development of renewable energy sources until 2024, and on May 13, 2019 by Decree No. 216 “On Approving the Energy Security of the Russian Federation”, the Doctrine of Energy Security of the Russian Federation was signed.
Krasnoyarsk State Agrarian University is conducting research to improve the technical characteristics of electricity generation systems using solar energy, studying the areas of their effective application in agriculture, as well as substantiating applications from the point of view of economic efficiency.

Studies were conducted for the use of PSPS in autonomous power supply systems for agricultural facilities, fishing industries and hunting grounds of the Krasnoyarsk Territory.

To conduct a pilot experiment to determine the dependence of the generated power of the PSPS on the wavelength of light irradiating the FEM, the staff of the Krasnoyarsk State Agrarian University developed a pilot experiment setup consisting of a DUHAOTEHNOLOGYSOLARMODULS photovoltaic module (P = 10 W), a GTPower 130 A multimeter, and a battery GP1272 F2 (12 V, 28 W, 7 A.h), a light source (40 W incandescent lamp), TKA-LUX meter, a set of concentrating light filters [1, 2].

The block diagram of the experimental setup is shown in Figure 1.

![Figure 1. Block diagram of the experimental setup: 1) Light source (incandescent lamp 40W); 2) A set of concentrating filters 3) Photovoltaic module.](image)

During the experiment, an incandescent lamp with a power of 40 W was used as a light source, the light of the lamp passes through the selected concentration filter. Next, the lighting was measured on the coordinate grid, without taking into account the lateral glow. Illumination was measured with a TKA-LUX meter in FEM center. The experimental results are summarized in table 1.

**Table 1.** The results of the experiment to identify the dependence of the generated power of the FES on the wavelength of light irradiating the FEM.

| Color/wavelength, nm | Red     | Orange  | Yellow  | Green   | Blue    | Violet  |
|----------------------|---------|---------|---------|---------|---------|---------|
|                      | 625-740 | 590-625 | 565-590 | 500-565 | 440-485 | 380-440 |
| Illumination, Lx     | 90      | 100     | 97      | 96      | 44      | 13      |
| Power, W             | 3.85    | 4.03    | 3.75    | 3.88    | 3.90    | 3.55    |

Studies have shown that the use of light filters in PSPS provides an increase in the generated power by 8-12% [1, 2].

The studies were conducted for the use of PSPS for autonomous facilities, the average load of which lies within 3-5 kW. In the calculations, a power of 3 kW was adopted.

The criterion for the effectiveness of the project is the net discounted income for the period of operation. The expected economic effect can be obtained by increasing the power of the PSPS using light filters and, as a result, reducing the required number of solar panels, which will reduce the
amount of capital investment, as well as operating costs (depreciation and maintenance and repair costs).

Capital investment are determined:

$$K_i = n \cdot K_{spi} + K_{inst} + K_{tri},$$

where \(n\) – number of solar panels, pcs.; \(K_{spi}\) – cost of one solar panel, rubles; \(K_{inst}\) – installation costs, rubles; \(K_{tri}\) – transport cost, rubles.

The cost of filters is determined by the price depending on the area of the solar panels.

Operating costs for the designed installation are determined:

$$I_{ope} = I_{am} + I_{rep} + I_{oth},$$

where \(I_{am}\) – depreciation charges, rubles/year; \(I_{rep}\) – expenses for current repair and maintenance of installations, rubles/year; \(I_{oth}\) – other expenses, rubles/year.

The cost of electricity received from the PSPS is determined depending on the costs of its operation and the amount of generated energy.

$$c_i = I_i/E_i,$$

where \(I_i\) – annual operating costs by options, thousand rubles/year; \(E_i\) – volume of generated electricity by options, kW·h.

The volume of electricity consumption is determined in accordance with the load schedule of an autonomous power supply facility.

Electricity generation depends on the area of solar panels and the average daily total solar radiation on their surface installed at a given angle, as well as the geographic coordinates of an autonomous power supply object. The average daily output was determined from the NASA website [4, 5].

The source data and calculation results are presented in table 1.

| Indicators                        | Variants                     |
|-----------------------------------|------------------------------|
| Power, kWt                        | existing PSPS | PSPS with filters |
| The number of solar panels, pcs   | 3                            | 3                |
| Capital investments, thousand rubles including cost of equipment (FSES and battery) | 195,8 | 163,4 |
| filter cost                       | -                            | 6                |
| Annual operating costs thousand rubles / year including depreciation deductions maintenance and repair costs other expenses | 12,9 | 12,7 |
| -                                 | -                            | -                |
| -                                 | -                            | -                |
| -                                 | -                            | -                |
| 7,8                               | 6,8                          |
| 3,9                               | 3,4                          |
| 1,2                               | 0,6                          |
| 11,7                              | 9,8                          |
| The level of cost reduction, %    | -                            | 7                |

Calculations show that additional investment in the modernization of one solar panel PSPS will amount to 0.75 thousand rubles. for filters, including installation costs of 0.9 thousand rubles.

Given the reduction in the number of solar panels, capital investments in the PSPS system generating 3 kW are lower than the corresponding costs of the installation before its modernization.
Operating costs are also lower. The implementation of the project for the use of light filters in the PSPS is absolutely effective. The level of reduction in the cost of electricity as a result of modernization will be 7%.

Calculations show that additional investment in the modernization of one

The economic efficiency of the implementation of the PSPS with light filters has been proved, since the one-time costs and annual operating costs using the design solution are lower. The advantages can be considered a reduction in the number of equipment used, which ensures a reduction in both one-time and ongoing costs, as well as a reduction in the area used for installing solar panels. The cost of electricity received from the PSPS is lower than the cost of using fossil fuels (gasoline or diesel power plants). The cost reduction level obtained using the modernized renewable energy source is 7%. Studies have shown that the project of the proposed PSPS using light filters is cost-effective and can be implemented for autonomous objects in agriculture, fishing industries and hunting areas of the Krasnoyarsk Territory.

References
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