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Evaluation of the operation efficiency of solar panels in winter

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Abstract. The article deals with the issue of increasing the comfort and safety of life in cities by applying an alternative energy source for power supply of transport infrastructure facilities. Due to the peculiarity of the Russian Federation territory location, most cities are characterized by a long winter period, which makes it necessary to consider the features of using solar panels under these conditions. It has been established that the efficiency of solar panels depends on their type and location, the presence of snow cover on their surface, and the ambient air temperature. It has been revealed that flexible solar panels have some advantages that determine their ability to be used for power supply of transport infrastructure facilities. In the paper, the optimum angle of inclination of rigid solar panels in the winter period of the year is determined.

1. Introduction

The growth of the population and the increase in the requirements for the comfort of living in cities lead to the need to create an environmental friendly and energy-efficient urban environment [1–7]. This concept is a combination of natural, architectural and planning, socio-cultural and other factors that determine the quality of life of a person in the area under consideration [8]. The most important component of improving the state of the urban environment is spatial organization of the city's territory, which ensures not only the efficiency and convenience of movement, but also the level of safety.

Currently, one of the ways to create an environmental friendly, energy-efficient and safe urban environment is the use of modern technologies, called the "Smart City" [9]. Its distinctive feature consists in using information to provide a stable link between a person and knowledge, which is the driving force for the transition to a new way of consuming energy.

One of the criteria for the quality of life in a "smart city" is safety, in particular, road safety. In February 2014, amendments were adopted to standards in which special attention was paid to ensuring the safety of pedestrians: GOST R 52289-2004, GOST R 52290-2004, GOST R 52605-2006, GOST R 51256-2011, GOST R 52765-2007, GOST R 52766-2007.These regulator documents overview typical schemes of traffic organization on unregulated and regulated pedestrian crossings, and also provide a number of basic requirements that should improve road safety in the areas under consideration. They are: the use of a pedestrian crossing marking on a yellow background, use of "Pedestrian crossing" traffic signs on retroreflective yellow-green shields, installation of duplicate road bumps in front of each pedestrian crossing in populated areas, except for main roads and streets, duplication of warning road signs by road markings on each lane. However, the main measure to improve the level of road safety is equipping pedestrian crossings near educational institutions with a traffic light T7 in a two-way version and a light indication of traffic signs.

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These transport infrastructure facilities should be provided with a constant supply of electricity. According to SNiP 2.07.01-89 section 7 "Engineering equipment", in particular, electric wires must be located within the transverse profiles of streets and roads, under sidewalks or dividing strips. Therefore, equipping a pedestrian crossing with a T7 traffic light and a light indication is difficult. The reasons are: placing engineering networks under sidewalks and carriageways; work on the placement of engineering networks (puncture, accounting for other adjacent heat and electricity networks); search for the nearest substation or switchgear.

An alternative option for power supply of transport infrastructure facilities are photoelectric converters. At present, the share of electricity generated by alternative sources is 9.3 %. The use of solar energy is 0.33 % [10]. The sun is an "environmentally friendly" renewable source of energy. The advantages of power supply using photoelectric converters consist in the simplicity and low cost of the installation. For example, the cost of equipment and works on supplying power from the 220V electric grid is 482000 rubles, while the power supply of transport infrastructure facilities with the help of photoelectric converters is 174000 rubles. Despite the economic benefits and ease of installation of this equipment, there are also disadvantages. It are complexity of production and disposal of panels, which is due to the presence of toxic substances in their composition, as well as the dependence of the amount of generated electricity on the spatial location of the solar panel, time of day, as well as natural and climatic conditions. The use of solar energy in winter is challenging due to a number of reasons: a short daylight, low ambient temperature, precipitation in the form of snow, which prevents sunlight from reaching the panel surface.

The purpose of this research is to study the regularities of the current intensity produced by solar panels, depending on the time of day, the spatial arrangement and type of equipment in winter conditions.

2. Methodology

Research aimed at studying the ways of using alternative energy sources has been considered by Erik Jarlsby, Michele De Carli, Rada E.C., Gudmestad Ove T., Kjell Traa, Ragazzi M., Ionescu G., Cioranu S. I., Boeri A., Gianfrate V., Longo D. [11–18]. The work of Vitali D., Garbuglia F., D'Alessandro V., Ricci R. presents a method of power supply for led standalone streetlight. This installation is completely autonomous [19]. Its work is supported by solar panels and a vertical wind turbine, which increases the overall efficiency of this equipment. However, the disadvantage of the installation is the rigid fixing of the solar panel, so it is impossible to change the angle of its inclination and increase the efficiency of its operation.

One of the ways to improve the efficiency of photovoltaic converters is to find the optimal angle of inclination of the solar panel depending on the time of day, the period of the year and the geographical location of the territory. These studies were carried out for individual territories, particularly Chisinau and Northern Alberta [20]. The work of Aculinin A., Smicov considers the dependence of the change in total solar radiation on the time of the year and on the angle of inclination of the solar panel, and provides energy calculations of the optimal orientation of the solar panel [21]. As a result of the analysis, the authors establish the dependence of the optimum angle of inclination of the solar panel on the month of the year in Chisinau. However, they indicate that the orientation of the solar panel can be changed twice a year – in the warm and cold period of the year, as monitoring its position during each month is difficult.

As a result of the analysis of the research work from the Institute of Technology of Northern Alberta, it was revealed that the angle of inclination of the solar panel in winter affects not only the amount of electricity produced, but also the amount of accumulated precipitation on its surface that hinders the ingress of solar radiation. In the paper we propose selecting the optimal angle of inclination of the solar panel in winter taking into account its minimal cleaning from snow. The dependence of the increase in electricity generation during snow cleaning on the angle of inclination is shown in Figure 1.

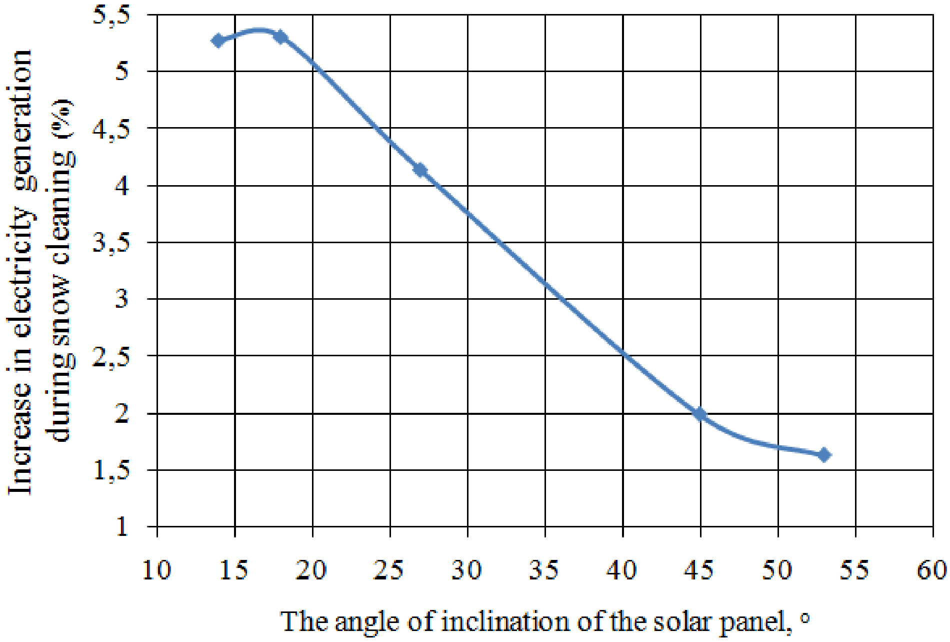

Figure 1. Influence of the angle of inclination of the solar panel on the increase in power generation during snow cleaning

Increasing the angle of inclination relative to the horizontal surface reduces the need to clean the solar panel from snow. This is due to an increase in the ability to naturally clean the snow with an increase in the angle of inclination of the solar panels. The authors state that when choosing the angle of inclination relative to the horizontal surface of 90° during 99.5 % of the winter period there is no snow cover on the surface of solar panels, and with a decrease in the angle of inclination from 53° to 14° the difference in the generation of electricity between the cleaned and uncleaned from the snow modules increases.

Ambient temperature is also one of the important factors affecting the efficiency of the solar panel [22, 23]. As a result of the analysis of previous studies it was established that a decrease in air temperature leads to an increase in the power produced by the solar panel. This is due to the fact that the temperature coefficient of the idling voltage exceeds the temperature coefficient of the short-circuit current and causes a significant drop in voltage with increasing temperature, which cannot be compensated by an increase in the current intensity. Power is the product of current intensity to voltage, so increasing the temperature causes a decrease in the efficiency of the solar panel. Thus, low ambient temperatures are a favorable factor that increases the efficiency of solar panels in winter conditions.

The results obtained in the course of the analysis will be the basis for identifying the dependences of changes in the value of the current intensity produced by the solar panel in winter on the time of day, the spatial arrangement and type of equipment.

2.1. Equipment and devices used in studies

In the course of experimental studies, two types of solar panels were used. The first type is the solar panel HH-MONO-80W – a silicon rigid single-crystal panel with a power of 80W and a current intensity of 3.67A. It is characterized by low efficiency, the values of which under ideal conditions can reach 15.7 %. The second type is EP-80W – a silicon flexible single-crystal panel with a power of 80W and a current intensity of 4.04A. Its efficiency values under ideal conditions reach 22 %. The network also consisted of a battery with a voltage of 12V and a capacity of 100A•h and a charge controller with a voltage of 12/24V.

2.2. Methodology of research

The purpose of the experiments was to study the regularities of the current intensity produced by solar panels of various types from the time of day in winter, as well as to reveal the effect of the angle of inclination of the solar panel surface relative to the horizontal surface in winter in Tyumen.

On the tripods, rigid and flexible solar panels were fixed, to which multimeters for measuring the amperage were connected. The assembled installations were placed on a uniformly illuminated platform. The experiment was carried out in several stages.

The essence of the first stage was to determine the dependence of the change in the current produced by the solar panel during the winter daylight. Experimental facilities with a rigid and flexible solar panel were located on a uniformly illuminated site. The rigid solar panel was arranged horizontally, the flexible solar panel was maximally curved to an arc describing a quarter of the sphere. The measurements were taken during the daylight hours in winter – from 8:00 to 18:00. The obtained results made it possible to establish the efficiency of the application of a flexible solar panel and reveal the effect of the Sun's progress during the daylight on the generated current intensity.

The second stage of the experimental studies consisted in revealing the influence of the angle of inclination of the solar panel at the invariable position of the Sun. To do this, the solar panel, located on a uniformly illuminated site, changed the angle of inclination, but the constancy of the location of the Sun was achieved. The measurements were taken several times during the daylight hours. The results obtained during this stage of the experimental studies allowed to determine the influence of the angle of inclination on the current intensity generated with the invariable position of the solar panel, and also to reveal the most optimal position of the solar panel corresponding to the maximum current intensity under the observed conditions.

The third stage of the experiment made it possible to reveal the effect of a change in the location of the solar panel. In this case, initially during the daylight hours, the angle of its inclination was changed so that the Sun's rays hit the surface perpendicularly. Then, according to the compass readings, the panel was directed to the south during the daylight. The obtained results made it possible to determine the influence of the change in the angle of inclination of the solar panel or the constancy of its location on the generated current intensity.

3. Results and discussion

The territory of the Russian Federation has some peculiarities: the predominance of its extent along geographical latitudes; location in high and moderate latitudes and under the influence of the Arctic. This explains the presence of a cold winter season almost throughout the country for the exception of the Black Sea coast of the Caucasus. It is characterized by average temperatures that vary depending on the location of the area from 0 to -4° C in the southern regions and down to -45° C in Siberia, the snow cover remaining in different regions from 2 to 7 months, and the short duration of daylight hours [24]. The presented features of the RF territory location make it necessary to consider the principal differences in the use of solar panels for power supply of the municipal transport infrastructure in winter.

3.1. Influence of the solar panel type on the current intensity produced during the daylight in winter

Initially, the types of solar panels (rigid and flexible) were studied to identify their advantages and disadvantages. This established that, together with the positive technical characteristics, the flexible solar panel has such advantages as waterproof construction, lack of glass parts, high wear resistance, and also light weight and thickness, which causes no additional wind resistance. Thus, for power supply of transport infrastructure facilities it is more efficient to use flexible solar panels. To confirm the hypothesis, experimental research was carried out to study the dependence of the change in the current intensity produced during the daylight on the type of solar panel. The results are presented in the form of graphical dependences in Figure 2.

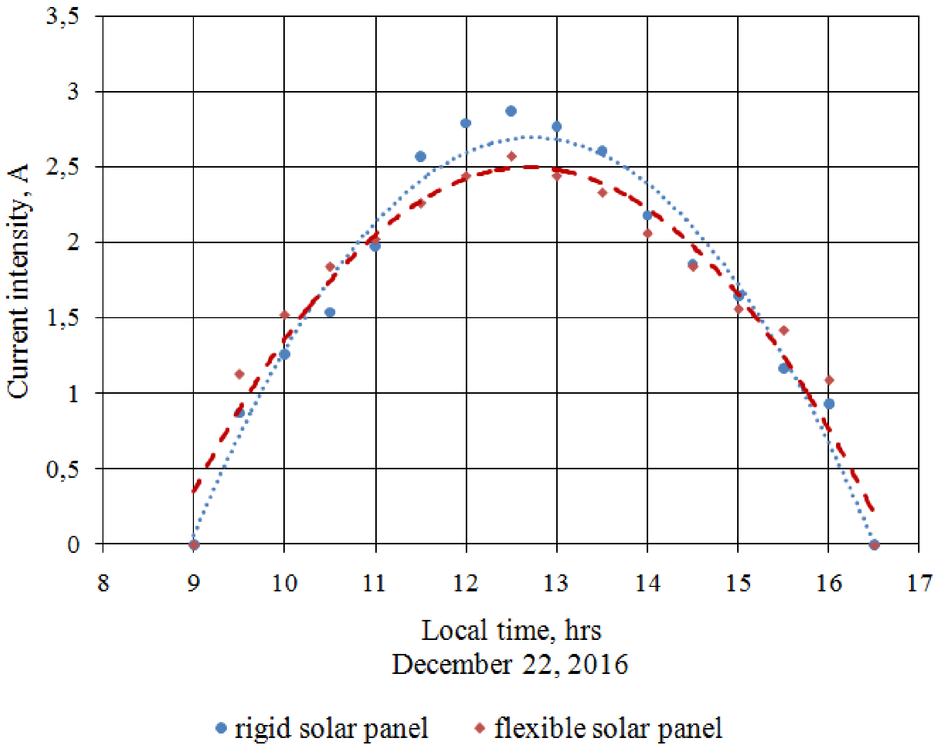

Figure 2. Influence of the solar panel type on the change in the current intensity during the daylight if located horizontally

Changes in the current intensity during the daylight are similar to the course of the sun, which is due to the constancy of the location of the solar panel. The maximum values are observed when the Sun reaches its maximum height and the perpendicular location of the solar panel surface relative to its rays. However, giving a flexible solar panel outlines of a quarter of the sphere made it possible to achieve a smoother change in the current intensity depending on the time of day. When calculating the area of the figure restricted by the OX axis and the curve, it is established that the difference between the current intensity produced during the daylight by a rigid and flexible solar panel is 0.45 units. This allows us to conclude that for the power supply of transport infrastructure facilities it is possible to use a flexible solar panel, since its efficiency is not inferior to a rigid solar module and has a sufficient number of advantages in its use.

3.2. Influence of the angle of inclination of the solar panel at the constant location of the Sun. The choice of the optimal angle of inclination during the daylight

Based on the results of the first stage of experimental studies, it was suggested that there is the optimum angle of inclination of the solar panel during the daylight. In the study, the installation with a rigid solar panel was located on a uniformly illuminated site and during the daylight every 30 minutes the optimal angle of inclination of the solar panel was found experimentally. The dependence of the current intensity generated by the solar panel on its angle of inclination at different times of the daylight is presented in Figure 3.

The obtained results made it possible to establish a change in the optimal angle of inclination of the solar panel during the daylight. For example, when the Sun is at the zenith (12:30 local time), the angle of inclination should be from 0 to 10°, while in the morning and evening hours this is 80 to 90° with respect to the horizontal surface. Thus, using the measurements made at different times of the daylight, the dependence of the change in the optimal angle of inclination of the solar panel was constructed, which is shown in Figure 4.

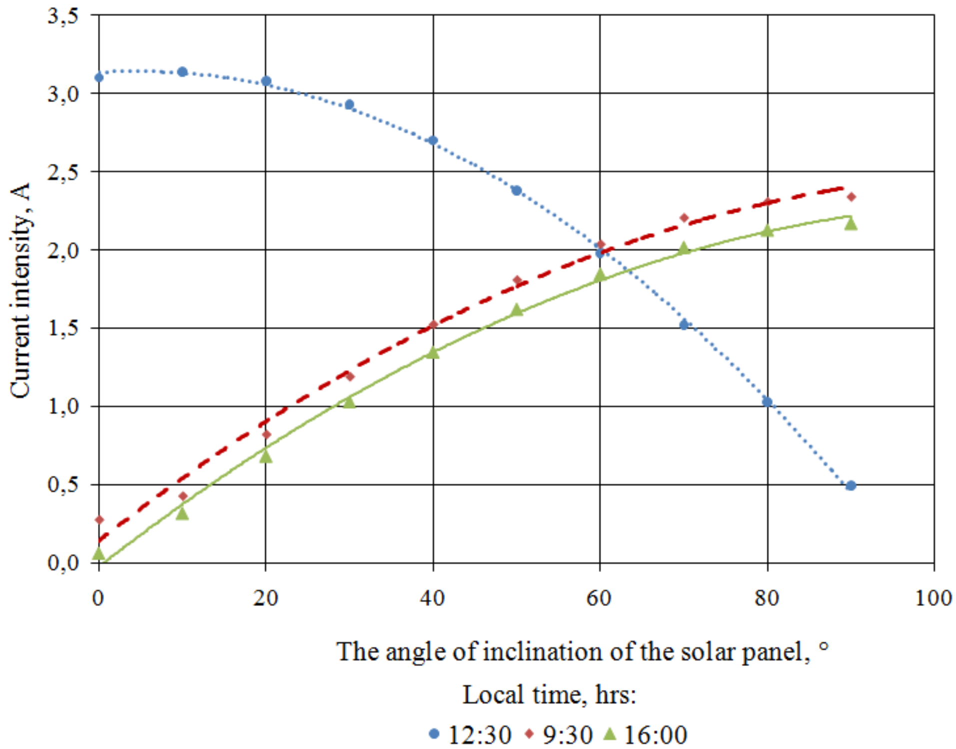

Figure 3. Change in the current intensity generated by the solar panel from the angle of inclination at different times of the daylight

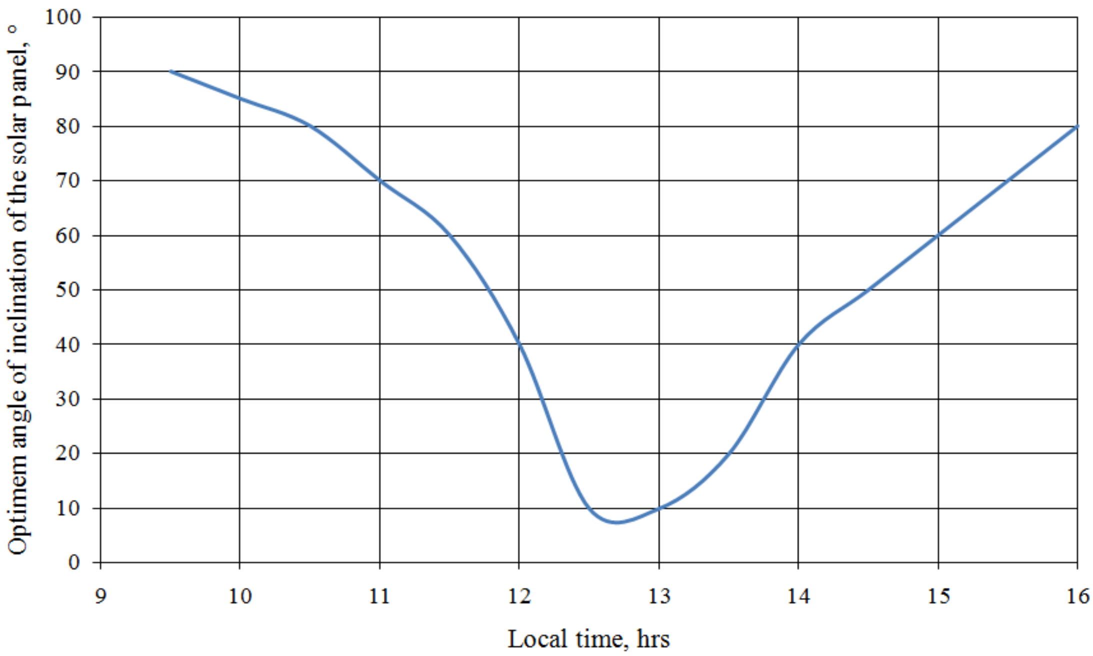

Figure 4. Change in the optimal angle of inclination of the solar panel during the winter daylight

The change in the optimal inclination angle during the winter daylight corresponds to the course of the Sun. The minimum value of the angle of inclination of the solar panel relative to the horizontal surface corresponds to noon. However, in winter conditions, as it was established earlier, it is necessary to take into account the presence of snow cover, which does not allow reducing the angle of inclination of solar panels to less than 53°. It is quite difficult to change the location of the solar panel during the day. This necessitates the development of a system for monitoring the location of the solar panel or selection of the optimal angle of inclination.

3.3. *Effect of the direction of the solar panel on the generated current intensity*

During the third stage of the experiment, the effect of the direction of the solar panel on the change in the generated current intensity is studied. The obtained dependences are presented in Figure 5.

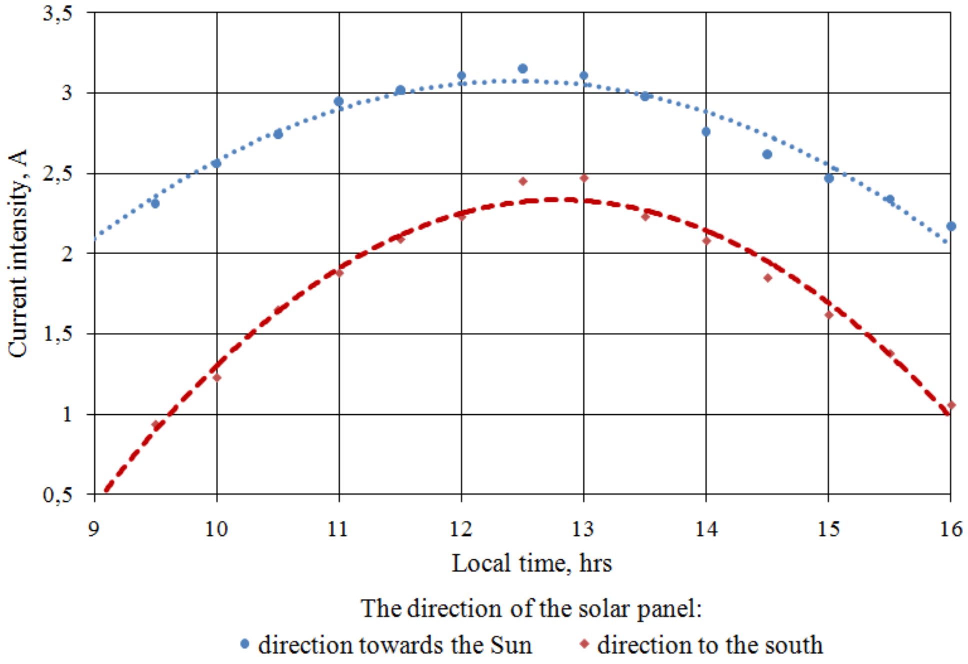

Figure 5. Effect of the direction of the solar panel on the generated current intensity.

This stage of the experiment was carried out in winter with the help of an installation with a rigid solar panel located on a uniformly illuminated site. Measurements were carried out every 30 minutes during daylight hours. One of the solar panels was continuously directed to the south during the experiment, the other changed its orientation according to the obtained results of the change in the optimal angle of inclination during the light day. The maximum values of the current intensity and the minimum changes correspond to the curve describing the direction of the solar panel to the Sun. In the case of a constant orientation of the solar panel to the south, the amount of incident solar energy is less, and, consequently, the efficiency of the installation operation is lower and the changes during the daylight are more drastic.

4. Conclusions

In the course of experimental studies, the influence of the type and location of the solar panel, the time of day on the current intensity produced has been studied. A flexible solar panel is most suitable for power supply of transport infrastructure facilities. This is due to the features of its design – a small thickness and weight, lack of additional resistance to wind and so on.

As a result of the analysis of the experimental data, the dependence of the change in the optimum angle of inclination of the solar panel during the daylight is constructed. The hypothesis is confirmed about the predominance of the current produced by directing it to the Sun over its orientation to the south. Taking into account the analysis of previous studies, it has been revealed that the angle of inclination of solar panels should not be reduced to less than 53° to maintain the possibility of its natural cleaning.

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