Photovoltaic panels operating modes modeling to improve operation efficiency of power supply autonomous system of Volgograd State Agricultural University

D D Nekhoroshev, A V Melikov, A Yu Rudenko, A P Panchishkin and M P Aksenov

1 Volgograd State Agricultural University, 26, University Avenue, Volgograd, 400002, Russia
2 Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, 49, Timiryazevskaya, Moscow, Russia

E-mail: dmitr-nech@yandex.ru

Abstract. The paper considers the possibility of solar panels implementing on the territory of the Volgograd region and the Volgograd city. The structure and characteristics of equipment for generating electricity are considered in the article. Equipment for receiving, storing and transferring energy to the consumer has been proposed. Research has been carried out to determine the photovoltaic panels’ operation efficiency, taking into account many factors, such as the solar energy change during the year/day, the daylight hours length, the solar energy amount, etc. The positive research results were obtained after the experiment.

1. Introduction
The Volgograd Region has a high potential for solar energy. Observations of the ”Volgograd Center for Energy Efficiency” show that the region under consideration is distinguished by the prevailing number of sunny days per year throughout the calendar year, which has a positive effect on the development of power supply systems based on solar energy. However, the alternative energy development level in the region, as well as in the Russian Federation as a whole, lags behind the advanced energy developed countries of Europe.

The development of decentralized systems for electricity and heat generating is aimed at expanding the existing electric power infrastructure of our country, as a result of which there is a losses decrease during the electrical energy transmission and conversion. With a certain optimizing method of the composition and characteristics of autonomous power supply systems, a significant reduction in the price of generated electrical energy is achieved. In addition, this direction will require relatively small investments and provides an opportunity to improve energy converters [1-5].

2. Materials and methods
The object of the study is an autonomous power supply system located in the medical and clinical complex of the Volgograd State Agrarian University, based on renewable energy sources.

The structure of the autonomous power supply system under consideration includes 15 photovoltaic panels MSW 180/90 installed at an angle of 60° to the earth's surface (to the south) and connected in parallel, 3 panels per branch. The total installed power of the solar battery with this connection is 2.7 kW.
In order to store electrical energy received from solar panels and its subsequent use by consumers, 4 helium batteries *HAZE HZY12-200* with a voltage of 12 V are implemented. The batteries are connected in parallel, forming a total system voltage of 48 V. The battery charging process is provided by the charging controllers *FLEXmax FM80*, which maximize the efficient and safe performance of solar panels.

Since the consumers of electrical energy in the system under study are AC receivers, the inverters *OutBack FX 2012ET* are implemented, which convert the DC voltage of the storage batteries into the AC voltage of 220 V. The control device *MATE* ensures the correct operation of the entire system, allowing you to program the inverters, monitor the operation of all elements of the autonomous power supply system. The switchgear *HUB* is the link between all devices in the autonomous system, ensuring the charger, inverter and device *MATE* to interact.

The efficiency of photovoltaic panels depends on many factors, such as the solar energy change during the year/day, the daylight hours’ length, the solar energy amount on cloudy and clear sunny days, the number of rainy days per year, the photovoltaic panels direction and elevation angle, its change during the day of the year, etc.

The effective operation of an autonomous power supply system is impossible without information about the energy characteristics of photovoltaic panels, the amount of energy that they are able to generate in normal operation mode. For this purpose, the dependence of the electricity generated by the photovoltaic panels in relation to the illumination during the daylight hours was determined.

The purpose of the experiment is to improve the photovoltaic panels’ operation efficiency using the example of an existing autonomous power supply system in a higher educational institution.

The experiment included: the illumination measurements during daylight hours while the photovoltaic panels’ energy characteristics monitoring, such as voltage, output current, power and generated electricity. The experiments were carried out in the summer with different weather conditions. The main criterion is experimental data and their subsequent comparative analysis obtaining at various degrees of daylight illumination.

The illumination parameters were measured with a luxmeter *DT-8809A*, a portable device for illumination measuring with a remote sensor equipped with a registration mode. Energy parameters were recorded by the charging controller *FLEXmax FM80-150VDC*, a device that allows you to carry out the necessary measurements, as well as store the measured data for 128 days.

Based on the results of experimental studies, the electricity generation simulation was carried out using the «PVSOL expert» software.

### 3. Results and discussion

According to the experiment results, it was found that the output parameters were more dependent on the measured illumination on the surface of the photovoltaic panels. The dependence of the illumination on photovoltaic panels on the time of day is shown in Figure 1. The illumination measured on the surface perpendicular to the sun position was used as the maximum possible illumination, namely the angle relative to the ground changed during daylight hours.

![Figure 1. The illumination dependence on photovoltaic panels on time.](image-url)
The illumination dependence on the surface perpendicular to the sun position on time is shown in Figure 2.

![Figure 2](image)

**Figure 2.** The illumination dependence on the surface perpendicular to the sun position on time.

Analysis of the graphs provided in Figures 1-2 showed that the maximum illumination occurs in the morning; an illumination decrease is observed on the panels during daylight hours; 100% of the maximum illumination was observed in the morning, at noon about 60%, and in the evening only 10.5%. According to approximate calculations, it is concluded that, on average, about 50% of the illumination on the panels is lost per day.

![Figure 3](image)

**Figure 3.** Dependence of the output power of solar panels on the illumination on the panels.

The power generated by solar panels is linearly dependent on the illumination on the panels (Figure 3), and therefore, if half of the illumination is not lost during the daylight hours, the installation efficiency will double. These results gave grounds for making measurements of the output power of the installation during the time of day for different control days. Figure 4 shows the dependence of illumination power on a cloudy day.

There is a significant variation in power values during the measurement time. Of course, this is due to the unstable nature of the weather and variable cloudiness. However, it can be noted that the highest output power of solar panels occurs in the morning hours.
Figure 4. Dependence of the solar panels output power on the time of day on a cloudy day.

For a clear day, you can notice a marked dependence of the output power on the time of day (Figure 5). The power peak falls on the morning hours, and then the output power decreases monotonically (with the exception of one dip in the period from 13:00 to 14:30, which is associated with short cloud cover). The resulting dependence of the output power on the time of day depends strictly for the time of day from 9:00 to 16:30.

Figure 5. Dependence of the solar panels output power on the time of day on a clear day.

When performing experiments on a cloudy and clear day, different total electricity generated during the measurement period was recorded. So, on a cloudy day, the generated energy during the experiment was 5.1 kW·h, on a clear day 6.5 kW·h. This means that the described arrangement of solar panels produces 26% less electricity on a cloudy day than on a clear day.

The next stage of work was the visualization of real objects (Figure 6) by means of three-dimensional modulation (taking into account the characteristics obtained as a result of experimental studies). "PVSOL expert" calculates the frequency of solar panels shading by nearby objects, presenting the result in a graphical form. The visualization of the 3D space program provides detailed information about the shading of solar panels, taking into account the time of day and season.
When choosing photovoltaic modules, a large number of module options from different manufacturers, which are constantly updated and supplemented, are available to the user. The photo-electric modules of the KZPV 230 M60 brand were selected as an affordable and inexpensive alternative in the work.

After the objects location and the photovoltaic modules selection, the program performs a calculation, according to which the user is offered a choice from a variety of inverter options. The number of inverters per group of modules and their connection options, as well as the useful action of the inverter in the system, is displayed in the inverter selection window. In the model under consideration, an inverter of the Fronius IG 4500-LV 4.5kW brand was chosen.

Based on the simulation results, the program generated complete data on shading as a percentage of the annual output of photovoltaic modules (Figure 7). By its means, it became possible to estimate shading for every day, every hour, in a ten-minute interval of the entire estimated year. The user can also reproduce the passage of daylight hours according to the date of his choice.

Based on the results of the photovoltaic panels simulation, the values of the generated electricity were obtained for the year, month, week and day in graphical form (Figure 8).
The constructed computer model made it possible to obtain not only practically significant results on the optimization of a specific autonomous power supply system based on photovoltaic modules, but also to carry out theoretical studies without the need for planning and to carry out long and labor-intensive experiments.

Comparison of the results obtained in the course of experimental measurements and computer simulation shows a high convergence of the results, the error limit is 7%. The obtained results high convergence of the experimental research and computer modeling tells us about the adequacy of the constructed model and the software used.

4. Conclusion

Based on the results of the experimental data, it was found that the output parameters depended to a greater extent on the measured illumination on the surface of the photovoltaic panels, for this system the peaks fall in the morning hours, and a decrease in the light maximum is observed during the daylight hours.

The experimental dependences data showed a decrease in the generated electricity during the measurement period by 26% on a cloudy day as compared to a clear day. With the initial position of the photovoltaic panels, about 60% of the maximum possible illumination was lost.

The high convergence of the obtained results of experimental research and computer modeling testifies to the adequacy of the constructed model and the software used (error limit is 7%), which will allow further use of this model for practical and theoretical research.

References

[1] A Yu Rudenko et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 577 012015
[2] D D Nekhoroshev et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 577 012020
[3] Chan C C 2007 The State of the Art of Electric Hybrid and Fuel Cell Vehicles Proc. IEEE 95(4) 704-718
[4] Pukrushpan J T, Stefanopoulou A G and Peng H 2005 Control of Fuel Cell Power Systems: Principles; Modeling Analysis and Feedback Design
[5] V F Beley et al 2021 IOP Conf. Ser.: Earth Environ. Sci. 689 012023