Creation of All-Season Photothermal Installation of Increased Efficiency

Muhammadjon Tursunov[1], Habibullo Sabirov[1], Tohir Axtamov[1], Mamasobir Tursunov[2], Maxamadi Chariyev[2] and Habib Abdullayev[3]
[1]Physical-Technical Institute, Chingiz Aytmatov Str. 2B, Tashkent, Uzbekistan
[2]Termez State University, Barkamol Avlod Str. 43, Termez, Uzbekistan
[3]Chirchik State Pedagogical University, Amir Temur Str. 104, Chirchik, Uzbekistan
muhammadtursunov54@gmail.com, sabirovhabibullo47@gmail.com, tohiraxtamov@gmail.com, mtursunov@tersu.uz, chariyevmaxamadi@gmail.com, habibabdullayev04@gmail.com

Keywords: Photovoltaic, Photovoltaic Systems, Photo Thermal, Monocrystalline, Heat Collector, Reflectors, Mobile Portable Device, Solar Radiation, Short Circuit Current, Open Circuit Voltage.

Abstract: In this article, a project of portable photoelectric and photo thermal devices with a power of 60W based on crystalline silicon photoelectric batteries for the production and use of electricity and hot water for household needs in the rural areas of the republic was created. This natural experiment served two purposes. The first is to determine the optimal type for the climate when the various types of PVs available in the local commercial market are used in hot climates. Second, the results of determining and comparing the changes in parameters and energy efficiency of PV and PVT with the same base and capacity at the same time under the same conditions are presented. The results of the study of the parameters that increase their effectiveness have been considered. Special attention is paid to modern components and equipment so that these devices are relatively compact and convenient to operate and control occurs easily.

1 INTRODUCTION

The efficiency of using photovoltaic systems depends on the efficiency of using photovoltaic arrays, energy storage systems, control and monitoring electronics, and the climatic conditions of the area. In rural regions of Uzbekistan, where the issue of supplying the population and farms with electricity and water for household and domestic needs is especially acute, the efficiency of using photovoltaic installations is largely determined by climatic conditions [1]. It is expressed in sharp amplitudes of day and night, summer and winter temperatures. The nature is arid, there is little precipitation, low relative humidity. The duration of a sunny day in summer (from the moment the Sun appears above the horizon till the visible sunset) is more than 13 hours, in winter - at least six hours. The coldest month is January, when the temperature in the north drops to 10 or more degrees below zero, and in the extreme south, near the city of Termez, it is above zero. The absolute minimum of winter temperatures is 35-38 degrees below zero. The hottest month is July, and in the mountainous regions is July-August. The average temperature during this period on the plains and foothills is 25-30 degrees above zero, and in the south (Termez and Sherabad) it reaches 41-42 degrees above zero [2]. From a comparison of sunshine during the daytime in summer and winter, it can be concluded that in summer the energy generated by photovoltaic arrays (PVA) is more than twice the energy in winter. In addition, the intensity of solar radiation in summer is twice the intensity of radiation in winter, due to the angle of incidence of radiation on the surface of the PVA.

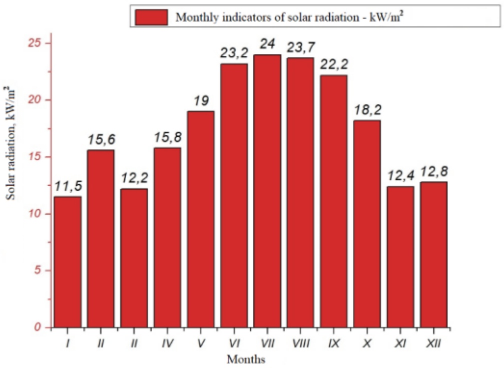

Figure 1: Monthly changes of the average intensity of solar radiation along the normal to the surface for Tashkent.

Figure 1 shows the monthly changes of the average intensity of solar radiation along the normal to the surface for Tashkent [3]. The deviation for the month of March is due to the relatively numerous cloudy and rainy days in this month (Figure 2). The trend of the distribution of temperature and precipitation by months for the overwhelming rural regions of Uzbekistan (to the west area of the country) will be similar to the trend for the city of Tashkent (Figure 2). This is due to the fact that the wind flow is directed from the west (Karakalpakstan) to the east towards Tashkent.

It can be concluded that from November to March we have low temperatures, which is favorable for the operation of the PVA, but at the same time, the prevailing cloudy weather is unacceptable for the efficient operation of the PVA. In addition, this time is characterized by relatively short days and low intensities of solar radiation. The southern region also has some features of the continental climate, such as a large difference in night and day temperatures, a large number of cloudy days and frequent fogs in the winter season. In general, these factors hinder the efficiency of traditional photovoltaic installations and their overall efficiency. Monthly, on average, it decreases by 50% or more in the winter months, and by more than 20-30% in the autumn-spring months [4]. And in the summer, the difference increases to 30-40%. In this regard, there is a need to create a new, more advanced energy supply system for rural regions based on photovoltaic installations equipped with photothermal batteries and reflectors of various designs.

2 METHODS AND MATERIALS

This paper presents the results of research and development of autonomous mobile photothermal installation of increased efficiency for use in the dry climate of Uzbekistan for all seasons of the rural regions of the republic.

In rural regions of the country there are specific factors that differ from the conditions of use the installations in other countries. Such factors are a large temperature difference between day and night, the number of cloudy days and, accordingly, precipitation in the form of rain and snow, and the presence of seasonal dust storms. In such conditions, supplying electricity and water to rural households and creating the necessary comfort for residents is an undeniably difficult task. From Figure 1 and Figure 2, it can be concluded that 5 months of the year (November-March) are unfavorable in terms of precipitation and solar radiation intensity for the use of photovoltaic (PVB), photothermal batteries (PTB) and installations based on them. From Figure 1 it can be seen that the minimum monthly indicators of solar radiation fall on the cold and cloudy and relatively short November-March months of the year. Although the temperature indicators are comfortable for PVB operation, however, the number of rainy and cloudy days is about half of the time period. Daylight hours are 2 times less in duration compared to the summer period of the year [5].

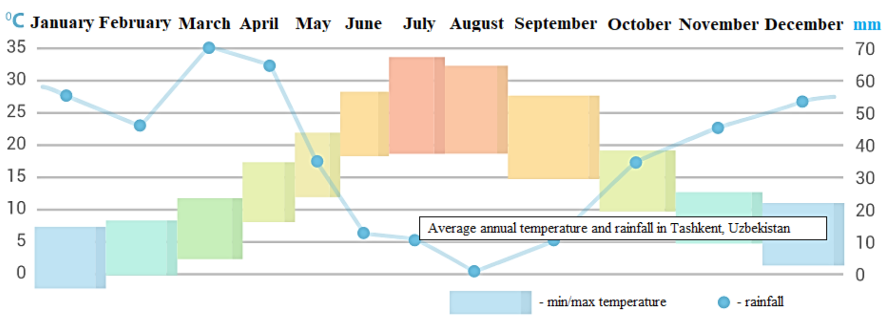

Figure 2: Distribution of temperature and precipitation by months for the conditions of Tashkent.

To determine the required level of solar radiation intensity for generating electrical energy and hot water in the winter months of the year, it is necessary to determine the applicability limit of frontal mesh contacts of solar cells (SC) of PVB based on crystalline silicon with an increase in the intensity of radiation incident on the surface of the battery. According to the condition AM 1, the short-circuit current of the SC is measured at 1000W/m^2 and a temperature of 25^{0}C. Grid contacts of modern solar cells made of crystalline silicon ensure the linearity of the short-circuit current up to the specified value of the illumination level of the AM 1 condition.

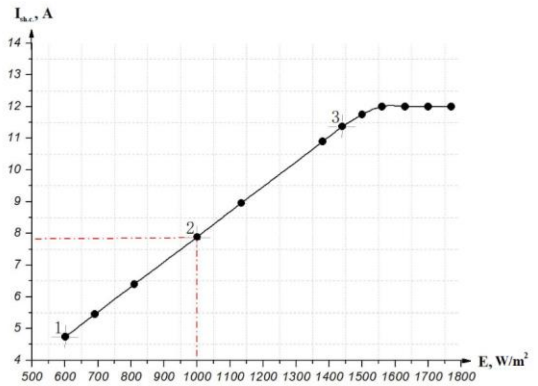

Figure 3: Dependence of the SC short-circuit current on the intensity of solar radiation. 1-Measurement start at 600 W/m^2 solar intensity, 2-Short circuit current at 1000 W/m^2, 3-Short circuit current bending point.

We have studied the dependences of the short-circuit current on the intensity of solar radiation by 40-50% more than in the AM 1 condition incident on the surface of a solar cell made of single-crystal silicon, which is shown in Figure 3. The experiments were carried out in natural conditions using sunlight. Solar cells sized 156x156mm^2 are installed on a cooled metal plate, to increase (change) the intensity of solar radiation, reflectors with a solar radiation reflection coefficient of 0.5 are used. As can be seen from Figure 3, the dependence of the SC short-circuit current on the intensity of solar radiation depends linearly up to a radiation intensity of 1450–1500W/m^2 without additional influence on the electrical properties of the front current-collecting contacts [6]. Thus, in the winter months of the year, with an increase in the intensity of solar radiation to the indicated values at a temperature of SC 25^{0}C during short winter daylight hours in clear sunny weather for 5-6 hours, with an efficiency of 19-20%, it is possible to obtain up to 1500W/m^{2}x1m^{2}x0.19x5h=1425W per day of energy from 1 m^2 of the PVB area, which is approximately equal to the energy received from the PVB with an area of 1m^2 in the summer at radiation intensity ~ 800W/m^2 for 8-9 hours. An increase in the value of the intensity of solar radiation to more than 1500W/m^2 leads to a loss of short-circuit current, respectively, power due to the non-linearity of the characteristic of the dependence of the short-circuit current on the intensity of solar radiation.

2.1 Installation Options

To conduct research and develop a photothermal installation with increased efficiency in the winter months of the year, there was used a low-power portable autonomous photovoltaic installation with a power of 60W [2-3]. The area of the photovoltaic battery is 0.36m^2. Four additional reflectors (two side ones, top and bottom) with a total area equal to two areas of the photovoltaic battery (Figure 4) were made on the chosen design of the installation to change and select the optimal value of the intensity of solar radiation incident on the surface of the photovoltaic battery. The PVB temperature was controlled by changing the water supply rate of the thermal collector installed on the rear surface of the photovoltaic battery.

a b

Figure 4: Four additional reflectors: a) Portable photovoltaic installation (initial), b) portable photothermal installation for the winter period of the year.

In order to determine the number of reflectors used depending on the months of the year, there were studied the dependence of solar radiation intensity on time by months of the year. For example, for the winter season, there was studied the dependence of solar radiation intensity on time on November 14-15th, 2022 (Figure 5.). There was determined the number of reflectors by months of the year using the data. In the winter season (November-March), the number of reflectors used should be four, and in the spring (April-May) and autumn (September-October) the number of reflectors should be two, while the upper and lower reflectors are removed, which are removable. We consider it optimal to install two side reflectors in the structure in the winter season. During daylight hours, the Sun is on the south side and therefore orientation in the direction of the Sun will be easier. For example, one of the options is to install two side reflectors at an angle of 120^0 to each other, then the side reflectors will be directed towards the Sun during daylight hours. The photo thermal battery is made according to the technology given in [7], cellular polycarbonate with parallel channels is used as a thermal collector. In the summer months, this PTB design is also used, which, when using two reflectors, provides electrical energy that is 1.5-1.6 times greater than the use of PTBs without reflectors [8]. Efficient heat removal and the possibility of obtaining, if necessary, an outlet water temperature of up to 60^0C; when using two side reflectors, the output of water can be increased up to 20liters/hour.

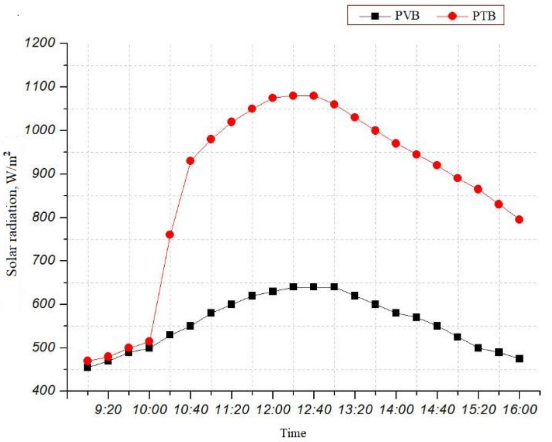

Figure 5: The dependence of solar radiation intensity on time.

3 RESULTS AND DISCUSSION

Figure 5 shows the dependence of solar radiation intensity on time dated on November 14th, 2022 (direct solar radiation), falling on the surface of the PVB in the interval from 9:00 to 16:00 400W/m^2 during the day. The maximum of solar radiation intensity 600-650W/m^2 becomes in the time interval from 11:20 to 13:30. When connecting 4 reflectors, the maximum value of solar radiation intensity reaches approximately 1100W/m^2. This value corresponds to the solar radiation intensity of photothermal batteries with two reflectors in the summer. Dependences of solar radiation intensities for direct solar radiation and enhanced with the use of four reflectors have a similar distribution over time, except for the interval from 10:00 to 10:40 during the deployment of reflectors.

Figure 6 shows the dependences of open-circuit voltages and short-circuit currents for PVBs and PTBs based on PVBs on time. As can be seen from Figure 6, the dependences of the short-circuit currents of the PVB and PTB are similar to the dependences of solar radiation intensity (Figure 5). The exception is the dependence of the open-circuit voltage of the PTB, starting from the time of deployment of four reflectors, leading to a sharp decrease in the voltage value from 21.65V to 17.3V due to heating of the rear surface of the PVB. Later, when cold water is connected to the heat collector, the open-circuit voltage increases to a value of 20.8V, as in. Water temperature can be changed within 25-50^{0}C. The dependence of the short-circuit current on time repeats the dependence of solar radiation intensity on time. The short circuit current of the PTB in the time interval from 11:30 to 13:00 is twice the short circuit current of the photovoltaic battery.

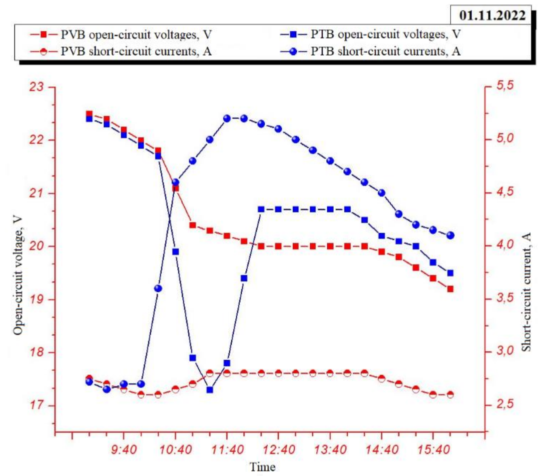

Figure 6: Dependences of open-circuit voltages and short-circuit currents for PVB and PTB based on PVB on time.

Figure 7 shows the dependence of the generated electric power on time for PVB and PTB. As can be seen, for the case of PVB, the dependence of power is largely determined by the dependence of the short-circuit current on time (Figure 6). In general, the electrical power of the PVB, generated from 10:00 to 14:40, is equal to approximately 40W per hour. For the PTB until 10 am, the power generated is the same as the power generated by the PVB.

Further, when opening 2 reflectors (upper and lower), the power increases to 63W (~ 1.5 times), and a further decrease in power is associated with heating of the PVB, which leads to a decrease in the open circuit voltage.

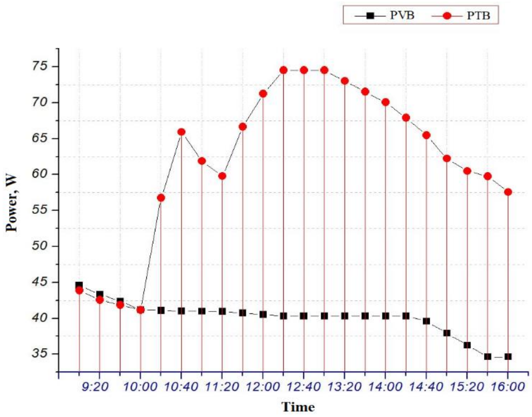

Figure 7: Dependence of the power for PVB and PTB on time.

When water is connected to the heat collector and two more side reflectors are turned on, the PTB power increases to 76W. After 13 hours and 30 minutes, the electrical power decreases due to a decrease in the intensity of solar radiation (with the appearance of scattered white "spots" in the sky). Generally, in clear weather in the winter season, the developed installation based on the PTB makes it possible to obtain an electric power that is almost twice the power of the PVB [9]. At the same time, if necessary, it is possible to obtain heated water up to a temperature of 40-50^{0}C, which is important for the population of rural regions [10]. Therefore, the development and use of such photo thermal installations with a power of up to 1000W is in great demand for rural residents of the regions of the country. In the future, there will be studied the efficiency of using such installations of low intensity of solar radiation and temperatures, which, according to Figure 1 and Figure 2 fall on January-April and October-December months of the year for rural regions of the country.

4 CONCLUSIONS

There has been made an analysis of the influence of climatic conditions in the regions of Uzbekistan on the possibility of using photovoltaic installations in all seasons of the year. For this purpose, an autonomous mobile photo thermal installation has been developed for use in the dry climate of Uzbekistan for all seasons of the country's rural areas. It was revealed that the efficiency of use (generated electric power) of the developed photo thermal installation in the winter period of the year (November) is two times higher than the electric power of a similar photovoltaic installation. The photo thermal installation, if necessary, also produces hot water with a temperature of up to 50^{0}C.

REFERENCES

[1] R.R. Avezov, N.R. Avezova, and E.Yu. Rakhimov, "Taking into account the orientation of heated rooms in the calculation of insolation passive heating systems," International Conference "Fundamental and Applied Problems of Physics", Tashkent, June 13-14, 2017, pp. 5-10.

[2] M.N. Tursunov, Kh. Sabirov, T.Z. Akhtamov, and B.A. Yuldoshev, Patent: Portable low power photovoltaic device. SAP 2021 0236.

[3] R.A. Muminov, M.N. Tursunov, Kh. Sabirov, T.Z. Akhtamov, and M. Eshmatov, "Comprehensive improvement of the efficiency of a mobile photovoltaic installation for water lifting through the use of photothermal batteries, side reflectors of solar radiation, and cooling water from deep underground aquifers," ISSN 0003-701X, Applied Solar Energy, vol. 58, no. 2, 2022, pp. 238-243.

[4] R.Yu. Akbarov and A.A. Kuchkarov, "Modeling and calculation of optical-geometric characteristics of a solar concentrator with flat fresnel mirrors," Applied Solar Energy, 54(3). 2018, pp.187-192.

[5] L.T. Kostic, T.M. Pavlovic, and Z.T. Pavlovic, "Influence of Reflectance from Flat Aluminum Concentrators on Energy Efficiency of PV/Thermal Collector," Appled Energy, 2010, vol. 87, pp. 410-416.

[5] V.P. Anand, Mohd. and Meraj Khan, et. al, "Performance Improvement of Solar Module System using Flat Plate Relectors," ICAEE, 2014.

[6] R. Arshad, S. Tariq, M.U. Niaz, and M. Jamil, "Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling," iCREATE, 2014.

[7] D. Augustin, R. Chacko, and J. Jacob, "Canal Top Solar PV with Reflectors," IEEE International Conference PEDES, 2016.

[8] N.V. Revzina, "Development of algorithms for calculating the optimal geometry of reflectors," Omsk region – a deposit of opportunities. Mat. V regional youth scientific and practical. conf. Omsk, 2014.

[9] L.T. Kostic, T.M. Pavlovic, and Z.T. Pavlovic, "Optimal Design of Orientation of PV/T Collector with Reflectors," Applied Energy, 2010, pp. 87. 3023-3029.

[10] D.T.P. Wijesuriya, K.D.S.H. Wickramathilaka, L.S. Wijesinghe, D.M. Vithana, and H.Y. Ranjit Perera, "Placeing Reflectors for Reducing Payback Period of Solar PV for Smart Buildings," IEEE 15th INDIN, 2017.