Analysis of Electric and Thermal Efficiency of Crystal Silicon Small Power Suppliers

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Abstract: The article presents the results of studying the electric and thermal efficiency of mobile photovoltaic and photothermal devices (MPVD and MPTD) based on crystalline silicon with a power of 60W panel, designed for the production of electricity and hot water for the domestic needs of rural residents. Our experiment conducted in natural conditions was carried out in the heliopolygon of the Physical-Technical Institute in July of the summer season. The device was manually adjusted and measurements were carried out in the directed mode. Reflectors are installed on the side of the photovoltaic panel (PV) in order to increase the intensity of sunlight in MPTD. As a cooling system, heat collector (HC) is installed in the back of the PV. The HC of the photothermal panel (PVT) is fundamentally different from the system of HC in other works. During the experiment carried out in natural conditions, the effects of the reflectors installed on the front surface of the photothermal device's PV and the heat collector attached to the back side were determined. Thermal efficiency was 5.5-6 times higher than electric efficiency for PVT panels. And 90% of the solar energy falling on the surface of the photothermal device is converted into useful energy.

1 INTRODUCTION

It is well known that the amount and volume of natural energy sources is declining for years. This demand for the rational use of renewable energy sources is an important task for humanity. Taking into account that the share of renewable energy sources will increase in the future, there is a lot of research that needs to be done by scientists in this field. The use of wise from solar energy is a key role in the development of work in this area. Several important factors adversely affect electricity in the process of obtaining power using a PV panel. These examples, the PV panel can be said high temperatures, pollination, and effectiveness of system devices. PV panel is a system consisting of solar cells based on the p-n junction, which converts light energy from the sun into electrical energy. In this case, the part of the energy that is not converted into electricity, but is absorbed by the solar cells, causes the PV to heat up. It is well known that the PV panel efficiency falls with an increase in its temperature [1-4]. Therefore, the PV temperature has practical and theoretical work on cooling, through which the goal is to effectively use thermal energy. The active, passive, and hybrid types of cooling PV are among them, including these methods differ from each other in the use of purpose and function [5-7]. A system of PV panel combined with a heat collector is called a PVT panel. Different types of heat collectors are used to cool PVT panels. As a coolant, various liquids, mainly water, in some cases air are used and they are passed through heat collectors. Such systems, in turn, need to evaluate the system's thermal efficiency. Heat collectors of different materials and shapes were tested in PVT panels [8,9]. The effect of reflectors on PVT parameters is widely covered in works such as [10-12], and its main function is to increase the radiation energy coming from the sun and protect PV from dusting. At present, it is necessary to develop energy devices based on PV and PVT panel and apply them to the population in rural areas. Using the results obtained on MPVD and MPTD, we assessed the electrical and thermal effects of these devices.

2 METHODS AND MATERIALS

The research is extensive and the main goal is to compare the parameters of two mobile devices. In this case, in our work, the electric and thermal efficiency of these two devices were calculated. One of the main goals of our work is to influence the effects of these reflectors and heat collectors on PV panel effects. Through this, the heat collector's thermal efficiency was calculated. Monocrystalline silicon PV was used in the device with a maximum power of 60W. The PV panel datasheet and PVT panel parameters based on it are presented in Table 1.

Table 1: Geometric dimensions, physical and technical characteristics of PVT parts.

Parameters	Dimension
Geometric dimensions	
PV surface, S_{PV}	0,36m^2
PV frame width, *d*	2.5sm
Reflector surface, S_{ref}	0,36m^2
Reflector thickness, d_{ref}	0,4sm
The surface of the back cover, S_q	0,36m^2
The thickness of the back cover, d_q	0,4sm
Physical and technical characteristics	
Maximum power of PV, P_{max}	60W
Electrical efficiency of PV, η	16,5%
Open circuit voltage of PV, U_{oc}	24,4V
Short circuit current of PV, I_{sc}	3,33A
The fill factor of the PV's volt-ampere characteristic, *FF*	0,74
Reflection coefficient of the reflector, *R*	0,5
Water capacity of the heat collector, *V*	9 litre

A heat collector and two reflectors along the long sides of the frontal surface are installed on the back of the PV (Figure 1).

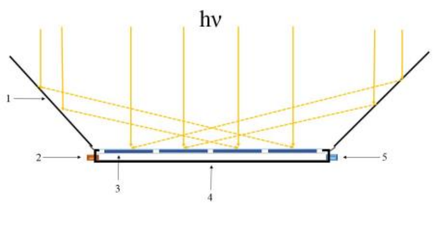

Figure 1: Structure of PVT. 1-reflector, 2-outlet water, 3-PVT, 4-back cover,5-inlet water.

The heat collector is specially designed. To achieve constant heat exchange with the back surface of the PV, liquid inlet and outlet devices are installed in the PV structure. The back side is closed based on alucobond material, which serves as a cover. An overview of the MPTD from the different cases is shown in Figure 2. Reflectors are made by glueing aluminium foil to an alucobond. The total surface of the reflectors is equal to the surface of the PV panel. They can be manually adjusted to the desired angle during the experiment. The advantage of the device is that it is easy to move the MPTD from one place to another, and it is easy to install it at the right angle.

Figure 2: General view of the MPVT from the different cases.

2.1 The Function of Reflectors and Collector in the Study

The main function of reflectors is to increase the energy of solar radiation falling on the PV surface. This is very important for winter, spring and autumn months due to increasing solar radiation. It is known that the PV parameters measured AM=1.5, E=1000W/m^2, T=25^{0}C are accepted as standard conditions. However, the amount of solar radiation specified in this standard is not maintained at almost all points on the earth's surface, and to ensure a situation close to this condition, additional devices are required, or the electrical parameters of PV corresponding to the value of solar radiation for that point are determined. In this article, the reflector serves to increase solar radiation and the heat collector serves to cool the PV. The energy falling on the PV surface in the reflector operating state is determined as (1):

$$W = W_{PV} + 2 \cdot W_{ref} . \quad (1)$$

It can be seen from this formula that additional energy was generated under the influence of the reflector. The task of the heat collector is to reduce PV electrical losses (at the expense of the standard 25 ^{o}C excess of temperature), and if necessary, taking additional heat energy from PV. If the electrical losses are reduced by cooling the PV, by increasing the voltage and power, thermal energy can be explained by the fact that the temperature of the liquid leaving the heat collector is higher than the liquid entering the collector. This energy can be calculated as (2):

$$Q = m \cdot c \cdot \Delta t \ . \tag{2}$$

The system energy efficiency assessment is done as follows. Of course, electricity and thermal effects are calculated separately and added then.

2.2 Electric and Thermal Efficiency in Our Research

The total efficiency was calculated as (3):

$$\eta_{total} = \eta_{el} + \eta_{ther}. \tag{3}$$

We can calculate the heat efficiency as (4):

$$\eta_{ther} = \frac{Q_{useful\_heat}}{S_{HC} \times E}. \tag{4}$$

The useful heat Q_{useful_heat} can be calculated from (5):

$$Q_{useful\_heat} = \dot{m} \cdot C_p \cdot \Delta T. \tag{5}$$

Where $\dot{m}$ is the fluid (air, water…etc, in our work this is water.) mass flow rate; C_p is the used fluid's specific heat, and ΔT is the fluid temperature difference between the inlet and outlet. The electrical efficiency is calculated in standard form (6):

$$\eta_{el} = \frac{FF \cdot I_{sc} \cdot U_{oc}}{S_{pv} \times E}, \tag{6}$$

where, FF is fill factor, I_{sc} – the short circuit current, U_{oc}– the open circuit voltage, E – the solar radiation intensity in [W/m^2], S_{pv}– the PV panel area.

3 RESULTS AND DISCUSSION

Our main purpose is to compare MPVD and MPTD electric parameters and study the electrical and thermal efficiency of the second device. In terms of reflectors and collector advantages in our second device, their effects are very important. The measurement results were measured on July 18, 2022, on an open sunny day at the heliopolygon of the Physical-Technical Institute. During the experiment, the temperature ranged from 34^{0}C to 41^{0}C, and the wind speed was 0.2–5m/s, and the air humidity was 14.2%. Our experiment was conducted in tracker mode (manual guidance mode). In order to ensure direct sunlight (90^0) to the front surface of the solar panels, the operator manually directed it at intervals of 15-20 minutes. MPVD and MPTD parameters were simultaneously measured for the reliability of the obtained data and parameter comparison. Figure 3 shows an overview of MPVD and MPTD in the measurement process. In this case, these two systems' electric and thermal parameters are also calculated and compared. The purpose of the work is to study the variation of PV and PVT short-circuit current (I_{sc}), open circuit voltage (U_{oc}) and produced electric power (P) under natural solar radiation conditions (PTI Heliopolygon). A different from MPVD, MPTD has reflectors on its side that increase the intensity of sunlight up to 1.5 times. Reflectors are made of 4 mm thick alukobond, and aluminum films with a reflection coefficient equal to 0.5 are glued to it as a coating. At night, the reflectors are used as a cover to protect the front surface of the PVT from dust and pollution.

The heat collector part of PVT panel is designed to increase cooling efficiency and reduce energy losses. Two water inlet and outlet valves are installed in the heat collector structure. The volume of the heat collector is 9 liters. MPVD and MPTD parameters were simultaneously measured for the reliability of the obtained data and parameter comparison.

Figure 3: An overview of MPVD and MPTD in the measurement process.

There are 3 modes for MPTD. 1 - measurements in PV mode: from 9:00 a.m. to 10:40 a.m. The current is directly proportional to the solar radiation incident on the PV and PVT surfaces, and in this mode, the solar radiation incident on the surface of both devices is the same. However, since the PVT surface has a higher temperature than the PV surface, there is a change in the values of U_{oc}. 2 - the reflectors are open: due to the increase in temperature due to the increase in the intensity of solar radiation, the value of U_{oc} of

PVT decreased to 20.45V and I_{sc} increased to 4.05A, and at the same time, the U_{oc} value indicator of PV increased to 21.4V, and I_{sc} to 3.05A which is equal. Since the back surface of PVT does not exchange convective heat with the atmosphere in a closed environment, the value U_{oc} is small, but due to the large radiation intensity on the PVT surface, I_{sc} is also relatively large. 3- in PVT mode, we can see that the value U_{oc} rises to 23.5V at PVT and I_{sc} remains constant around 4A due to the triggering of HC.

When the reflectors are placed at the optimal angle (mode 2), the short-circuit current increases from 3.05A to 4.1A as a result of the increase in radiation intensity from 880W/m^2 to 1260W/m^2. In mode 3, the short circuit current remained almost unchanged. During the experiment, the solar radiation intensity versus time graph is presented in Figure 4. We can see from the graph that the reflectors increase the intensity of sunlight up to 1.5 times. As a result of collector cooling, the open circuit voltage difference was restored to 2.3V, and an electrical recovery of 20% was achieved for this voltage.

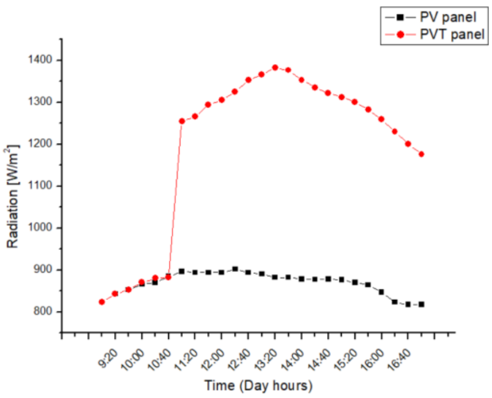

Figure 4: Time dependence of solar radiation.

The electrical power of the devices can be calculated using (7), based on the values of the parameters obtained during the measurements:

$$P = FF \cdot I_{SC} \cdot U_{OC} \,. \qquad (7)$$

The time dependence graph of PV and PVT panel power are shown in Figure 5. It is clear from this graph that in normal cases, 60W PV capacity cannot produce 60W energy at any part of the day. In this case, the maximum power of the PV is around 50W, and considering that in our experience we measured the device in the directed mode, this result means that it will be smaller if the device is in a stationary state.

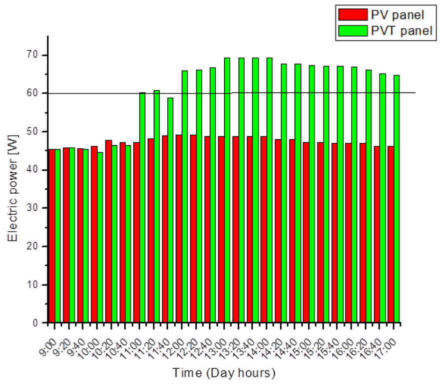

Figure 5: Time dependence of PV and PVT panel electric power.

The goal of the experiment is to maintain the maximum PV power for as long as possible during working hours. This purpose is achieved in the example of PVT. In our experiment, the inlet water temperature is not changed, and at the 3 different water flows (0.005, 0.01 va 0.015 kg/s) additional 1.5l, 3l va 4.5liters of hot water at per minute was obtained from the heat collector. This is proof that the heat losses can be used effectively. The calculations of the average capacity of the PV Panel was 47.6W, and the average power of the PVT panel was 61.6W. In the hot chilla of summer, our above experiment proved that it is possible to make good use of the fixed capacity of PV.

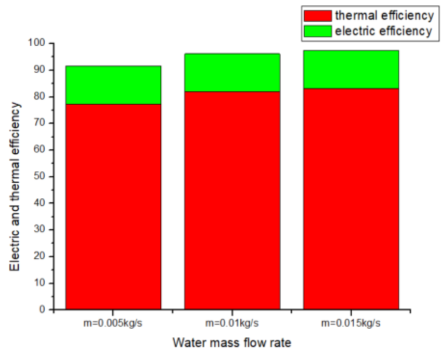

Figure 6: Electric and thermal efficiency of PVT panel for different water flow.

The collector's thermal efficiency was 77.33%, 81.88% and 83.24% respectively for three different water flows. PVT panel electric efficiency, in this case, was almost unchanged upper 14% and for PV panel electric efficiency was above 15%. However, it is to note that PVT's total efficiency was 90% -95%. We can see this clearly in Figure 6 above.

4 CONCLUSIONS

The electrical parameters of MPVD and MPTD used in our experiment were compared. It was found that 60W monocrystalline PV does not provide this rated power at any time of the day, due to insufficient solar radiation and overheating of the PV. In PVT panel, specified power was achieved to 69W by reducing electricity and heat losses. As well as the increase in the average power to 29% was determined by calculations. As a result of the experiment, the following conclusions were obtained:

- Thermal energy obtained from PVT are 5.5-6 times higher than electric energy.
- Reflectors should be used in low radiation days and heat collector systems.
- The energy, which falls on the PVT panel surface, can become 90% profitable energy.
- In PV Panel, it was found that this figure was around 15%.

If we cool PV panels effectively, it is possible to reduce their electrical losses, and also we can get additional thermal energy.

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APPENDIX

The list of abbreviations used in this paper is given below:

W	total light energy (J)
W_{PV}	light energy incident on the PV surface (J)
$W_{ref.}$	light energy returned from the reflector (J)
E	radiation intensity (W/m^2)
S	surface (m^2)
Q	amount of heat (J)
m	mass (kg)
c	specific heat capacity (J/kg·^{o}C)
Δt	temperature difference (^{o}C)
I_{sc}	short circuit current (A)
U_{oc}	open circuit voltage (V)
P	electric power (W)