Analysis of Electrical Parameters of a Metal Collector Photovoltaic-Thermal Device

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Keywords: Renewable Energy, Solar Energy, Photovoltaic-Thermal Device, Metal Heat Collector, Electrical and Thermal Efficiency, Short Circuit Current, Open Circuit Voltage, Electric Power, Energy, Reflector.

Abstract: A photovoltaic-thermal device (PVTD) is developed to reduce energy losses due to high temperatures in photovoltaic batteries (PVBs) and to obtain thermal energy. To enhance heat exchange with the heat-carrying fluid, a copper absorber and a metal heat collector (HC) were used in the PVTD. Additionally, reflectors were integrated to increase the amount of radiation energy incident on the PVB surface. In experiments conducted under natural conditions, the electrical power outputs of PVB and PVTD were compared. Based on experimental results, the key electrical parameters of the PVB and the PVTD were analyzed. The PVTD included a metal heat collector and reflectors to enhance cooling and solar radiation intensity. As a result, the open circuit voltage of the PVTD was 1V higher, and the short circuit current was 1.56 times greater than those of the PVB. Additionally, the average electrical power values for the PVTD and PVB were recorded as 70.3W and 43W, respectively.

1 INTRODUCTION

The utilization of solar energy worldwide is increasing year by year, and this trend is expected to continue in the future [1, 2]. Additionally, the efficiency and technical solutions for using solar energy effectively are advancing annually [3, 4]. The development of science and manufacturing technologies also plays a significant role in the progress of this field. The creation of devices capable of generating both electrical and thermal energy simultaneously is of great importance [5, 6]. During the operation of PVBs, cooling and reflectors are widely used to prevent the decline in electrical efficiency due to high temperatures and insufficient solar radiation [7]. Extensive research is being conducted globally to optimize the shape, material, and other physical properties of heat collectors attached to the back of PVBs to enhance cooling efficiency [8, 9]. Studies also focus on improving system energy efficiency by increasing the density of solar energy incident on the PVB surface through reflectors [10, 11]. Cooling of PVBs is typically achieved using air, liquid, or nanofluid-based systems [12-16]. The geometric and material selection of heat collectors is also crucial [17-19] since the flat backside of PVBs necessitates maximum contact area with the heat collector to improve heat exchange. The choice of material with high thermal conductivity further enhances system efficiency. Ensuring effective heat exchange between components leads to simultaneous improvements in electrical and thermal efficiency. When the system is designed to extract thermal energy, the heat collector must be optimized in all aspects [20].

2 METHODS AND MATERIALS

2.1 Experimental Device

A 60W PVB was selected for the experiment and equipped with a metal heat collector. A thermal paste was used to attach the HC to the PVB. The electrical and additional parameters of the PVB are provided in Table 1, and the characteristics of the thermal paste are listed in Table 2.

Table-1: Physical parameters of photoelectric battery.

Parameters	Size
Geometric size	
PVB surface, S_{PVB}	0.33m^2
PVB frame width, *d*	2.5sm
Back cover thickness, d_q	4mm
Electrical parameters	
Electric power, P_{max}	60W
η	18,36%
Salt circuit voltage, $U_{o.c.}$	21,6V
Short circuit current, $I_{s.c.}$	3,53A

Thermal paste was used to improve heat transfer between parts and create good thermal contact.

Table-2: Physical parameters of thermal paste.

Parameter	Numerical value
Working temperature range	from -50°C to 180°C
Thermal conductivity	3–4.5 W/m·K
Average density	2.5 g/cm³
Validity period	4-5 years

The components of the PVTD are shown in Figure 1. The heat collector was made from steel metal.

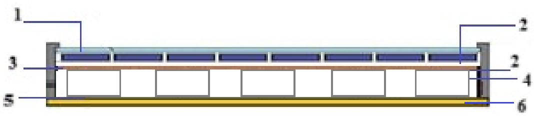

Figure 1: The structure of PVTD. 1 – PVB, 2 – thermal paste, 3 – copper absorber, 4 – metal HC, 5 – foil insulation, 6 – back cover.

The copper absorber serves to ensure uniform heat exchange between the PVB and HC. The absorber thickness is 0.5mm. The general structure of the HC is shown in Figure 2. Five profiles are used, allowing water to move from the bottom to the top. The profile dimensions are 5×2.5cm, with an inter-profile distance of 3.5cm.

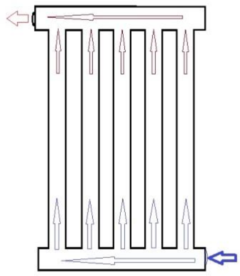

Figure 2: General view of the HC.

The system includes two reflectors, which can be adjusted via brackets as needed. The total reflector surface area is twice that of the PVB surface, with a reflection coefficient of ~ 0.75. The PVB used in the system has a power rating of 60W and consists of 32 solar cells.

2.2 Experimental Method and Basic Measuring Devices

During the experiment, short circuit current, open circuit voltage, solar radiation, inlet and outlet water temperatures, and cooling water mass flow rate were measured. The results were used to create graphs and tables, leading to conclusions.

Short circuit current and open circuit voltage values were measured using UNI-T (UT52 and UT89X) multimeters, while solar radiation was determined using a DT-1307 (Solar Power Meter) device. The parameters of the measurement device are listed in Table 3.

Table 3: DT-1307 Solar Power Meter.

Specifications	
Display	3-1/2 digits LCD with maxmum reading 1999.
Range	1999W/m^2,634BTU/(ft^2·h)
Resolution	1W/m^2;1BTU/(ft^2·h).
Accuracy	typically within ±10W/m^2 [±3BTU/(ft^2·h)]or ±5%
Sampling time	Approx 0.25 second.

Variable resistors (potentiometers) are used to obtain volt-ampere (VAC) and volt-watt characteristics (VWC).

3 RESULTS AND DISCUSSION

The experiments were conducted in September 2024 under natural conditions at the heliopolygon of the Physics-Technical Institute, with measurements taken at 20-minute intervals. The general setup of the PVB and PVTD during the experiment is shown in Figure 3.

Figure 3: General view of PVB and PVTD during the experiment.

The short circuit current time dependence of PVB and PVTD is shown in Figure 4. From the graph, it can be seen that the increase in solar radiation falling on the PVTD surface due to reflectors led to a 1.5-1.7-fold increase in short circuit current. Since the short circuit current is proportional to the solar radiation falling on the surface, the reflectors increased the average current by 56.64%. Despite the fact that the short circuit current of the 60W FEB is 3.53A, the average short circuit current of the PVTD is 4.28A, and for the PVB this indicator is 2.73A.

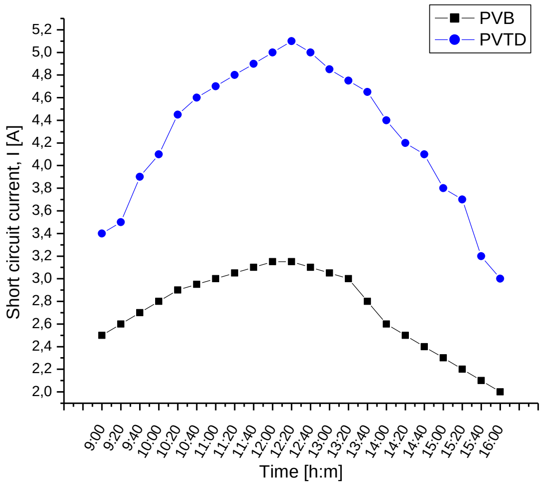

Figure 4: Graphs of short circuit currents of PVB and PVTD over time.

Open circuit voltage versus time is shown in Figure 5. Cooling reduced electrical losses, and additional thermal energy was obtained from the temperature difference between incoming and outgoing water.

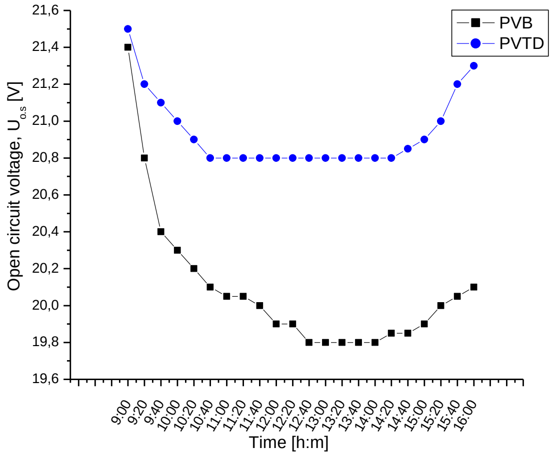

Figure 5: Graphs of the time dependence of the PVB and PVTD's open circuit voltage.

As a result of cooling, the PVTD open circuit voltage was a minimum of 20.8V, while in PVB this value was 19.8V. The difference in open circuit voltage, and electrical power is clearly visible in the volt-ampere characteristic (VAC) and volt-watt characteristic (VWC) of the devices (Fig. 6). Two multimeters (UNI-T brand UT89X and UT52) and a reostat were used to measure VAX and VVX. Figures 6 and 7 depict the VAC and VWC of PVB and PVTD measured over the same period of time under natural conditions.

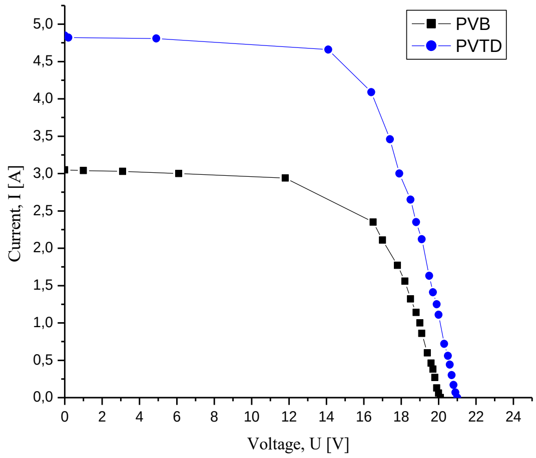

Figure 6: PVB and PVTD VAC.

Due to the cooling and reflectors of the PVTD, the voltage was improved by 1V and the current by 1.6A. As a result, the electrical power was 38.78W

(900W/m^2) for the FEB and 67.1W (1500W/m^2) for the PVTD.

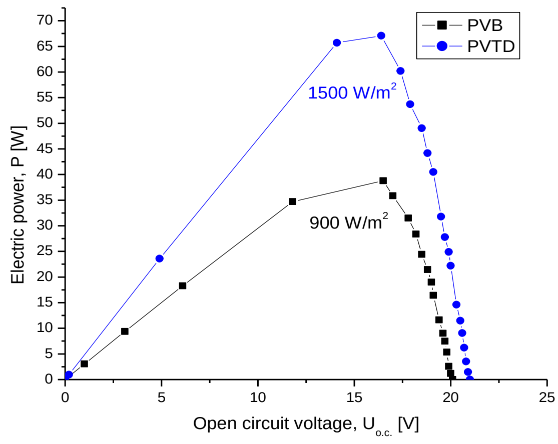

Figure 7: PVB and PVTD VWC.

At the same time, when the PVB power reached 37W, the PVTD power was around 68W. The PVB and PVTD electrical power indicators are displayed in a single graph for the purpose of analyzing the efficiency of reflectors and cooling (Figure 8). The maximum power in PVTD was 83.38W, and in PVB it was 49.27W. The average power values showed values of 70.3W and 43W, respectively.

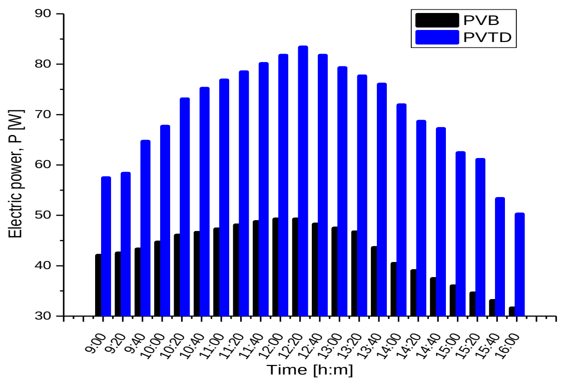

Figure 8: Time dependence of PVB and PVTD electric powers.

In the experiment, the simultaneous use of cooling and reflectors led to an increase in system efficiency. With an inlet water temperature of 18^{0}C, the outlet water temperature was 30^{0}C (water consumption 0.4 liters/min). Experimental results have shown that the average electrical efficiency in FEIQ is 15-16%, and the thermal efficiency is over 50%. The average daily electricity output power for PVTD was 63% higher than for PVB.

4 CONCLUSIONS

In PVTD, the results of cooling and reflector efficiency are reflected in open circuit voltage, short circuit current, and electrical power. In addition, it was possible to extract thermal energy from the temperature difference between the incoming and outgoing water. The average power values for PVTD and PVB were 70.3W and 43W, respectively. This showed that the average daily electricity for PVTD production was 63% higher. Such low-power FEB-based devices can be used as the main power supply for charging and operating smartphones, notebooks, and other low-power devices in extreme situations. Additionally, it can be used for certain purposes in hot water supply.

5 ACKNOWLEDGMENTS

We would like to express our gratitude to Termiz State University, which greatly supports the field of renewable energy sources and scientific work.

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