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Abstract

© 2020 Ridwone Hossain et al. Solar photovoltaic (PV) and solar thermal systems are most widely used renewable energy technologies. Theoretical study indicates that the energy conversion efficiency of solar photovoltaic gets reduced about 0.3% when its temperature increases by 1°C. In this regard, solar PV and thermal (PVT) hybrid systems could be a solution to draw extra heat from the solar PV panel to improve its performance by reducing its temperature. Here, we have designed a new type of heat exchanger for solar PV and thermal (PVT) hybrid systems and have studied the performance of the system. The PVT system has been investigated in comparison with an identical solar PV panel at outdoor condition at Dhaka, Bangladesh. The experiments show that the average improvement of open circuit voltage (Voc) is 0.97 V and the highest improvement of Voc is 1.3 V. In addition, the overall improvement of output power of solar PV panel is 2.5 W.

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Research Article

New Design of Solar Photovoltaic and Thermal Hybrid System for Performance Improvement of Solar Photovoltaic

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Solar photovoltaic (PV) and solar thermal systems are most widely used renewable energy technologies. Theoretical study indicates that the energy conversion efficiency of solar photovoltaic gets reduced about 0.3% when its temperature increases by 1°C. In this regard, solar PV and thermal (PVT) hybrid systems could be a solution to draw extra heat from the solar PV panel to improve its performance by reducing its temperature. Here, we have designed a new type of heat exchanger for solar PV and thermal (PVT) hybrid systems and have studied the performance of the system. The PVT system has been investigated in comparison with an identical solar PV panel at outdoor condition at Dhaka, Bangladesh. The experiments show that the average improvement of open circuit voltage (Voc) is 0.97 V and the highest improvement of Voc is 1.3 V. In addition, the overall improvement of output power of solar PV panel is 2.5 W.

1. Introduction

Solar photovoltaic (PV) and solar thermal systems are among the most widely used renewable energy technologies. However, the solar PV and thermal (PVT) hybrid system is not popular to that extent. Solar PV systems are available in different sizes from single solar panel system to large-scale solar PV power plants. And solar thermal systems are mostly used for household and commercial purposes. The operation of solar photovoltaic is highly dependent on weather conditions like temperature, precipitation, air condition, and most importantly solar irradiance. Like all other semiconductor devices, solar PV cells are sensitive to temperature. With the increase in temperature, the band gap energy of semiconductor material gets reduced, so the current increases slightly

but the voltage decreases significantly. Therefore, the energy conversion efficiency of silicon solar cell reduces about 0.3% when its temperature increases by 1°C [1, 2]. The working temperature of solar cell could be as much as 50°C above the ambient temperature and consequences of high working temperature are, drop in cell efficiency and permanent structural damage of the solar panel if the thermal stress remains for a longer period [3].

$$I_{\text{cell}} = I_0 - I_{\text{ph}} \left(e^{qV/KT} - 1 \right) \quad (1)$$

Equation (1) shows how temperature is related to current and voltage of a solar cell, where I_0 is the dark current, I_{ph} is the photo current, q is the charge of electron, V is the

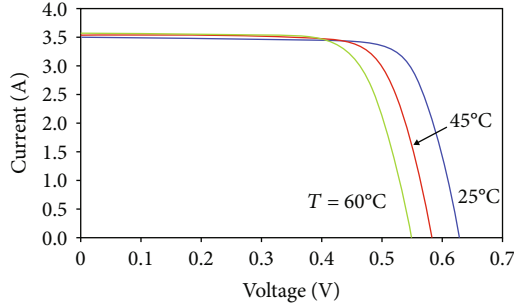


FIGURE 1: The impact of temperature on current and voltage of a solar cell. The reduction in voltage is higher than the increase in current; therefore, the output power of solar cell decreases with increase in temperature.

voltage, K is Boltzmann's constant, and T is the temperature. The simulation result (Figure 1) based on the current Equation (1) of silicon solar cell shows that the voltage of the cell reduces noticeably when its temperature increases. However, the increment of cell current due to temperature raise is negligible. Therefore, the output power of solar cell decreases with the increase in temperature.

When thermal energy system is integrated with the solar photovoltaic system, it is called the photovoltaic and thermal (PVT) hybrid system [4]. Since, the hybrid system utilizes same area for the production of electricity and heat energy, it increases the overall efficiency of the system in terms of energy generation from per unit area [5]. The solar PVT system can be used for crop drying and air heating, and it can also be integrated with building facade, known as the building integrated PVT system (BI/PVT) [6]. The theoretical calculation says that the overall energy conversion efficiency of a hybrid system could be 60–80% [7]. However, the first priority of most of the hybrid systems is to bring down the temperature of solar PV, so that its electrical performance can be improved [8]. Different types of heat exchanger have been integrated with solar PV panel for improving its efficiency by reducing its temperature, for example, the use of fins, hexagonal honeycomb heat exchanger, and V-grooved absorber [9]. Three different designs like V-groove, honeycomb, and stainless steel wool have been installed horizontally into the channel located at the back side of a solar PV panel to improve performance of the PV panel [10]. In another case, 12 units of rectangular tunnel have been installed parallel at the back side of a solar PV panel as a heat exchanger to improve the efficiency of the system [1, 11]. It has been reported that four different hybrid systems like (i) PV with water flow, (ii) PV with water flow and glazing, (iii) PV with air circulation, and (iv) PV with air circulation and glazing have been experimented based on commercial PV panel at outdoor conditions. The result shows that PV cooling can increase the electrical efficiency of the PV panel. The efficiency can improve further by using a booster diffuse reflector [12]. However, the hybrid system with solar PV panel underneath of a glazing system has its own disadvantages. The electrical efficiency of the panel reduces due to the absorption and reflection of sunlight by the glazing system [13]. Recent study shows that the water-based PVT system

can improve the power of the solar PV panel by 6% in average compared to the conventional PV panel [14]. Another study shows that the top surface of the solar PV panel cooling by water can improve the panel efficiency by almost 1.5% [15]. However, the water-based PVT system requires more energy to circulate the working fluid and the system is more complex. Different PVT systems have been tested under same environmental conditions using artificial neural network- (ANN-) based multilayer perceptron (MLP) system [16]. The study shows that the nanofluid/nanophase change material- (PCM-) based system enhances both the electrical and thermal efficiency. It also improves the voltage significantly. Among various PVT systems such as air, water, air/water, phase change material (PCM), and nanofluid, it is found that the air heater PVT system is promising for future preheating air applications [17]. The PVT system has the potential to integrate thermoelectric generator with the system to produce electricity from the thermal energy that is extracted from the solar panel [18, 19].

Here, we have proposed a hybrid system with a new type of heat exchanger for improving performance of the solar PV panel. As shown in Figure 2, the heat exchangers are arranged in such a way that they guide air to circulate in waveform through the channels located inside the solar thermal system. The upper side of heat exchangers is bended and is attached to the back side of the solar PV panel so that conduction heat transfer can happen from the PV panel to the heat exchanger. Performance of the PVT system has been investigated with respect to a solar PV panel with identical specification. Both the systems, solar PV and thermal (PVT system) and normal solar PV panel (normal system), have been examined simultaneously at outdoor conditions.

2. Materials and Method

The solar PV panel attached to the heat exchanger and internal construction of the heat exchanger are shown in Figures 3(a) and 3(b), respectively. The enclosure of the heat exchanger is made of corrosion resistive stainless-steel sheet, and exposed surfaces to air of the heat exchanger are insulated using the glass wool. The fins guide air circulation; the channels are made of aluminium. The upper side of fins is bended and tightly attached to the back surface of the solar PV panel, so that heat transfer from the PV panel to fins occurs by the conduction process. Equation (2) is the heat flow rate across materials by conduction.

$$\frac{Q}{t} = \frac{kAdT}{d}, \quad (2)$$

where k is the thermal conductivity of the material, A is the heat transfer area, dT is the temperature difference across the materials, and d is the thickness. So, the conduction process of heat increases with the increase in thermal conductivity of the material and increase in the heat transfer area. But the heat transfer decreases with the thickness of the transferring material. Thermal conductivity of aluminium is less than that of copper, but aluminium is cost effective, so it has been used as heat transferring material. Since heat transfer rate is

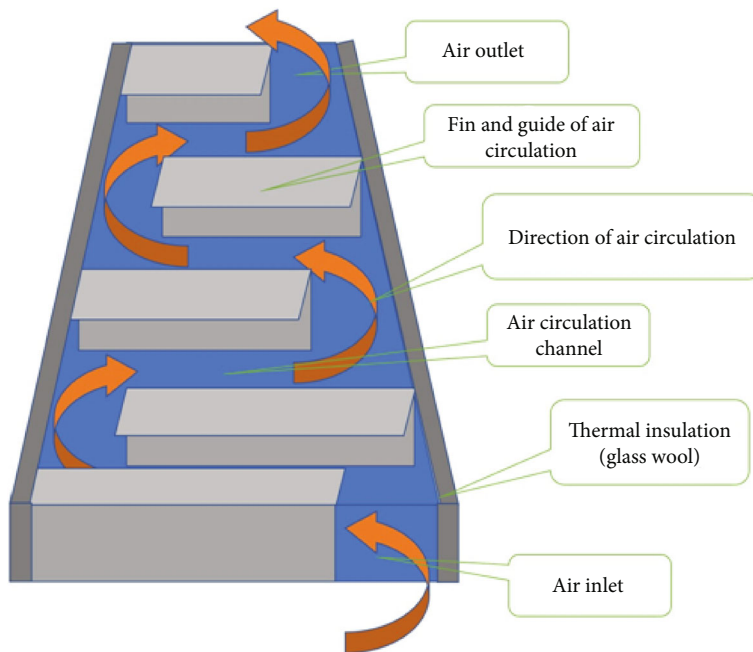


FIGURE 2: Schematic of solar thermal system. The solar PV panel is to set on the top of the solar thermal system.

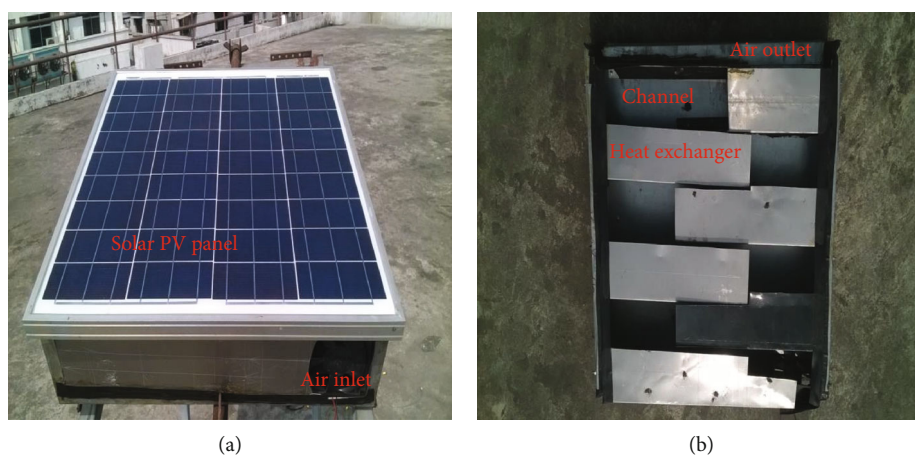


FIGURE 3: (a) The solar PV panel installed on the top of the heat exchanger. (b) Internal construction of the heat exchanger.



FIGURE 4: Digital multimeter is connected to measure the voltage and current. (a) The PVT system and (b) the normal system.

inversely related to thickness of heat exchange material, therefore, thin aluminium sheet (1 mm of thickness) has been used as heat exchange material. The heat transferring area of the sheet has been kept as long as possible to increase the heat transfer.

Performance of the PVT system has been evaluated with respect to an identical solar PV panel at outdoor environmental condition. Identical multicrystalline solar PV panels of 50 W and 12 V rating have been used in both PVT and normal systems [20]. Both the systems have been measured simultaneously at outdoor condition for several days. The experiments are carried out at Dhaka, Bangladesh. Digital multimeters have been used to measure the voltage and current of solar PV panels. The temperature of air at inlet and outlet of the PVT system has been measured by thermocouple. The experimental setup for performance evaluation is shown in Figure 4.

3. Results and Discussion

Different parameters, for example, air temperature at inlet and outlet of the PVT system, voltage and current of the PVT system and the normal system have been measured to evaluate performance of the systems. The power output of the solar PV panels is calculated based on the voltage and current readings. Temperature of air at inlet and outlet of the PVT system, open circuit voltage, and short circuit current readings of the systems have been taken in every 10 min interval.

3.1. Temperature of Air at Inlet and Outlet of PVT System. Except two readings, temperature of air at outlet of the PVT system is always higher than temperature of air at inlet of the system as shown in Figure 5. It indicates that the heat is effectively transferred from the PVT system to the air when the air is circulating through the channels of the heat exchanger. Average temperature difference of air between outlet and inlet is 2.6°C, and maximum difference is more than 4°C. The result shows that the heat exchanger works properly to transfer heat from the PVT system to the circulation air and it should help to improve the electrical output of the PVT system. The air flow rate is an important parameter to performance evaluation of the solar PV and thermal hybrid system. The air flow rate through the heat exchanger can be regulated by controlling the speed of the cooling fan. In our experiments, we have used natural air flow and have not measured the air flow rate.

3.2. Open Circuit Voltage and Short Circuit Current. The open circuit voltage (V_{oc}) measurement of the PVT and the normal systems are shown in Figure 6. There is a significant improvement in V_{oc} of the PVT system compared to the normal system. The V_{oc} of the PVT system is always higher than the V_{oc} of the normal system throughout the day. This result indicates that the heat exchanger is successfully transferring heat from the PVT system to the circulating air. The average improvement in V_{oc} is 0.97 V, and the maximum improvement in V_{oc} is 1.3 V. On the other hand, the reduction in short circuit current (I_{sc}) of the PVT system

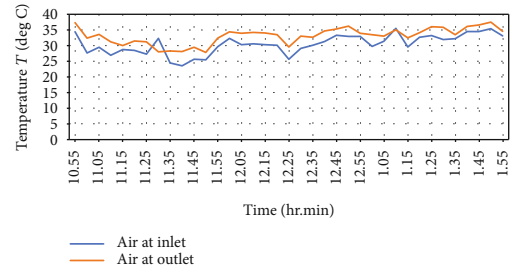


FIGURE 5: Temperature of air at inlet and outlet of the PVT system. Average difference in temperature of inlet air and outlet air is 2.6°C, and maximum difference in temperature is more than 4°C.

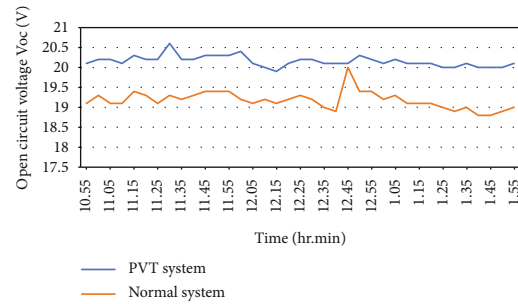


FIGURE 6: Open circuit voltage (V_{oc}) of the PVT and the normal system. The average improvement in V_{oc} is 0.97 V where the maximum improvement in V_{oc} is 1.3 V for the PVT system compared to the normal system.

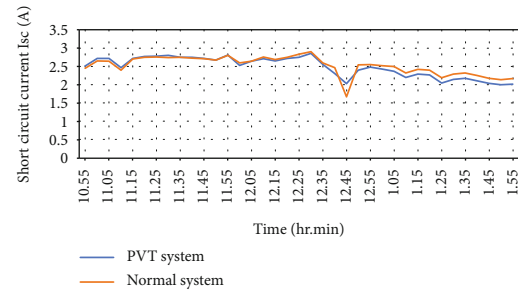


FIGURE 7: Short circuit current (I_{sc}) of the PVT and the normal system. Average reduction in I_{sc} of PVT system is 0.04 A compared to the normal system and maximum reduction in I_{sc} is 0.16 A.

compared to the normal PV system is not significant as shown in Figure 7. The average reduction in I_{sc} of the PVT system is 0.04 A compared to the normal system and maximum reduction in I_{sc} is 0.16 A. The air temperature readings at inlet and outlet of the PVT system and voltage and current readings of the PVT and normal systems support each other.

3.3. Output Power of PVT System. The output power of both systems has been calculated from the V_{oc} and I_{sc} readings. Figure 8 shows that there is an overall improvement in output power of the PVT system in comparison to the normal system. The average improvement in output power of the PVT system is 2.5 W, and maximum improvement is 7.4 W. Temperature difference between the inlet air and outlet air of the PVT system is a clear indication of temperature drop

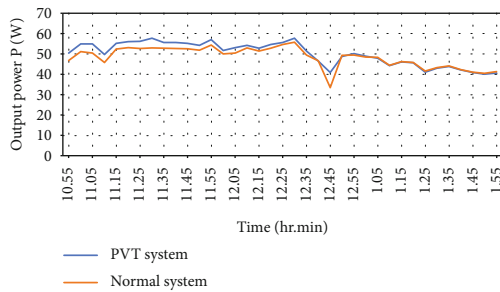


FIGURE 8: Output power of PVT and normal system. Average improvement in output power of PVT system is 2.5 W, and maximum improvement is 7.4 W.

of the PVT system. And improvement in output power of the system is due to this temperature drop. However, the output power of PVT and normal system are almost same, and the PVT system is fairly less effective very effective after 12.55 pm. This could be due to the less difference between outlet temperature of the PVT system and the ambient temperature in the afternoon afternoon. The performance of the PVT system is better when the ambient temperature is low compared to the air temperature at the outlet of the system.

4. Conclusions

Design of a new heat exchanger for solar PV and thermal hybrid system has been implemented successfully. The performance evaluation of the PVT system in comparison to the normal solar PV panel shows that the new design of heat exchanger successfully transfers heat to the circulating air. And therefore, there is a significant improvement in the open circuit voltage and the output power of solar PV panel. The overall improvement of voltage is 0.97 V, and overall improvement of the output power is 2.5 W.

Data Availability

The dataset is provided as supplementary material. The data set file is titled "Data Temp Voc Isc Power".

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Al Jumlat Ahmed conceive the idea and experiment design. Nirupam Saha and Preetom Debnath performed the experiments and result compilation. Ridwone Hossain and Sheik Md Kazi Nazrul Islam wrote the manuscript. M. A. Parvez Mahmud and Abbas Z. Kouzani made the scientific explanation and revision of the manuscript.

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Supplementary Materials

The dataset and a video clip on the solar PV and Thermal (PVT) system are provided as supplementary materials. (*Supplementary Materials*)

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