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ER Jay Bharat Doshi
Department of Renewable Energy Engineering, CTAE, MPUAT, Udaipur, Rajasthan, India

Dr. Sudhir Jain
Professor and HOD, Department of Renewable Energy Engineering, CTAE, MPUAT, Udaipur, Rajasthan, India

Development of water-cooling system for enhancing the efficiency of solar photovoltaic panel

ER Jay Bharat Doshi and Dr. Sudhir Jain

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Abstract

The solar photovoltaic module converts solar energy into electrical energy. It converts only 5-15% of incoming solar radiation into electricity and the remaining more than 80% of solar radiation either gets reflected into the atmosphere or dissipated into the solar photovoltaic module in the form of thermal energy. Elevated module temperature reduces the electrical efficiency of modules. Keeping in view to enhance the efficiency of a solar photovoltaic module, a water cooling system for the photovoltaic module was developed which is fixed at the rear side of the module. The developed system generates both electric energy and thermal energy. The experimental results like electrical efficiency of photovoltaic module, thermal and combined efficiency at a constant mass flow rate were obtained under the climatic condition of Udaipur, Rajasthan. The results at water mass flow rate of 0.0056 kg/s and average solar radiation of 540.82 W/m2, significant improvement in the efficiency of a photovoltaic module by 7.38% with a thermal and combined efficiency of 53.28% and 66.47%.

Keywords: Photovoltaic module; electrical efficiency; thermal efficiency; combined efficiency; water cooling system

1. Introduction

Solar Photovoltaic (SPV) module utilizes solar radiation to generate electricity raising its operating temperature. Cooling of PV module improves its electrical power output and efficiency. PV module can be cooled by circulating cold water through the water-cooling system fixed at the rear side of the PV module. In a hybrid developed system, PV module and thermal unit are mounted together to enable simultaneous conversion of solar energy into electricity and thermal energy. The developed system generates higher combined energy output per its square meter area making it cost-effective compared to conventional PV modules if the cost of thermal components is minimum.

Dubey *et al.* [1] stated that solar cell performance decreases with an increase in temperature. The operating temperature plays a key role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a photovoltaic module depend linearly on operating temperature. Also, the performance ratio decreases with latitude because of temperature. Regions with high altitudes have a higher performance ratio due to low temperature, like the Andes, Himalaya region and Antarctica.

Popovici *et al.* [2] studied the different cases of modifying the height of the ribs ranging from 0.01 m to 0.05 m with the inclination angle of the ribs 450, 900, and 1350. The results show that the cooling of the photovoltaic panel is directly proportional to the height of the ribs and inversely proportional to the inclination angle. For 0.03 m height of the rib, more heat transfer was recorded for the inclination angle of 450, while in the case of 1350 angle, the heat transfer rate is very low.

Fudholi *et al.* [3] studied the electrical and thermal performances of photovoltaic- thermal collectors that were determined under 500-800 W/m2 solar radiation levels and mass flow rates ranging from 0.011 kg/s to 0.041 kg/s. The PVT collectors were tested with respect to PV efficiency, thermal efficiency, and a combination of both. The results show that the spiral flow absorber exhibited the highest performance at a solar radiation level of 800 W/m2 and a mass flow rate of 0.041 kg/s. This absorber produced a PVT efficiency of 68.4%, a PV efficiency of 13.8%, and a thermal efficiency of 54.6%.

Corresponding Author:
ER Jay Bharat Doshi
Department of Renewable Energy Engineering, CTAE, MPUAT, Udaipur, Rajasthan, India

Palaskar and Deshmukh have extensively reviewed various literature available on research, development and selection of PV absorber types, materials of its construction and use of concentrators for improvement in the energy output of hybrid solar systems [4]. The article shows that the overall performance of the hybrid system improved considerably using above- mentioned techniques. It was also noticed that the spiral flow type of system fabricated from copper tubes with reflectors works with higher combined PV/T efficiency compared to hybrid systems. It was also revealed that such a system has better commercial viability in the future.

Jin-Hee Kim and Jun-Tae Kim [5] studied two-hybrid PV/T water collector systems with different arrangements namely, sheet and tube and fully wetted absorber surfaces. The combined PV/T efficiency of these systems observed was 65% and 60.6% respectively. The comparison of the performance of the absorber surfaces using unglazed and glazed PV module designs revealed that an unglazed PV module produced more electrical energy and the glazed PV module generated more thermal energy because of its more efficient ways of absorbing solar energy.

The performance evaluation of a hybrid photovoltaic thermal double pass facade for space heating was developed using the energy balance equations for the climate of New Delhi by Tiwari G N *et al.* [6]. In this study, from numerical results, it was observed that the yearly thermal and electrical energy generated by the façade system were 480.81 kWh and 469.87 kWh respectively. It was also observed that thermal energy generated by the system was 1729.84 kWh per year.

In the current research, performance analysis of simple PV modules and developed systems are compared with various technical parameters at ATC for latitude of Udaipur. For this work, a commercial PV module was attached with a water cooling system at its back surface. The absorber surface was fabricated using aluminium sheets. Box type absorber surface was used to fabricate hybrid system increasing its surface contact with the back surface of PV module. Increase in photovoltaic output power, thermal output power, photovoltaic, thermal and combined efficiency and decrease in the top and back surface temperatures of a module at different flow rates of cooling water for highest PV power condition are discussed and analyzed.

2. Development of water cooling system

The assembly consists of the bonding of the PV module and a flat absorber surface. Solar radiation was used to generate physical processes in the PV module which converts sunlight into electricity and also generates excess heat. This excess heat was carried out by the water flowing through the absorber surface. Exchange of heat from PV module was possible due to good thermal capacity of water. A pump was used to supply water at a constant mass flow rate from the storage tank to the absorbing surface. Inlet and outlet were provided to the absorber surface for the continuous circulation of water.

Fig 1: Developed System

Table 1: Specification of PV panel at STC

General Information	
Rated power (Pmax)	50 WP
Open Circuit Voltage (Voc)	21.5 V
Short Circuit Current (Isc)	3.14 A
Voltage at max. power	17.7 V
Current at max. power	2.85 A
Cell area	635 x 520.7 mm

3. Calculation of technical parameters

Equations used to calculate output photovoltaic and thermal power, input solar power, thermal and combined efficiency at ATC for Udaipur are as explained below.

Electrical power (PPV) generated by un-cooled and cooled module and thermal power (PT) produced by the developed system at ATC condition are given by:

$$PPV = V \times I \qquad \ldots\ldots\ldots(1)$$
$$PT = \dot{m} \times CP \times (T_{wo}-T_{wi}) \qquad \ldots\ldots\ldots(2)$$

Total solar radiation (IT) on normal to the module surface (W) and solar radiation (It) calculated on normal to module surface (W/m2) are calculated by using the following formulas:

$$IT = It \times APV \qquad \ldots\ldots\ldots(3)$$

The electrical efficiency (ηPV) of PV module and thermal efficiency (ηT) of a developed system (%) are found by following equations:

$$\eta PV = PPV / IT \qquad \ldots\ldots\ldots(4)$$
$$\eta T = PT / IT \qquad \ldots\ldots\ldots(5)$$

Combined photovoltaic and thermal efficiency developed system are calculated as under:

4. Performance analysis

The developed system was tested to determine its electrical and thermal performance at constant mass flow rates and various operating temperatures. The inlet temperature of the water was not constant due to the closed-loop system, it changes as the outlet temperature changes. For measuring the current and voltage multi-meter was used. To measure solar radiation solar pyrheliometer sun tracker and data tracker was used installed at DREE, CTAE, and Udaipur. The system was operated at constant mass flow rates during the experimentation. A temperature gun was used to measure the top and back surface temperature of the panel. All data related to electrical and thermal performance were taken at every 30-minute interval. This data was used to evaluate the overall performance of the developed system. The Figure below shows the efficiency results of the solar photovoltaic module versus time and top and back surface temperature of PV module versus time.

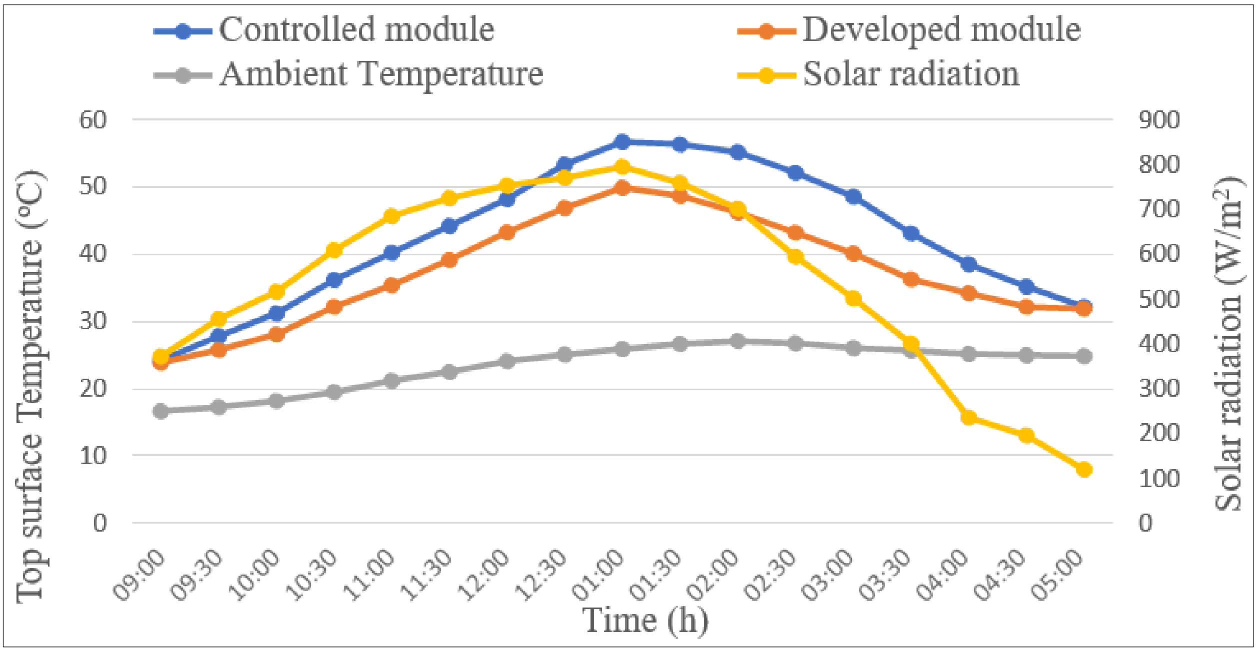

Fig 2: Top surface temperature of photovoltaic module with respect to time

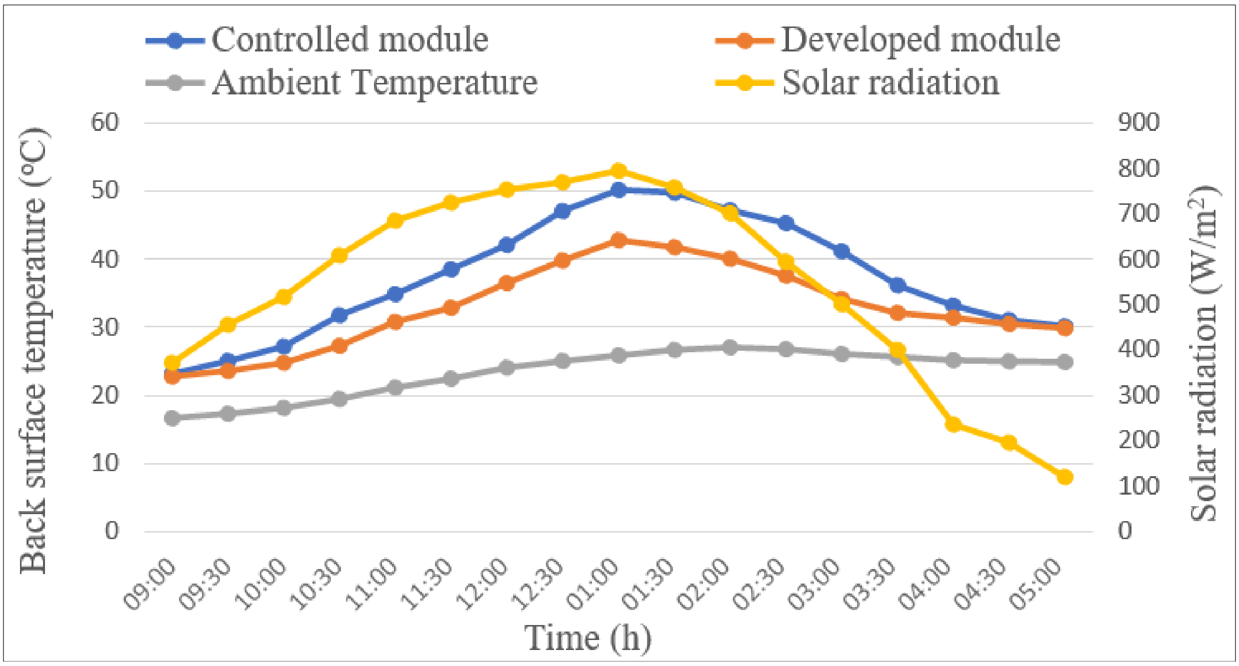

Fig 3: Back surface temperature of photovoltaic module with respect to time

Figure 2 presents the top surface temperature of the controlled and developed a photovoltaic module with respect to time. The results show that the minimum top surface temperature of the controlled module was 24.2 ºC at 9:00 AM, while the maximum top surface temperature attained by the controlled module was 56.7 ºC at around 1:00 PM. While the minimum and maximum back surface temperature of a controlled module was 23.2 ºC and 50.2 ºC respectively as shown in Figure 3. As for the developed photovoltaic module, the minimum and maximum top surface temperature was 23.9 ºC and 49.9 ºC respectively (Figure 2). Also, the back surface temperature for the developed module was 22.8 ºC and 42.8 oC respectively (Figure 3). Corresponding minimum ambient temperature was 16.7 ºC at 9:00 AM and maximum ambient temperature was 27.1 ºC at 2:00 PM. It was also observed that the minimum and maximum solar radiation was 120.5 W/m2 at 5:00 PM and 795.06 W/m2 at 1:00 PM respectively.

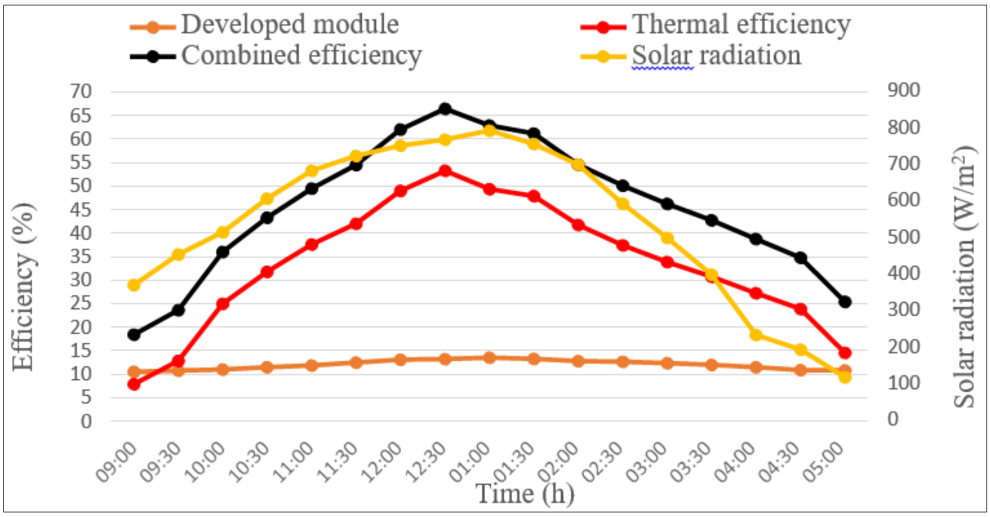

Fig 4: Experimental results of efficiencies of developed module with respect to time

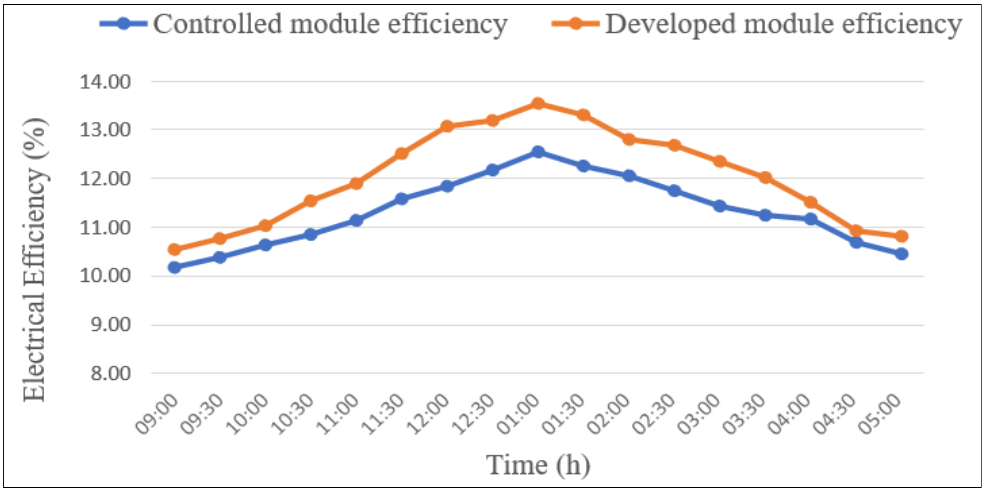

Fig 5: Experimental results of electrical efficiency of controlled and developed module with respect to time

Figure 4 shows the efficiencies of four distinctive parameters like electrical efficiency of a developed module, thermal efficiency, combined efficiency of the developed module and solar radiation with time. The results show that the maximum electrical efficiency obtained by the developed module was 13.54% and the controlled module has 12.55% at 1:00 PM as shown in Figure 5. There was an increase in electrical efficiency of a developed module by 7.38% than the controlled module. The efficiency of the controlled module decreases with increasing the surface temperature of a solar photovoltaic module. This mainly reveals that the cooling of module improves its electrical efficiency. The thermal efficiency of the developed module increases from 7.87% to 53.28% in the time period of 9:00 AM to 1:00 PM. Also, the combined efficiency of developed module increases from 18.42% to 66.47%.

5. Conclusion

Aluminium absorber surface fitted at the rear side of the photovoltaic module supplying cooled water through it reducing the operating temperature of PV module from 56.7 °C to 49.9 °C as compared to a controlled module. Due to this reason, the efficiency of the photovoltaic module increases by 7.38%. The developed system generates 1598.74 Wh of combined energy with 229.42 Wh of electrical energy for the module area of 0.4 m2. These results reveal that the developed system can be used for alternative power production.

6. References

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