Performance Evaluation of Solar Photovoltaic/Thermal Hybrid Water Collector

Pratish Rawat[1], Mary Debbarma[2], Saurabh Mehrotra[3], K. Sudhakar[4], Prakash Kumar Sahu[5]

[1,2,3,4,5]*Energy Centre, Maulana Azad National Institute of Technology Bhopal, Madhya Pradesh, 462 051, India*

Abstract: Solar photovoltaic/thermal (PV/T) system is an integrated system of consists of PV modules with heat extracting media such as water or air, produces both thermal energy and electricity simultaneously. The electrical efficiency of the photovoltaic (PV) module can be increased by reducing the operating temperature of the PV module by extracting the thermal energy simultaneously which is associated with the PV module. In this paper, an attempt has been made to describes the effectiveness in terms of exergy of a solar photovoltaic-thermal (PV/T) hybrid water collector that generates both electricity and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation than that of plain photovoltaic. It is observed that PV module temperature has a great effect on the thermal, electrical and exergy efficiency. The thermal, electrical and exergy efficiency can be improved if the heat can be removed from the PV module surface. The performance analysis including all aspects i.e. electrical, thermal and exergy efficiencies are discussed. It is observed the overall efficiency (Thermal Efficiency + Electrical Efficiencies) varies between 50-75% and maximum exergy efficiency is 13.12%.

Keywords: Solar PV/T collector, Thermal efficiency, Electrical efficiency, Exergy analysis, solar energy

1. INTRODUCTION

A solar photovoltaic/thermal (PV/T) hybrid system is an integrated of solar photovoltaic (PV) and solar thermal systems which simultaneously convert solar energy into electricity and heat. There are different approaches in PV/T system designing. The design parameters are based on collector type, thermal efficiency, electrical efficiency, solar fraction and operating temperature. In conventional photovoltaic system, high incident solar radiation on (PV) panel should give high electrical output. However, high incident will increase the temperature of the solar cells and that will decrease the efficiency of the panel. A solar cell converts solar radiation to electrical energy with peak efficiency in the range of 6–15%, depending on type solar-cell at standard temperature and pressure. With increase of 1 ^{0}C in temperature there is reduction of the photoelectric conversion efficiency by 0.5%. The solar PV/T hybrid design gives additional advantages, such as:

- it works on noiseless environment
- high performance and reliable system
- does not produce any toxic waste or radioactive material
- reduction of the thermal stresses and hence a longer life of the PV module
- low maintenance system.
- a stabilization of the solar cell current–voltage characteristics.

The exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. Exergy is the energy that is available to be used. Energy is never destroyed during a process; it changes from one form to another. In contrast, exergy accounts for the irreversibility of a process due to increase in entropy. Exergy is always destroyed when a process involves a temperature change. This destruction is proportional to the entropy increase of the system together with its surroundings. The destroyed exergy has been called anergy. The ratio of exergy to energy in a substance can be considered a measure of energy quality. Exergy analysis is used to find out the energy utilization efficiency of an energy conversion system. Exergy analysis yields useful results because it deals with irreversibility minimization or maximum exergy delivery. The exergy analysis has been increasingly applied over the last several decades largely because of its advantages over energy analysis. To perform energy and exergy analyses of the solar PV, the quantities of input and output of energy and exergy must be evaluated.

2. METHODOLOGY

2.1 SOLAR PV/T WATER COLLECTOR CONSTRUCTION

The solar PV/T is constructed using 37 W polycrystalline silicon solar panel of area 0.3216 sq. m. The sheet and tube concept is used to design the system. Copper sheet acts as an absorber, which absorbs heat from the panel and transfers it to water flowing in copper tubes.

Table 1: Technical specification of PV/T system

1	Solar PV module type	Polycrystalline
2	Maximum power	37 W
3	Voltage at max. power (V_{mp})	17 V
4	Current at max. power (I_{mp})	2.18 A
5	Short circuit current (I_{sc})	2.30 A
6	Open Circuit Voltage (V_{oc})	21 V
7	Module area	0.3216 sq. m.
8	Absorber	Copper sheet and copper tubes

Figure 1: Experimental setup of PV and PV/T system

2.2 MEASUREMENTS

Table 2: Instrument used in experiment

S.No.	Instrument	Accuracy	Range	Model make	Parameter Measured
1	Solar Module Analyser	+/- 1%	0-10 V 0.01-10A	MECO 9009	Electrical Characterstics
2	Solar Power Meter	+/- 5%	0-1999 W/m^2	Tenmars TM-207	Global Radiation
3	Humidity/Temperature meter	0.1% R.H. +/- 0.8 ^{0}C	R.H. – 0 – 80% & 0-50 ^{0}C	Lutron HT-3006A	Temperature and humidity
4	IR Thermometer	+/- 2 ^{o}C	-18 to 400 ^{o}C	Raytec MT4	Front and back temperature of Panel
5	Mercury Thermometer	+/- 1 ^{0}C	-10 ^{0}C to 110 ^{o}C	Elite	Inlet and Outlet temperature of water

Figure 2: Instruments used in the experiment

2.3 EXPERIMENTAL PROCEDURE

The experimental study was done in the month of April 2014 under the meteorological conditions of Bhopal, M.P, India. The latitude and longitude of the location are 23°25 N and 77°42 E. The ambient temperature fluctuates in the range of 5 to 48 ºC during a year in Bhopal. Water is used as a coolant in the system with a constant mass flow rate of 0.0025 kg/sec. Wind velocity, Solar intensity, ambient temperatures, relative humidity, open circuit voltage, short circuit current, maximum power, front side and back side temperature of module, fill factor, voltage and current at maximum power, initial and final temperature of water were measured every one hour for both solar PV and solar PV/T systems.

Photo Electric conversion efficiency, $\eta_e = I_m V_m$ (1)

GA

Thermal Efficiency, $\eta_{th} = mc_p (T_f - T_i)$ (2)

GA

Overall Efficiency, $\eta_o = \eta_{th} + \eta_e$ (3)

Energy saving efficiency, $\eta_f = \eta_e / \eta_{power} + \eta_{th}$ (4)

Where η_{power} is the electric power generation efficiency of the conventional power plants; its value can be taken as 38%.

General equation for the exergy balance:

$$EX_{in} - E_{out} = E_{loss} \quad (5)$$

$$n_{ex} = \frac{E_x\ output}{E_x input} \quad (6)$$

3. RESULTS AND DISCUSSIONS

Actual data obtained for a typical day in the month of April 2014 at Bhopal was applied to investigate the effect of the ambient conditions on the performance of the module. The exergy efficiency of solar PV System has been computed on the basis of second law of thermodynamics, by taking exergy of sun radiation. An energy and exergy balance for the solar panel was carried out. Exergy analysis is more convenient than the energy analysis for predicting the efficiency of the solar panel. It is concluded that exergy is more effective and more efficient tool for the performance analysis of the solar panel.

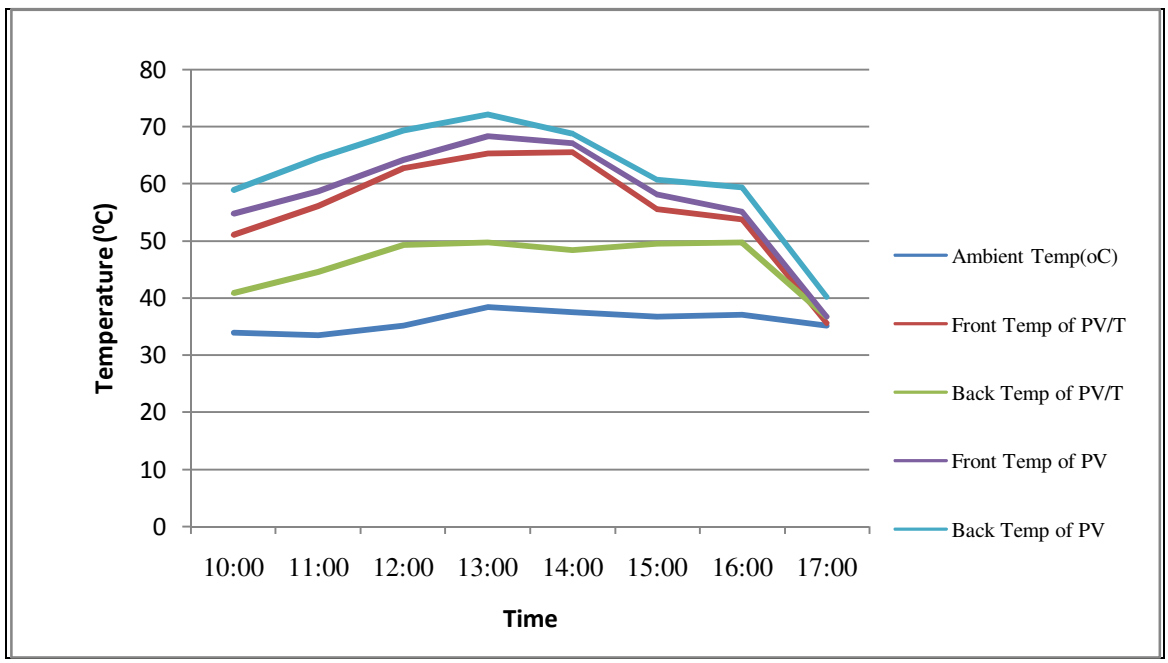

Figure 3: Variation of front and back temperature of PV and PV/T

Figure 3 shows the variation of front and back temperature of PV and PV/T panel with ambient temperature. Temperature plays an important role in performance of solar panel. The temperature of PV/T panel is lower than that of PV panel. The back temperature of PV/T panel varies between

40 ^{0}C – 50 ^{0}C and front temperature varies between 50 ^{0}C – 70 ^{0}C. Figure 4 shows the variation of electrical efficiency of PV and PV/T. There is slight variation in electrical efficiency of PV and PV/T systems. The electrical efficiency of PV/T varies between 7.58% and 8.25% whereas electrical efficiency of PV varies between 7.42% and 8.35%.

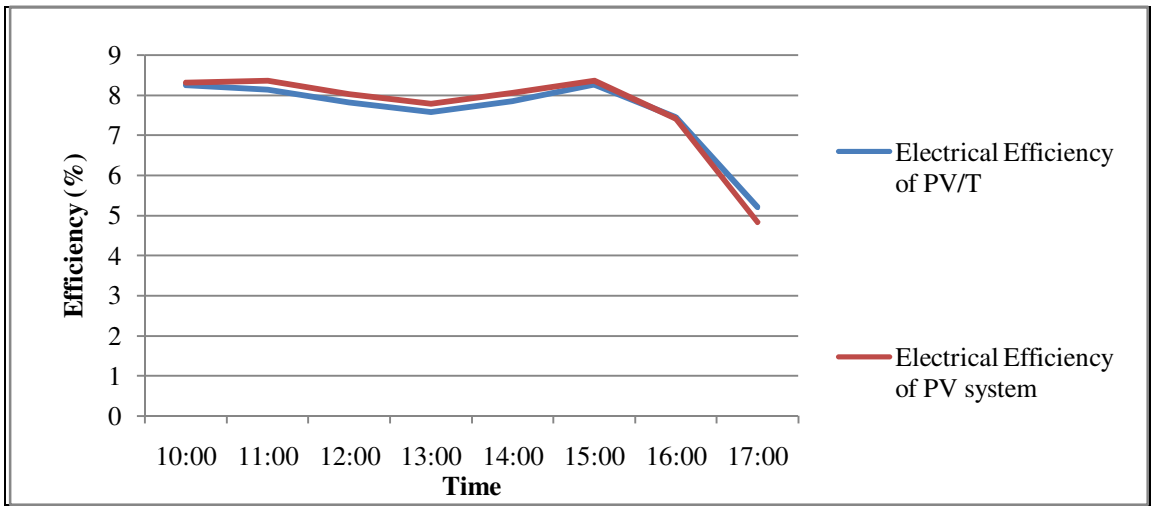

Figure 4: Variation of Electrical Efficiency

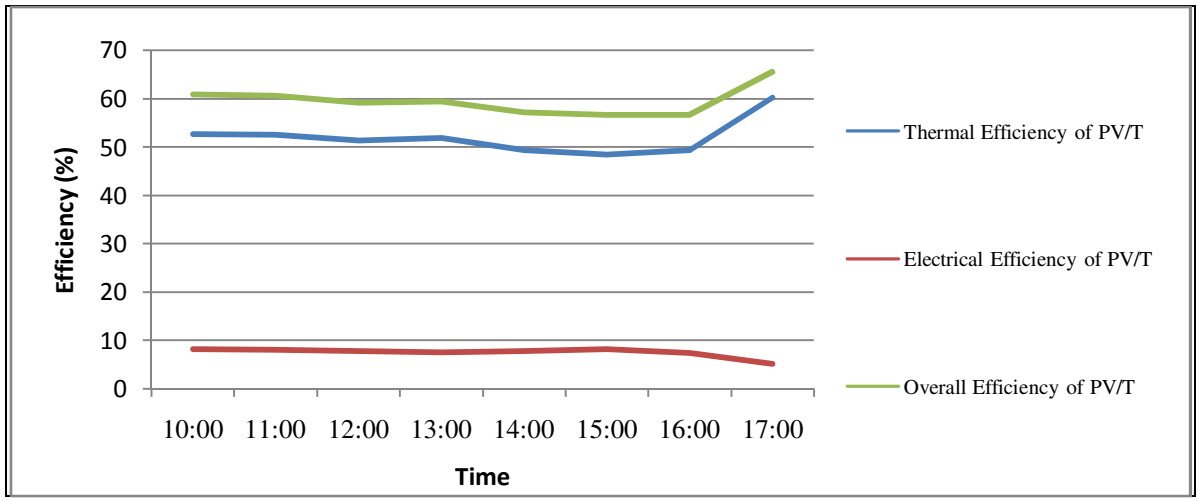

Figure 5: Variation of Electrical, Thermal and Overall Efficiency of PV/T

Figure 5 shows the variation of electrical, thermal and overall efficiencies of PV/T system. It can be seen that with the constant mass flow rate of 0.0025 kg/sec, the thermal efficiency was varies between 48% - 60% and the temperature rise in flowing water is about 21 ^{0}C. The final temperature

of water exceeds 48 ^{0}C. The average overall efficiency and energy saving efficiency were exceeds 57.61% and 50.23% respectively.

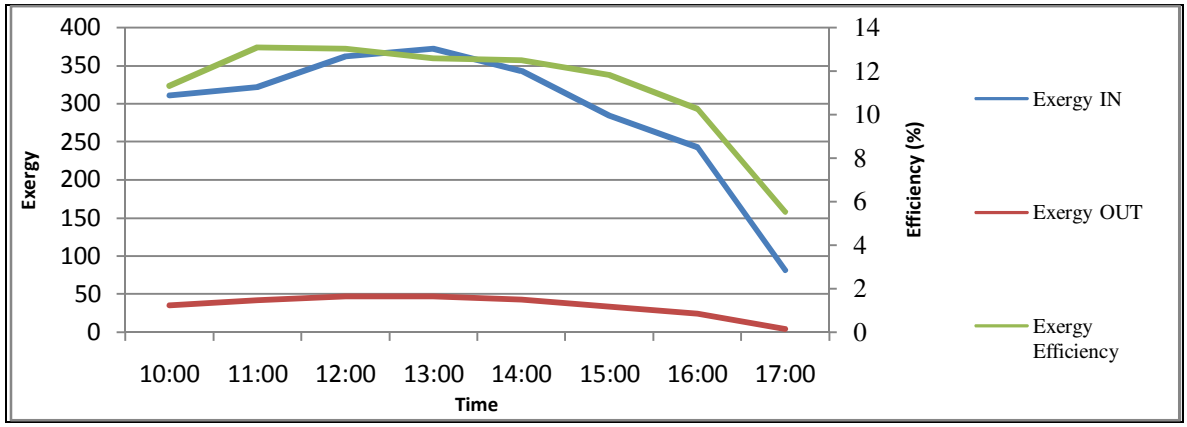

Figure 6: Variation of Exergy Efficiency of PV/T system with Exergy IN and OUT

Figure 6 shows the variation of exergy efficiency of PV/T system and variation of Exergy IN and Exergy OUT. Exergy is the energy that is available to be used. The exergy efficiency varies between 10.25% - 13.08% for the whole day and reduces to 5.52% in the evening. The maximum exergy efficiency of PV/T system was found to be 13.08%. The exergy in was around 371 W/m^2 and maximum exergy out was 47 W/m^2.

4. CONCLUSION

In this study, a comprehensive energy and exergy analysis of the Solar Photovoltaic/ Thermal hybrid water collector system installed at Energy Centre, NIT-Bhopal, India is conducted experimentally. A parametric study has been carried out to investigate the performance of a solar PV/T panel. Experiments are conducted with fixed water flow rate of 0.0025 kg/sec. With the proposed design and operating condition the average electrical efficiency was about 7.57%, the average thermal efficiency was about 45.5%, and the total efficiency of the system exceeded 65%. The energy saving efficiency of the PV/T system exceeded 60%. The results show that the electrical and thermal performance of the combined PV/T system is much more than that of employing the PV alone. This kind of PV/T system is especially suitable for low temperature applications like pre-heating of domestic water, space heating or hybrid solar still.

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