PERFORMANCE ANALYSIS OF PARTIALLY COVERED PHOTOVOLTAIC THERMAL (PVT) WATER COLLECTOR

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Abstract

In this paper the photovoltaic thermal (PVT) water collector partially covered by glass and its energy and exergy analysis were carried out. The various parameters were computed such as thermal efficiency, electrical efficiency, exergy efficiency etc on daily basis for Meteorological conditions of Bhopal, India in the month of May. It is found that the maximum temperature of hot water from PVT system on particular day was found to be 47.5 0C with mass flow rate of 0.0025 kg/sec. The thermal efficiency, electrical efficiency and energy saving efficiency of the system were found to be exceeding 67%, 9% and 67% respectively. The use of PVT system, not only reduce the electrical load from conventional energy sources but also produces two form of energy from single system i.e. electricity and thermal.

Key Words: *Energy, Exergy, Solar PVT Collector, PVT System, Solar Energy, Performance Analysis*

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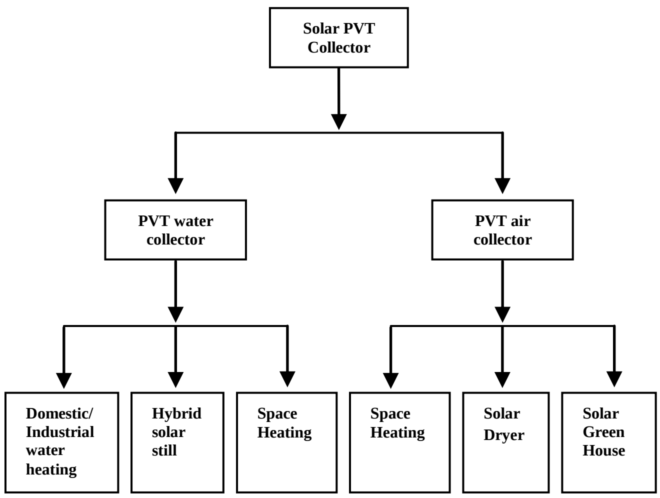
1. INTRODUCTION

A huge amount of research on solar PV-thermal hybrid collectors has been carried out over the past three decades. A photovoltaic-thermal (PVT) system is developed by combining solar photovoltaic and solar thermal system. The PVT system is an integrated system which can produce both electricity and heat at the same time. A hybrid photovoltaic thermal (PVT) solar energy system consists of a PV panel at the back of which a heat exchanger is attached. The PVT system refers to a system that extracts heat from the panel by using heat transfer fluid, usually water or air and sometimes both. There are many reasons which motivate the researchers to develop various models and designs of the PVT system. One of the main reasons is that PVT system can provide higher efficiency than individual PV and thermal collector system. The integration of two systems to one not only increases the efficiency of overall system but also reduces the payback period. Solar PVT collectors can be classified as:

1. PVT liquid collector
2. PVT air collector
3. PVT Liquid and air collector
4. PVT concentrator (CPVT)

There are various approaches in PVT system designing. The solar PVT design parameters are based on type of working fluid, thermal and electrical efficiency, solar radiation and working temperature. The solar PVT water collector system consists of conductive-metal pipes or plates attached to the back of a PV module which acts as an absorber, absorbs heat from back of module and transfer it to circulating fluid. In this arrangement, water is flowed through these pipes with the help of pump. In solar PV system, high incident solar radiation on solar PV panel give high electrical output but at the same time it also increase the temperature of the solar cells and that results in reduction in the efficiency of the panel. At standard temperature and pressure (STP) conditions and depending on type of material of solar cell, the electrical conversion efficiency of commercially available solar panel is in the range of 6–15%. It has been found that with every increase of 1 ^{0}C in temperature of solar PV panel, there is reduction of the efficiency by 0.5%.

1.1 Application of solar PVT system



1.2 Advantages of PV/T system

1. Maximizes yield from sun's energy where roof space is restricted
2. Cooling circuit improves efficiency of solar PV cells
3. Cost of manufacturing and installation reduced
4. Low maintenance

2. METHODOLOGY

2.1 Experiment Methodology

In the construction of solar PV/T system 37W polycrystalline silicon solar panel is used. A combination of copper sheet and tubes is attached at back side of panel which act as absorber. Water is circulated as coolant in the pipes with the help of pump. A transparent glass cover is used which partially cover the solar PV panel. The experiments were carried out at M.A.N.I.T. Bhopal (latitude of 23.16ºN; longitude of 77.24ºE) India. Various parameters are measured during the experiment such as Solar intensity, wind velocity, ambient temperatures, relative humidity, open circuit voltage, short circuit current, maximum power, front side and back side temperature of module, fill factor, etc. The parameters were measured in every one hour from 10.00 a.m. in the morning to 5.00 p.m. in the evening.

Table 2.1: Meteorological Conditions

Location	Bhopal, Madhya Pradesh, India
Meteorological Conditions	Latitude of 23.16ºN; Longitude of 77.24ºE
Month	May 2014
Time	10.00 a.m. to 5.00 p.m.

Table 2.2: 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 0.5 mm thick and copper tubes 12 mm diameter
9	Fluid	Water
10	Submersible Pump	AC-220V, 50Hz, 18W, Maximum lifting height = 1.65 m.

Table 2.3 Instruments Used in experiment

S.No.	Instrument	Accuracy	Range	Parameter Measured
1	Solar Module Analyser	+/- 1%	0-10 V 0.01-10A	V_{oc}, I_{sc}, $V_{m,}$ $I_{m,}$ $P_{m,}$ Efficiency, Fill Factor
2	Solar Power Meter	+/- 5%	0-1999 W/m^2	Solar Irradiance
3	Humidity/ Temperature meter	0.1% R.H. +/- 0.8 ^{0}C	R.H. – 0 – 80% & 0-50 ^{0}C	Ambient Temperature, Humidity
4	IR Thermometer	+/- 2 ^{o}C	-18 to 400 ^{o}C	Surface Temperature
5	Water proof digital thermometer	+/- 1 ^{0}C	-50 to 300 0C	Inlet and outlet water temperature
6	Hot wire Anemometer	+/- 0.1 m/s	0.2 – 20 m/s	Wind velocity

2.2 Performance Evaluation

Photo electric conversion efficiency is the ratio of useful electrical output of the system to the incident solar irradiation on the surface of collector within a given period.

Photo Electric conversion efficiency

$$\eta e = (I_m V_m)/(GA) \quad (1)$$

Thermal efficiency is the ratio of useful thermal energy output of the system to the incident solar irradiation on the surface of collector within a given period.

Thermal Efficiency,

$$\eta th = mc_p (T_f - T_i) /(GA) \quad (2)$$

The sum of thermal and electrical efficiency is known as overall efficiency and is commonly used to assess the overall performance.

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

Considered electrical energy as a high grade form of energy gain, the energy saving efficiency η_f is also used [1]: it is defined as:

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%.

2.2.1 Energy and Exergy Analysis

According to first law of thermodynamics,

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

General equation for the exergy balance:

$$EX_{in} - E_{out} = E_{loss} \quad (6)$$

For the steady-state flow process during a finite time interval, the overall exergy balance of the solar PV can be written as follows [2].

Exergy Input = (Exergy Output + Exergy Loss + Irreversibility) (7)

The energy conversion efficiency of the solar PV (η_{energy}) is calculated from the following equation: [3-4]. The current-voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation

$$I = I_1 - I_0 \times \exp\left[\frac{q \times (V - IR_s)}{A \times K \times T}\right] \quad (8)$$

The electric power output of PV is:

$P_{el} = I \times V$ (9)

The maximum power output is given by:

$P_{max} = V_{OC} \times I_{SC} \times FF$ (10)

$P_{max} = V_{mp} \times I_{mp}$

A dynamic thermal model proposed by Duffie and Beekman, included a lump overall loss coefficient UL for a unit area [5]. Exergy efficiency of the photovoltaic module is also defined as the ratio of total output exergy to total input exergy [2, 6, 7]. An exergy efficiency of the solar PV can be defined as the ratio of the exergy gained by the solar PV (exergy output) to the exergy of the solar radiation (exergy input) [8].

$\eta_{ex} = (E_{x\ output}) / (E_{x\ input})$ (11)

Electrical Exergy in the output electrical power of PV module [4]

E_x electrical = V_{oc} x I_{sc} x FF (12)

Table 2.4: Input parameter used for analysis

Input parameter	Value
Nominal operating cell temperature (NOCT)	41 ^oC
Stefan Boltzmann constant (σ)	5.67×10^{-8} W/m^2-K
Emissivity of the panel (ε)	0.9
Sun temperature	5800 K

3. RESULTS AND DISCUSSION:

The maximum global radiation reaches to 850 W/m^2 and maximum temperature of 44.7 ^0C. Figure 3.1 shows the variation of global radiation and ambient temperature with time for PV. The maximum global radiation reaches to 990 W/m^2. Figure 3.2 shows the variation of front and back temperature of panel of PV and PV/T. Back temperature of PV/T is lower than PV because of heat transfer from panel to flowing water. The back side temperature of PV panel reaches upto 73 ^0C whereas back side temperature of PV/T reaches upto 65 ^0C. Figure 3.3 shows the difference of inlet and outlet temperature of water. The inlet water temperature is kept below the ambient temperature for higher heat transfer rate and better efficiency. The temperature of outlet water exceeding 47.5 ^0C and maximum inlet temperature reaches upto 35^0C. Figure 3.4 shows the variation of electrical, thermal and overall efficiency with time for PV/T. the electrical efficiency is around 6-7% and maximum of 9.7%, thermal efficiency exceeding 67% and overall efficiency exceeds 69%. Figure 4.18 shows the variation in electrical efficiency of PV/T and PV. The average electrical efficiency of PV/T is 6.39% for the day and that for PV is 7.50%. Exergy efficiency is the ratio of exergy out to exergy in. The exergy efficiency is exceeding 13% for the mass flow rate of 0.0025 kg/sec. The maximum exergy input is about 300 W/m^2. Exergy out is the addition of electrical exergy and thermal exergy which is reaches up to 30.8 W/m^2.

Table 3.1: Test Result of PV and Partially Covered PV/T system

Time	Global Radiation (PV/T)	Global Radiation (PV)	Thermal Efficiency of PV/T	Electrical Efficiency of PV/T	Overall Efficiency of PV/T	Electrical Efficiency of PV system	Exergy Efficiency	Energy Saving Efficiency
10:00	640	767	46.509	9.765	56.275	8.789	13.310	46.766
11:00	690	888	51.198	8.277	59.476	8.352	12.156	51.416
12:00	707	918	53.206	7.181	60.387	8.176	12.341	53.395
13:00	850	990	48.873	6.758	55.631	6.578	10.130	49.050
14:00	770	826	47.153	6.041	53.195	8.107	10.603	47.312
15:00	542	666	39.228	6.755	45.983	7.595	9.948	39.405
16:00	250	375	47.102	4.067	51.170	9.466	4.588	47.209
17:00	150	210	67.601	2.373	69.865	2.946	2.820	67.660

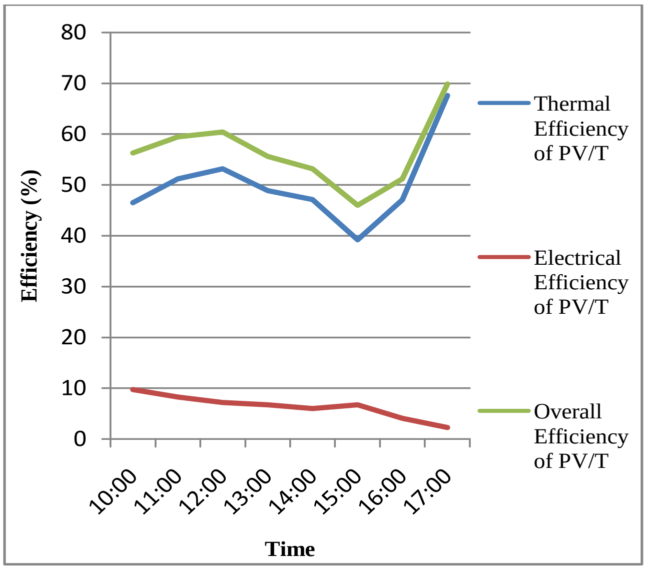


Figure 3.1: Variation of Electrical, Thermal and Overall Efficiency of PV/T with Glass Cover

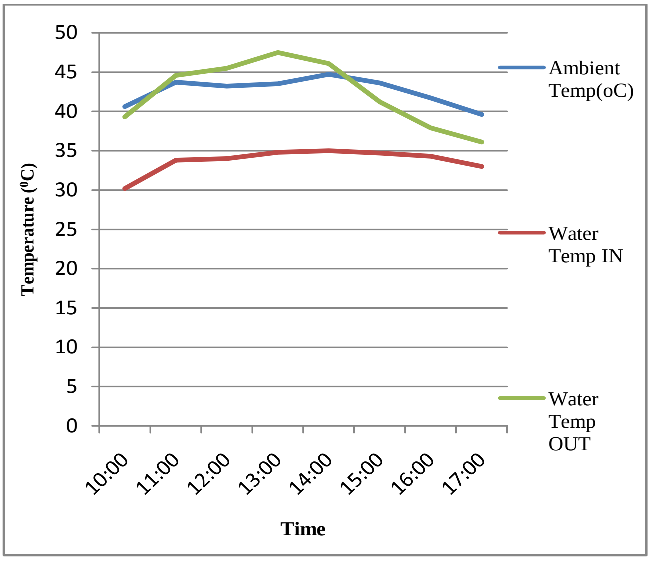


Figure 3.2: Variation of Inlet and Outlet Water Temperature for PV/T with Glass Cover

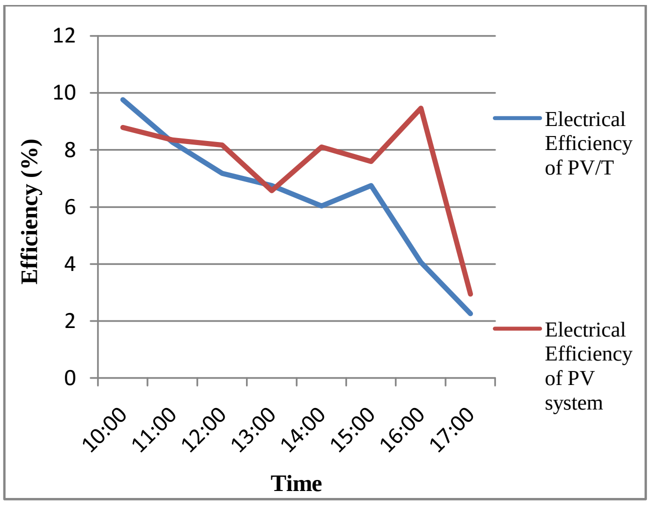


Figure 3.3: Variation of Electrical Efficiency of PV and PV/T with Glass Cover

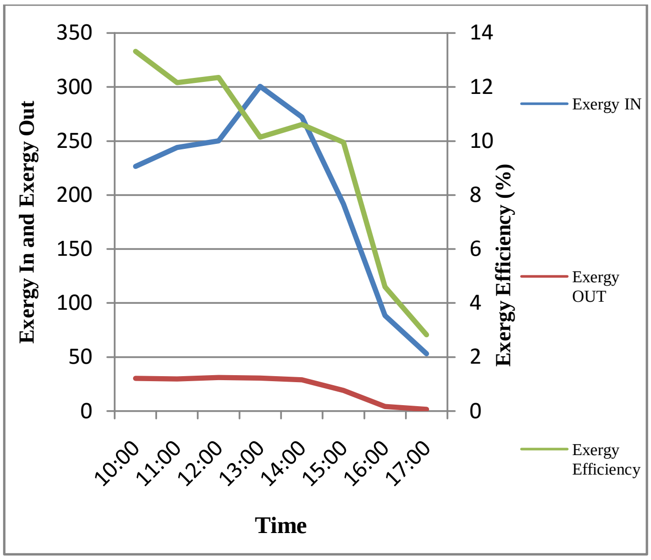


Figure 3.4: Variation of Exergy IN, Exergy OUT and Exergy Efficiency of PV/T with Glass Cover

Table 3.2: Comparison of various efficiencies of PV/T and PV

S. No.	Partially Covered Solar PV/T Hybrid System						Solar PV
	Mass Flow Rate (kg/sec)	Average Electrical Efficiency (%)	Average Thermal Efficiency (%)	Average Overall Efficiency (%)	Average Energy Saving Efficiency (%)	Average Exergy Efficiency (%)	Average Electrical Efficiency (%)
1	0.0025	6.39	50.11	56.49	50.27	9.48	7.50

4. CONCLUSION

This article has presented performance evaluation of the partially covered photovoltaic thermal water collector. A partially covered solar PVT system was successfully designed and a preliminary study of this technology was carried out in a university building of MANIT, Bhopal. The surface temperature of solar PV panel is directly proportional to intensity of solar radiation. With increase in solar irradiance electrical efficiency increases but surface temperature of solar panel also increases which can affect the electrical performance of the PV system. With the combination of solar PV and solar thermal system as PVT system, the energy yield per unit area, can be improved. By using the PVT technique partially covered with glass, it was concluded from the experimental result that with the mass flow rate of 0.0025 kg/ sec, the daily average electrical efficiency was about 6.39%, the characteristic daily thermal efficiency exceeded 67%, the characteristic average overall efficiency was above 56.49% and the characteristic daily energy saving was up to 67.66%. The exergy efficiency was exceeds 13%. The effect glass cover reduces the heat loses but it also increases the reflective losses which can be seen by comparing electrical efficiency of PV and PVT system. The high efficiency of the combined system can shorten the payback period of the entire system. The cost of adding the collector to the PV module is not very significant compared to the price of PV module itself. Therefore, the PV/T system is worth developing in the industry.

NOMENCLATURE

η_f	Energy Saving Efficiency	%
η_{th}	Thermal Efficiency	%
η_e	Electrical Efficiency	%
η_o	Overall Efficiency	%
V_{oc}	Open circuit voltage	V
V	Voltage	V
V_{mp}	Voltage at maximum power point	V
I_{mp}	Current at maximum power point	A
I_{sc}	Short circuit current	A
I	Current	A
FF	Fill factor	No units
m	Mass flow rate	Kg/sec
A	Surface area of the module	m^2
G	Global irradiance	W/m^2
K	Boltzmann constant	J/K
P_{el}	Electrical power	W
P_{max}	Maximum power	W
T	Temperature	K
T_a	Ambient temperature	K
T_m	Module temperature	K
NOCT	Nominal operating cell temperature	^oC

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