Development and Performance Evaluation of Solar PVT Technology with Plane Mirror

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Abstract— Photovoltaic Thermal (PVT) combines the solar thermal and photovoltaic systems. This technique benefits from both light and heat of the solar radiation to produce electricity and hot fluids. Research in PVT systems is rapidly growing with more methods and techniques to increase the overall efficiency, reduce the cost, improve the modeling, and maintain the system for long periods of time and employing them for suitable application. The thesis aims to study some of the research conducted in this field in order to understand and derive key points to producing more research and providing constructive criticism for the work presented. In the current project experimental investigation is carried out to improve the output power of solar cell using cooling and light reflection from mirrors. The results show that by adding mirror, the current and output power of solar cell increase but the open circuit voltage and maximum power voltage decrease due to heat. By adding cooling, the open circuit voltage and the maximum power voltage are improved, so the output power also increases.

Keywords: Solar PVT, Performance Evaluation, Efficiency

I. INTRODUCTION

The world's energy consumption is increasing day by day and with increase in demand, the generation is also increasing. Most of the energy generated from conventional sources of energy like fossil fuels, etc. Solar energy can easily be converted directly into electricity by using photovoltaic (PV) and concentrating photovoltaic (CPV) systems. However, the main drawback of such systems is that with increase in temperature, their efficiency decreases. The PV and CPV cells will also exhibit long-term degradation, if the temperature exceeds a certain limit, and the life-span would reduce rapidly. Hence, a suitable cooling technology is required for such systems to achieve better performance.

In the present study, cooling technology is developed for the cooling of PV system, which are named as Photovoltaic and Thermal system (PVT). For the development of such technology, the development and performance evaluation were carried out with PV panels.

The demand of electricity is increasing at the rate of 3% per year due to globalization and the increase in technology for human comfort.

Overall, the sources of energy are renewable energy and non-renewable energy. Wind, water wave and solar energy are examples of renewable energy. Coal, oil and natural gas are examples of non-renewable energy.

If the current trend of global energy use-demand continues, the supply of fossil fuels is predicted to be exhausted within the next centuries. A report by International energy agency in 2001, estimated that with the existing rate of consumption, the oil reserves will last up to the year 2100 and the coal reserves will exhaust in the next 170-200 years. The major challenges lie with developing nations like India, which has 18% population of the world. It is very difficult to meet this ever increasing energy demand. As shown in Figure 1 the total current electricity generation capacity of India is 371.97 GW out of which 65% are still fossil fuel based power plants. (Jakhar et al., 2016)

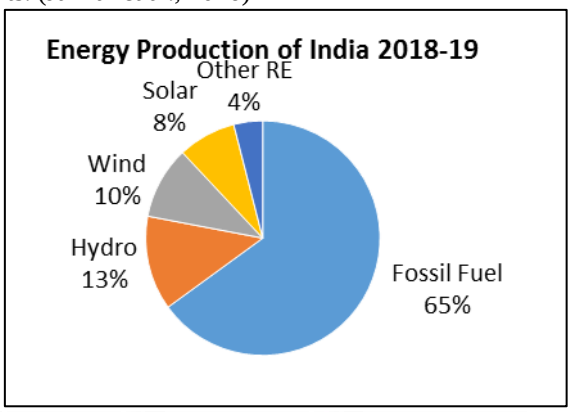

Fig. 1: Power Generations from Different Sources (India)

Most of the researchers are focused on the efficiency improvement of the PV panel and solar thermal system. The performance improvement of the solar PV panel was started in various methods namely, selection of semiconductor material, solar concentrator with PV panel, solar tracking system and combined photovoltaic thermal cooling system (air/water).

Even by applying all the above methods, the performance of the PV panels gets affected because of temperature effect. Finally they found out that, the reduction of temperature of the PV panel will give better improvement in efficiency. So, the performance improvement of PV panel with proper cooling system will give better result out of all other methods that is called as PVT (Photovoltaic & Thermal) system.

This PVT technology maximizes the electrical efficiency of the PV panel. Absorb the thermal energy from the solar PV panel by cooling with the solar thermal system and utilize the more amount of solar energy falling in the same area with a single system with simple construction. It reduces the system cost and minimizes the area utilization for solar collector.

II. METHODOLOGY

This section deals with the materials, methods and techniques adopted for design and development of PVT panel. This PVT panel was fabricated and the experiments were carried out to evaluate the performance of solar PVT panel with plain mirror at the Agricultural Engineering Department, Parul Institute of Technology, Parul University, and Vadodara. The study area lies at 22° 31' N – latitude, 73° 19' E – longitude and at an altitude of 35.5 m above mean sea level. The details

of the experiment and the principles employed during the proposed research work are given in the following sections:

A. Construction of PVT Panel

Firstly dismantling of solar panel was done and removed the aluminium frame from the side of the panel, then after copper pipe of 8 mm diameter is taken and gives U-shape and attach this pipe at the back of the solar panel. Copper pipe is attached with sealant with zero clearance to get maximum heat from back of the panel. Electric wire is attached with panel and took is up to where power requirement. After that at last insulation sheet is placed to avoid loss of heat in atmosphere.

This all system is assembled and put it in the wooden box and fix from the boundary with sealant to avoid passing of air and water in the panel. Here we have attached plane mirror with adjustable plane with certain angle. At other side wooden stand is made for panel also because we have to put panel in front of sunlight at 30-45 degree angle to get maximum power. At last all boundaries of panel and back of the mirror are sealed with cello tape to not showing the M-seal sealant. All these attachment done in panel is based on given diagram.

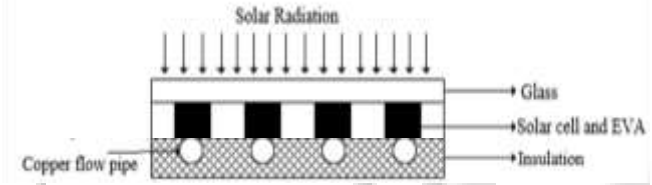

Fig. 2: Sectional view of PVT panel

Fig. 3 Solar PVT Model

Sr. No.	Particulars	Dimension
1	Length of solar panel	24.5 cm
2	Height of solar panel	18.5 cm
3	Breadth of solar panel	2.5 cm
4	Length of Cu pipe	100 cm
5	Diameter of Cu pipe	8 mm
6	Thickness of Cu pipe	1 mm
7	*Diameter of plastic pipe*	1 cm
8	Thickness of plastic pipe	1 mm
9	Length of mirror	30 cm
10	Height of mirror	22.5 cm
11	Capacity of water tank	2.5 ltr
12	Height of water tank from ground	23.5 cm
13	Angle for solar panel from ground	38
14	Thickness of insulation sheet	2 cm
15	Area of solar cell	317.75 cm^2

Table 1: Construction material details

Sr. No	Instrument	Uses	Image
1.	Pyranometer	To measure solar light intensity and solar insolation.	
2.	Thermo-couple	To measure the temperature	
3.	Multimeter	To measure the voltage and current of PV panel	

Table 2: Data of Instruments Used for the Study

III. RESULT AND DISCUSSION

This chapter deals with the results of the investigation carried out on studies on Solar PVT developed at Department of Agricultural Engineering, Parul institute of Technology, Parul University, Vadodara. The experimental data during the test along with the input environmental parameter such as solar radiation. The recorded data was analyzed to evaluate the efficiency of PV panel and efficiency of water heating system, and economic performance of the PVT panel.

Also 3D diagram of model is created and analyzed simultaneously when practical was done in front of solar radiation.

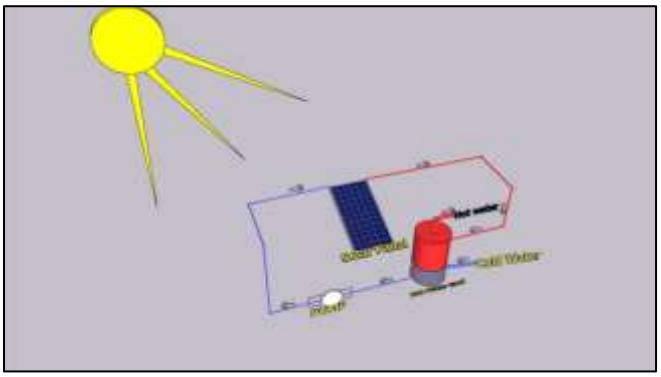

Fig. 4(a): 3D diagram of PVT model

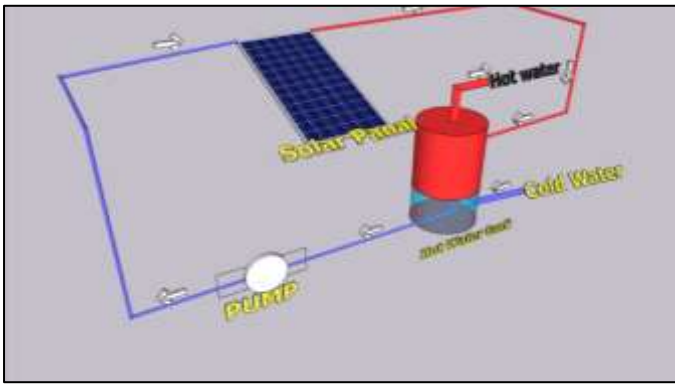

Fig. 4(b): 3D diagram of PVT model

As shown in diagram solar panel reassembled into solar PVT panel was attached with water circulation system (Water tank, pump and pipe). Here water flow is given starting from water tank its outlet from bottom of the tank because of cold water is stored in tank at the bottom due to density difference. Hot water is flows outward at the top of the PVT panel and transferred into water storage tank.

A. Calculation of Design Consideration of Drying System

The solar PVT is made for water capacity of 2.5 liter and Solar panel is taken about 6 W. For the design calculation, we have several factors as below:

B. Solar Radiation

The average solar radiation measured throughout the day of testing was 1005 W/m^2. This radiation is taken into account for further calculation.

C. Open Circuit Voltage & Short Circuit Current

Here we have measured open circuit voltage by multimeter attached at the time of testing and that measured data given in appendix C. The average V_{oc} is 19.47 V. Short circuit current is also measured by multimeter and its average value is 0.248 A.

D. Total Power Availability

Average solar radiation we got about 1005 W/m2 and solar panel area is about 0.0317 m^2 and our model has only one panel so,

$$P_a = S \times A \times n$$
$$P_a = 1005 \times 0.0317 \times 1$$
$$P_a = 31.85\ W$$

E. Electrical Efficiency

Maximum voltage and maximum current at maximum power is measured at values 18.47 V and 0.22 A respectively.

$$\eta = \frac{P_{max}}{P_a}$$
$$\eta = \frac{V_{max} I_{max}}{S \times A}$$
$$\eta = \frac{18.47 \times 0.22}{31.85}$$
$$\eta = 12.75\ \%$$

F. Thermal Efficiency

The inlet cool water temperature and the outlet hot water temperature are measured for calculating the thermal efficiency of the system. In this system, the inlet water temperature is 27˚C and outlet hot water temperature is 42˚C. The thermal efficiency of the system achieved is 59.06%. After attaching the thermal cooling system, the temperature of the PV panel gets decreased and the electrical power generation is increased.

$$\eta_{th} = \frac{Q_u}{S \times A \times n}$$
$$Q_u = mC_p\Delta T$$
$$Q_u = 0.03 \times 4180 \times (42 - 27)$$
$$Q_u = 1881\ J$$
$$\eta_{th} = \frac{1881}{1005 \times 0.0317 \times 1}$$
$$\eta_{th} = 59.04\ \%$$

G. Total Efficiency

Total efficiency is efficiency of PVT panel with both Solar PV and water heating system combined.

$$\eta_T = \eta + \eta_{th}$$
$$\eta_T = 12.75 + 59.04$$
$$\eta_T = 71.79\ \%$$

H. Economics of solar PVT panel

It is considered that the economics of solar PVT is compared with the Power using from our panel generated and electrical heaters. The cost required for solar hot water system and electrical systems are calculated and the payback period is calculated.

Cost of solar PVT, Investment = *Rs.* 2035

Daily power generated from the panel,

$$Q_E = 0.024\ kWh$$

Cost of electricity per day, P_E

$$P_E = Q_E \times Unit\ Price$$
$$= 0.024 \times 5$$
$$= Rs.0.12$$

(Assuming 300 days of annual utilization of system)

Annual saving (PV panel), Rs.

$$= P_E \times 300$$
$$= 0.12 \times 300$$
$$= Rs.36$$

Daily thermal energy requirement, Q_E

$$Q_E = \frac{Q_U}{0.95 \times 3600}$$
$$= \frac{1881}{0.95 \times 3600}$$
$$= 0.55\ kWh$$

Cost of electricity per day, P_E

$$P_E = Q_E \times unit\ price$$
$$= 0.55 \times 5$$
$$= Rs.2.55$$

Assuming 300 days of annual utilization of solar hot water system,

Annual saving (Thermal system), Rs.

$$= P_E \times 300$$
$$= 2.55 \times 300$$
$$= Rs.825$$

Total Annual savings (PVT Panel), Rs.

$$= 36 + 825$$
$$= Rs.861$$

Simple payback period, Rs

$$= \frac{Investment}{Annual\ Savings}$$
$$= \frac{2035}{861}$$
$$= 2.36\ Years$$

I. Performance Evaluation of Solar PVT

The performance of solar PVT was evaluated and discussed under the following.

J. Effect of solar radiation and Temperature on panel

This test was conducted with a view to find out variation in temperature of solar panel and temperature of water from the outlet. It was observed that the maximum temperature gained by the panel was 51.8 °C at 01:00 PM, while the minimum temperature was at the starting of day around 28 °C. At other side maximum temperature of water was observed 43.3 °C and minimum at ambient temperature was 28 °C. It was observed that there is an increment of 23.8 °C temperature of panel and 15.3 °C temperature in water as compared to ambient temperature.

It was observed that the maximum and minimum solar radiation was 1250 W/m2 at 01:00 PM and 685 W/m2 at 09:30 AM respectively. The trend of result for temperature and solar radiation was plotted on graph as shown in fig. 5

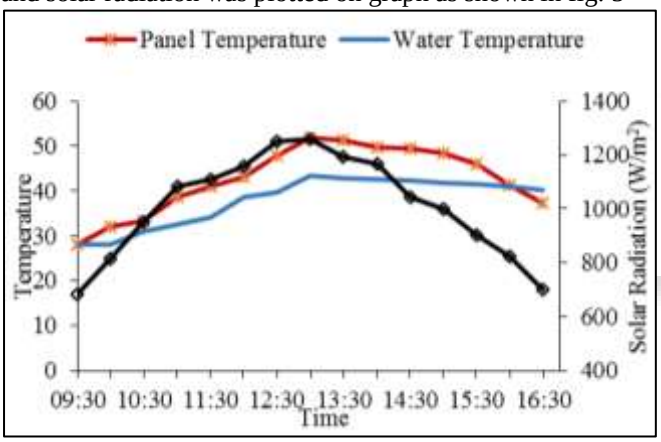

Fig. 5: Performance curve of PVT panel

K. Measurement of Open circuit voltage and short circuit current without mirror

It was observed that the maximum V_{oc} was 19.2 volt at 01:00 PM and minimum V_{oc} was 16.9 volt at 04:30 PM. And maximum I_{sc} was 0.24 A at 01:00 PM and minimum I_{sc} was 0.17A at 04:30 PM. Performance curve showed in fig 6

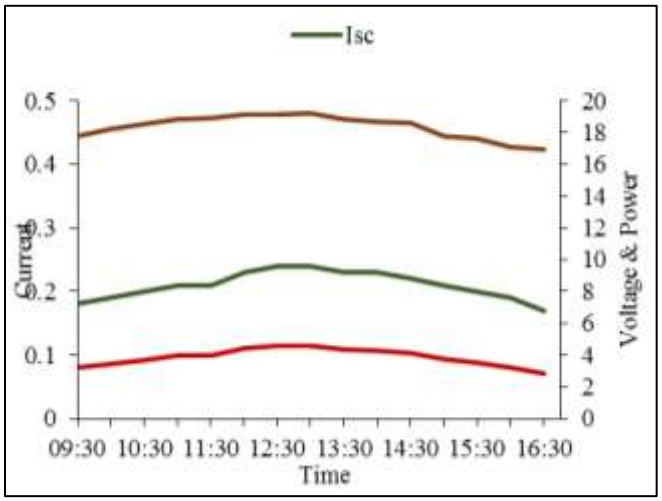

Fig. 6: Voltage and current data of PVT panel without mirror

L. Measurement of Open circuit voltage and short circuit current with mirror

It was observed that the maximum V_{oc} was 20 volt at 12:30 PM and minimum V_{oc} was 18.1 volt at 04:30 PM because temperature of panel at 04:30 was 37.2 °C. So current was low as compared to starting of the day. And maximum I_{sc} was 0.29 A at 12:30 PM and minimum I_{sc} was 0.20 A at 09:30 AM. Maximum power P_{max} is obtained was 5.13 W at 01:00 PM. Performance curve showed in fig 7 and fig 8

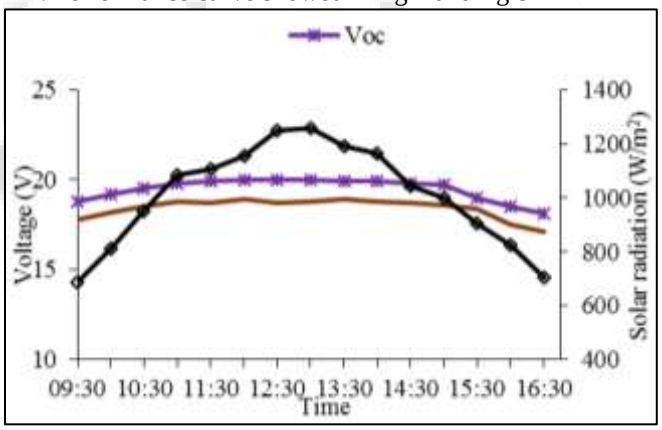

Fig. 7: Voltage data of PVT panel with mirror

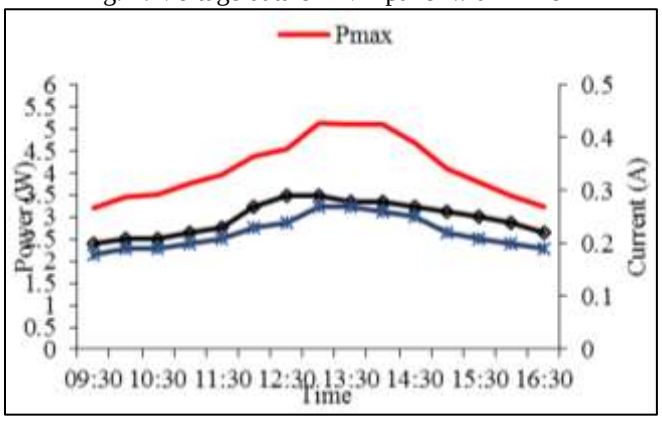

Fig. 8: Current and Power data of PVT panel with mirror

From these Charts it was observed that Temperature of panel and temperature of water is increased with solar radiation. From fig. 6 it was observed that Voc is increasing with solar radiation but decrease slowly with temperature was

increase, at this moment cooling effect comes in role to decrease the temperature of panel and maintain the voltage and current supply shown in fig 6 and maintains the maximum power up to required quantity throughout the day.

IV. CONCLUSION

The following major conclusion was drawn from the experimental studies and performance of Solar PVT.

1) During testing temperature of panel is reduced compare to simple solar panel up to 15°C that helpful in better power generation from the panel and gives better efficiency.
2) During testing at thermal part of the system maximum temperature of water was 42.2°C while minimum was 28°C. It was observed that there is an increment of 14.2°C temperature of water.
3) Solar PVT (Photovoltaic & Thermal) with plane mirror was better than simple solar panel and Simple solar PVT (Air & water cooling). In this developed model increment in Electrical efficiency was observed 1.75-2.25%, increment of Thermal efficiency was observed 2-3% and increment of overall efficiency of solar PVT using mirror was observed 3-4%.

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