World Applied Sciences Journal 31 (6): 988-992, 2014
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2014.31.06.14358

An Experimental Study of a Composite Photovoltaic/Thermal Collector with a Tracking Concentrator System

[1]*Ibrahim E. El-Seesy* and [2]*T. Khalil*

[1]Solar Energy Department, National Research Centre, Dokki, Giza, Egypt, P.O. Box 12622
[2]Physics Department, Faculty of Engineering and Materials Science, German University in Cairo, Egypt

Abstract: Photovoltaic/thermal (PV/T) system showed that it can combine the thermal energy system and the photovoltaic energy system to form a composite photovoltaic/thermal (PV/T) system. The system generates both thermal and electrical energy simultaneously. The suggested system is a photovoltaic plus solar thermal hybrid system which provide up to 4 times the total energy from the same surface area. We thought about using one photovoltaic module and use cheap mirrors to concentrate more sun light on the Photovoltaic module and by that we can produce more electricity with less cost. The problem about concentrating sun light on one module would lead to increase the temperature of the Photovoltaic module and by that photovoltaic module would decrease its efficiency, so we thought about cooling photovoltaic system by water and use the heated water. The tracking system for a PV/T Concentrator is an integration of several innovative proprietary technologies, such as 4 x geometrical solar concentration design, solar tracking, bifacial receiver concentration and PV panel cooling. The system has been designed, installed and tested under the climatic conditions of Cairo, Egypt. The system is provided with the necessary measuring instruments to carry out the required tests. The experimental results show that Bifacial-concentrated solar module with cooling has higher short circuit current and open circuit voltage with compared normal solar module. Thereby, the power produced by Bifacial-concentrated solar module with cooling is nearly 3 times the power produced by normal solar module. Also, the system produces a hot water with temperature average of 53°C.

Key words: Concentrating photovoltaic/thermal · Photovoltaic/ thermal · Solar energy

INTRODUCTION

The solar energy conversion in electricity and heat with a single device is a good advancement for future energy demand called hybrid photovoltaic thermal collector (PVT). The use of PV/T in combination with concentrating reflectors has a significant potential to increase the power production from a given solar cell area. Presently, research is going to fabricate a hybrid PV/T collector by a Tracking Concentrator System for more electricity as well as heat generation. Few authors have worked in this direction enabling the multipurpose hybrid systems to fulfill the increasing demand of both electrical and thermal energy, while protecting the environment. Bin-Juine Huang *et al.* [1], Brogren *et al.* [2], Karlsson *et al.* [3] and Othman *et al.* [4], have been suggested to increase the thermal and electrical output of concentrating photovoltaic/thermal (CPVT) systems. Regarding medium concentration, PV/T systems based on linear parabolic reflectors [5] or linear Fresnel reflectors [6] have been investigated. Although concentrators of low or medium concentration ratio are interesting devices to be combined with photovoltaic, 3D Fresnel lens or reflector type concentrators have been recently developed, aiming at the market of concentrating photovoltaic. Kostic *et al.* [7] designed the optimal orientation of PV/T collector with reflectors. In order to get more thermal and electrical energy, flat reflectors for solar radiation have been mounted on PV/T collector. Their results showed that the energy-saving efficiency of PV/T collector decreases slightly with the solar radiation intensity concentration factor. Mittelman [8] designed the desalination with the concentrating photovoltaic/thermal (CPVT) systems also.

Corresponding Author: Ibrahim E. El-Seesy, Solar Energy Department,
National Research Centre, Dokki, Giza, Egypt.

Fig. 1: Photographs of a hybrid PV/T collector with a tracking concentrator system.

The combined system produces solar electricity and simultaneously exploits the waste heat of the photovoltaic cells to desalinate water. The results indicate that this approach can be competitive relative to other solar-driven desalination systems and even relative to conventional reverse osmosis (R.O.) desalination. Bernardo *et al.* [9] simulated and evaluated the performance of of low concentrating photovoltaic/thermal system. Monia *et al.* [10] were designed and tested low concentrating photovoltaic (PV) and photovoltaic/thermal (PVT) systems for a given spring climatic condition of the Tunisian Saharan city. They predicted the possible improvements numerically.

So, the objective is to investigate experimentally a performance of a hybrid PV/T collector with a tracking concentrator system under the climatic conditions of Cairo, Egypt.

Experimental System and Procedure: A photographs of the experimental system are shown in Fig. 1. The system consists mainly of:

PV Modules: The System has 2 PV modules of Mono-crystalline Silicon with dimensions: 66cm x 147 x 4cm. the nominal power is equal to 130 Watt. The upper PV panel receives 1 x sun irradiance and the lower one should receive 4 times sun irradiance with concentration.

Cooling System: Lower PV panel has 8 Rectangular Aluminum tubes (8 x 2cm) cross-section and 143 cm length with 2 inlets and 2 outlets of water for cooling PV. Storage tank with 80 liter readily insulated was used to store the hot water. Also, Poly-propylene pipes, plastic hoses and T-joints water connections to connect water from the tank to the PV/T panels were used. A circulated pump with 40 Watt was also installed to raise the water from tank to the panels.

Mirrors: Four mirrors of thickness 6 mm were installed to give four times of sun irradiance on the lower PV/T panel. There were two large mirrors of dimensions 63 x 167cm and two smaller ones of dimensions 54 x 167cm. The fourth mirrors and two of PV/T panels are supported by a frame. The whole frame was made of aluminum bars of different length, cross-sections and cut into different angles.

The Tracking System: The system is able to track the sun automatically from east to west by a stepping motor and a microcontroller based electronic circuit. The circuit senses the sun by two solar cells and a comparator in the microcontroller. The system consisted of, two photovoltaic (solar) Cells, Microcontroller (PIC 16F877), stepper motor, motor drivers/controllers, power supply, voltage regulator, chip board and wiring. The support was made of hollow steel bars and hollow steel tubes. Bearings, pins, gears and rollers were used. This support was used to hold the frame on different angles. Fig. 2 show front view for the PV/T with a tracking concentrator system.

In the closed-loop water system, the incoming water is circulated to the storage tank through valve, cold water in the tank is circulated by a pump to the PV/T collector tubes and the hot water produced in the PV/T collector flows to the storage tank. The tracking system is able to track automatically the sun from east to west by a stepping motor and a microcontroller based electronic circuit. The circuit senses the sun by two solar cells and a comparator. A stepping motor was installed to rotate the system in order to track the sun. The step-angle of the motor is 1.8^0.

The setup is provided with necessary measuring instruments to carry out the required tests. The quantities measured during each experiment were:

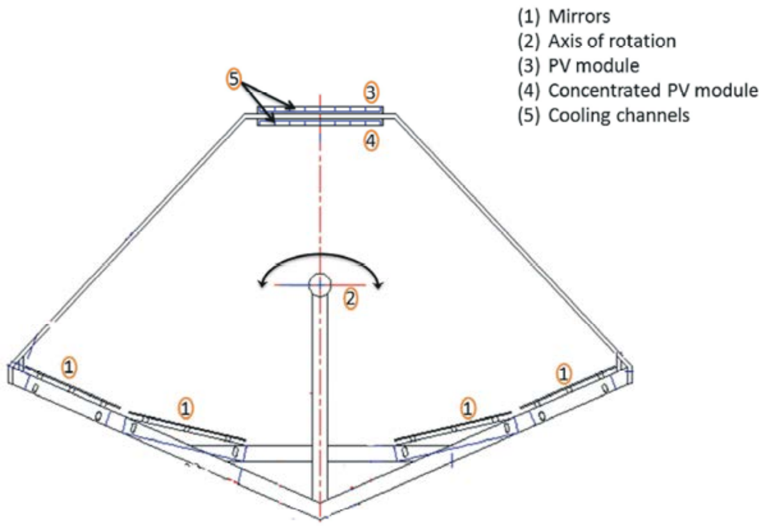

Fig. 2: Front view for the PV/T with a tracking concentrator system.

- Voltage, current and resistance are measured from the PV with digital Multimeter of accuracy 1 %.
- PV surfaces, ambient and water temperature in tank (°C) are measured with thermocouple type K (Aluminium-Chromel). Two thermocouples were placed on each PV module surface facing to the sun and facing to concentrating reflectors. The other thermocouple was placed inside the highest point of the storage tank to measure the temperature of water during the operation of the circulation. One additional thermocouple is used to measure the ambient temperature near to the setup. The thermocouples are calibrated by direct comparison with mercury in glass thermometer with uncertainty of 0.1°C.

The operation of a composite PV/Thermal with a tracking concentrator system was monitored by data acquisition system and stored in personal computer in the solar energy lab.

RESULTS AND DISCUSSION

The results are including the experimental measurements and calculated under the climatic condition of Cairo. In order to be able to compare between concentrated and non-concentrated PV/T with/without cooling, we must be clear the effect of changing (current, voltage and power) and PV module temperature surface. Fig. 3 shows the variation of measured current and voltage for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling.

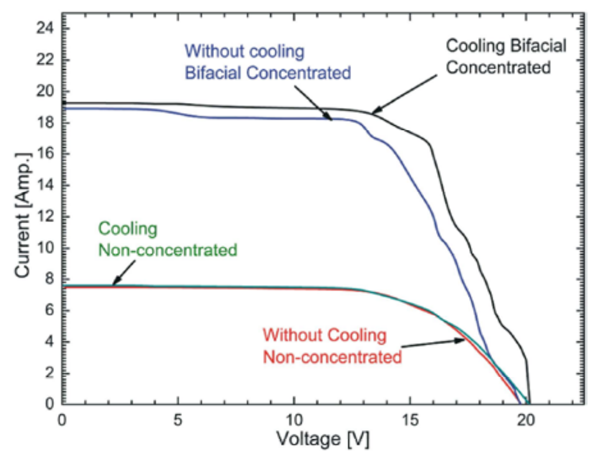

Fig. 3: Current and voltage curve for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling.

It is noticed that Bifacial-concentrated PV with cooling has higher short circuit current (ISC) with 19.3 A, but concentrated PV without cooling was 18.6 A and non-concentrated PV with/without cooling were 7.6 A and 7.5 A respectively.Also, It is showed that Bifacial-concentrated PV with cooling has higher open circuit voltage (VOC) with 20.2 V, but concentrated PV without cooling was 19.7 V andnon-concentrated PV with/without cooling were 20.1 V and 19.6 V respectively.The Peak power point (P_{Peak}) was determined from the measured current (I_{peak}) and voltage (V_{peak}). For peak power, voltage and current for Bifacial-concentrated PV with cooling has the highest values with 16.2 V and 16.7 A, respectively, but concentrated PV without cooling

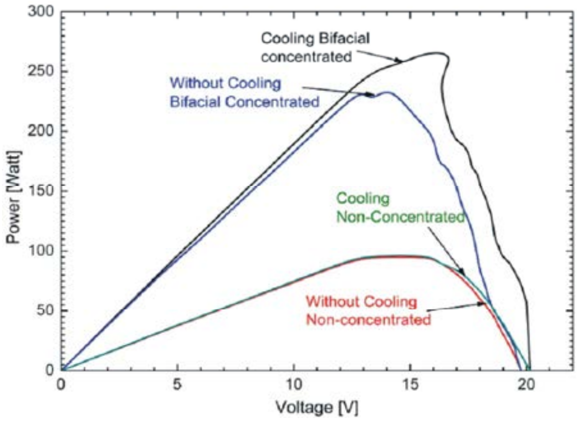

Fig. 4: Power and voltage for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling.

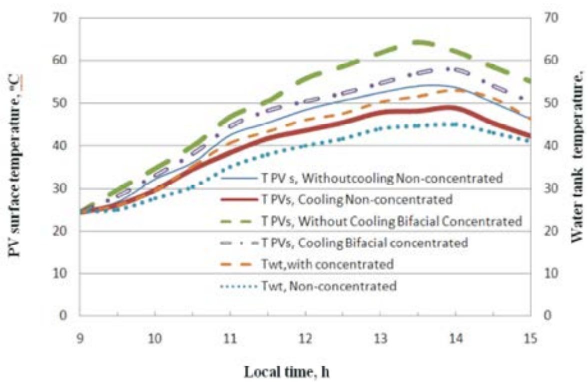

Fig. 5: Variation of PV surface for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling and water temperatures in tank.

were 14.2 V and 16.2 A respectively and non-concentrated PV with/without cooling were 13.6 V,7.3 A and 13.3 V,6.7 A, respectively. The variation Power with voltage for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling is illustrated in Fig.4. It is seen that the power produced by Bifacial-concentrated PV with cooling is 270 Watt, nearly 3 times the power produced by non-concentrated PV without cooling. Also, the output power produced concentrated PV without cooling and non-concentrated PV with cooling are 230 Watt and 100 Watt, respectively.The variation of PV surface temperature (TPvs) for Bifacial-concentrated PV with/without cooling and non-concentrated with/without cooling and water temperatures in tank(T wt) with local time is illustrated in Fig. 5. It is seen that the difference in temperature of PV surface with/without cooling is about 6°C that lead to raise of water tank temperature to 45°C but,difference in temperature of Bifacial-concentrated PV with/without cooling is about 8°C that lead to raise of water tank temperature to 53°C on a clear day in spring season. It reduces the operating temperature of the PV modules and thereby improves the electrical performance and provides hot water.

CONCLUSIONS

The experimental investigations of the performance of PV/T system are performed. During whole operation period, the system can work stably. For peak power, theBifacial-concentrated PV with cooling had a higher voltage and current with 16.2 V and 16.7 Arespectively with incresing of 18 % and 60 % with compared non-concentratedPV without cooling. Also, the power produced by Bifacial-concentrated PV with cooling is 270 Watt, nearly 3 times the power produced by non-concentrated PV without cooling.The Bifacial-concentrated PV with cooling system produces hot water in the tank that rises from 22.4°C to 53°C. The non-concentratedPV surface temperature without cooling decreases from 46.4°C to 42.2°C when it used PV with cooling. The concentratedPV surface temperature without cooling decreases from 55°C to 50.2°C when it usedconcentratedPV with cooling. The use of Bifacial-concentrated PV with cooling has a potential to significantly increase electrical power productionand reduce its cost from a given PVarea to increase the radiation intensity falling on it.On the other hand,the system should deliver hot water for other purposes. The further study will be under taken to investigate the system performance in long time and explore different control schemes for better system performance.

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