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Experimental Investigations and Developing of Photovoltaic/Thermal System

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Abstract: Solar systems can be classified into two categories; thermal and photovoltaic systems which convert solar energy to thermal and electrical energy respectively. Normally, both types are used separately. The combination of both types in one unit is named photovoltaic thermal (PV/T) system to produce simultaneously thermal and electrical energy. The worldwide fast developed of building-integrated solar technology has prompted the design alternative of fixing the solar panels. Photovoltaic thermal (PV/T) system has the advantage of increasing the energy output per unit installed collector area. This paper describes an experimental investigations and developing of a photovoltaic and hot water collector system. The collector is mounted and adjustable with PV module. The system has been designed, installed and tested under the climatic conditions of Cairo, Egypt (30° latitude north). The system is provided with the necessary measuring instruments to carry out the required tests. The experimental results show that the total efficiency of PV/T system reaches 42.45% with deceasing the PV surface temperature about 10°C. Also, the system produces a hot water with temperature average of 46.2°C. Then, PV/T system is installed on roof of building or integrated with building envelope will could simultaneously fulfill the electricity generation for lighting purpose and hot water which be used for tropical domestic uses.

Key words: Solar Energy · Photovoltaic · Thermal · Water heating

INTRODUCTION

Normally, the thermal and the photovoltaic energy systems are used separately. It has been shown that these systems can be combined to form a hybrid photovoltaic/thermal (PV/T) system. The term PV/T refers to solar thermal collectors that use PV cells as an integral part of the absorber plate. The system generates simultaneously both thermal and electrical energy simultaneously. The number of the photovoltaic cells in the system can be adjusted according to the local load demands. A number of simulation as well as experimental studies have been reported on the photovoltaic-thermal (PV/T) system. The performances of PV/T system with water as the working fluid have been studied in recent years. An experimental study of a centralized photovoltaic and hot water collector wall system was carried out and different operating modes were performed with measurements in climatic condition of Cairo. In principle, a PV/T system is an integration of photovoltaic components and solar thermal components in one single system. Through the electricity-and-heat co-generation, the overall output is higher for a given solar collector area than the outputs of two commercial photovoltaic and solar thermal collector units placed close together side-by-side. The hybrid PV/T technology is considered to be attractive particularly in the warm and hot geographical regions, where the working temperature of PV modules on average is much higher than in the cold regions. The PV cooling methods, using fluid stream like air or water that runs through the back surface of the PV panel, has been investigated via numerical simulation and experimental works as well as field projects [1-5]. The results showed that natural water circulation was more preferable than forced circulation in this hybrid solar collector system and the thermal efficiency was 38.9% at zero reduced temperature and the corresponding electricity conversion efficiency was 8.56% during the late

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summer of Hong Kong [6]. The experimental study on energy generation with a photovoltaic (PV)- solar thermal hybrid system was performed and it is clear that measurements based on electrical characteristics and water pre-heating makes the hybrid module economically attractive [7]. A numerical model of a wall-mounted hybrid photovoltaic/water-heating collector system was developed and the simulation results indicated that the system operation at the optimum mass flow rate not only can improve the thermal performance of the system, but also can meet the PV cooling requirement so that a better electrical performance can also be achieved [8]. A water-type hybrid collector with polycrystalline PV module on at a box type Aluminum-alloy thermal absorber was constructed and tested. The test results indicated that daily thermal efficiency was about 40% and higher water temperature in the storage tank was achieved after a 1 day exposure [9]. The simulation results for hybrid PV/T solar systems for domestic hot water applications both passive (thermosyphonic) and active were presented and the results showed that a considerable amount of thermal and electrical energy was produced by the PV/T systems and the economic viability of the systems was improved [10]. The application in the industry of PV/T systems with water heat extraction was presented. The system consisted of 300 m^2 of hybrid PV/T collectors producing both electricity and thermal energy and a 10 m^3 water storage tank. The results indicated that the electrical production of the system was more than the amorphous ones but the solar thermal contribution was slightly lower [11]. So, the objective is to investigate experimentally a PV/T hybrid system under the climatic conditions of Cairo, Egypt (30° latitude north).

Experimental System and Procedure: Flat plate PV/T collector looks very similar to the well known flat plate thermal collector. The only significant difference, as shown by the Fig.1a, b is the PV panel which is attached on the top of the metallic absorber plate. The absorber plate with the tubes and the PV module, as well as the insulation, is clearly shown.

The system consists mainly of:

PV Module: PV module of polycrystalline Silicon of the dimensions: 46 cm x 56.5 cm.

Absorption Unit: Absorber plate made of red copper with outer area 51.5 cm x 65 cm and welded with 2 headers and 3 risers. The absorber plate was manufactured from red copper due to its high thermal conductivity that is 385 (W/m K) [12]. Silicon sealant is used as an adhesive to fix the edges of the absorber plate to the PV module.

Fig. 1a: Photograph of photovoltaic/ thermal system.

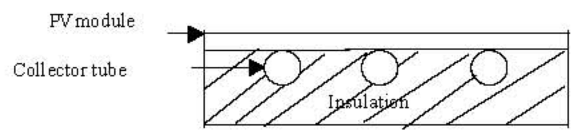

Fig. 1b: Collectors Tubes in-line with absorber plate and PV Module.

Wooden Box and Insulation: The PV module and the absorber plate are installed in a wooden box to minimize the heat losses as it is a very good insulator. Thermal conductivity of wood= 0.17 (W/m K) [12]. The heat losses by conduction are reduced by insulating the bottom and sides of the casing with glass wool with thermal conductivity of 0.04 (W/m K) [12]. The tank was also insulated with the same insdulation. Armaflex pipe insulation (Tube) is used for the 1 inch water hose (4 m long) which connects the storage tank with the system together.

Storage Tank: The tank used is of capacity 80 liter. In the closed-loop water system, the incoming water is circulated to the storage tank through valve, cold water in the tank is circulated to the PV/T collector tubes and the hot water produced in the PV/T collector naturally by thermosyphon, flows to the storage tank. The heated water expands through the collector tubes by absorbing of maximum possible energy absorbed by the absorber and consequently achieve higher output temperature.

The heated water outlet from the collector tubes starts to rise up the tank where the driving force is the bouncy force resulting from the density difference between cold and hot water. In the storage tank, stratification happens and the hotter water (lighter density) takes place the cold water (higher density) and the water temperature is fluctuated until stratification occurs. The setup is provided with necessary measuring instruments to carry out the required tests.

The quantities measured during each experiment were:

- Global solar-radiation intensity on the PV plane tilted at angle of 30° to the horizontal, with a Pyranometer having an accuracy 5 % that has a sensor to measure solar irradiance (global irradiance, including direct and diffuse irradiance) on a planar surface (GW/m^2).
- Voltage, current and resistance are measured from the PV with digital Multimeter of accuracy 1 %.
- PV surfaces (T_s, °C), ambient and water temperature in tank (T_w,°C) are measured with thermocouple type K (Aluminium-Chromel). Two thermocouples were placed on the PV module surface facing to the sun and 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 system was installed and directed to face south with fixed and tilted at 30° to the horizontal. The operation of PV/Thermal system was monitored by data acquisition system and stored in personal computer in the solar lab. Many researchers used the total efficiency (η_T) to evaluate the performance of a PV/T system and defined as the sum of the solar electricity efficiency (η_e) and the thermal efficiency (η_{th}) as given in the following equation [13]:

$$\eta_T = \eta_e + \eta_{th} \qquad (1)$$

The electrical efficiency of PV/T system is mainly dependent on incoming solar irradiation (G) and the output power of PV cell (P_o) that is depending on voltage and current. It can be calculated by:

$$\eta_e = \frac{P_o}{G\ A}$$

where, G is the Global solar-radiation intensity on the PV plane.
A is the area of PV module.

The thermal efficiency of PV/T system is determined by the incoming solar irradiation (G) and the outlet and inlet temperature of PVT collector (T_o, T_i). It can be calculated by:

$$\eta_{th} = \frac{m\ Cp\ (T_o - T_i)}{G\ A}$$

where m and C_p are the water mass flow and specific heat respectively.

The parameters of equations 2 and 3 are measured and recorded by data acquisition system.

RESULTS AND DISCUSSION

The results are including the experimental measurements and calculated under the climatic condition for two sequence days 11 &12 on April. Figure 2 shows the variation of measured solar irradiation (G) and ambient temperature (Ta) with local time for two sequence days 11&12 on April. Stat, solar irradiation (G) begins to increase to reach its maximum value at solar noon time (G 12/4 = 845 w/m^2 & G 11/4 = 832 w/m^2, then it decreases down. Also, the ambient temperature (Ta) increases to reach its maximum value (Ta 12/4 = 26.5°C & Ta 11/4 = 26°C) at local time = 14:50 h. It can be seen that the deviation between solar irradiation (G) and ambient temperature (Ta) through two sequence days 11&12 on April are1.66 % and 1.9 % respectively. Then, the following results are based on the same climatic conditions for two days. The variation of PV cell surface temperature (Ts) without and with collector and water temperature in the tank (Tw) with local time is illustrated in Fig.3. Ts without and with collector and Tw are equal to the ambient temperature (Ta = 21.1°C), Then, they begin to increase gradually to reach their maximum values (Ts without collector = 57.5 °C, Ts with collector = 47.6°C and Tw in the tank = 46.2°C) at local time = 14:5h). The temperatures reach to values (Ts without collector = 51.6°C, Ts with collector = 44.1°C and Tw in the tank = 40.2°C) at local time = 16:0 h). It is seen that the difference in temperature of PV surface without and with collector is about 10°C that lead to changing of water

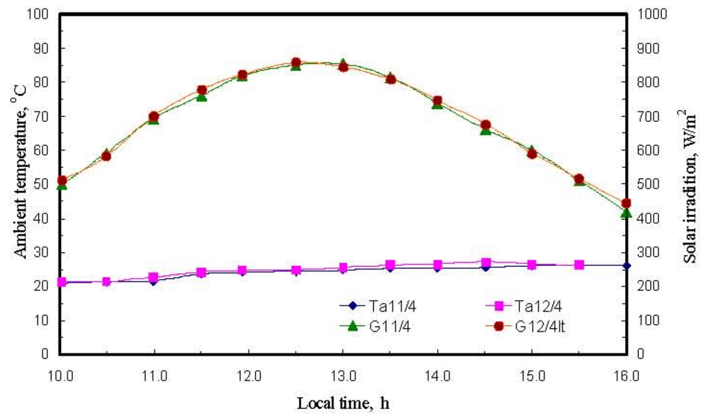

Fig. 2: Variation of solar irradiation (G) and ambient temperature (Ta) on two sequence days 11 &12 on April.

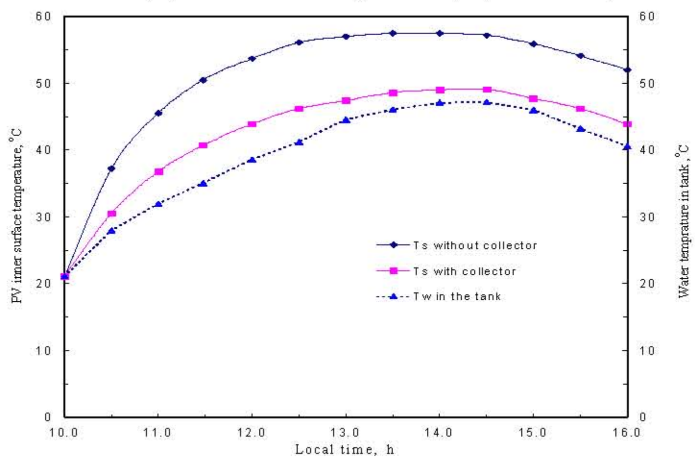

Fig. 3: Variation of PV cell surface temperature (Ts) without, with collector and water temperature in the tank (Tw).

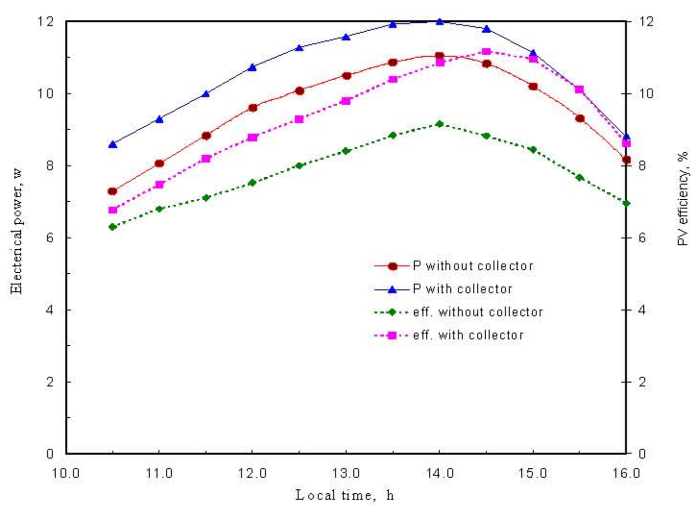

Fig. 4: Variation of electrical power and efficiency of PV cell with and without collector.

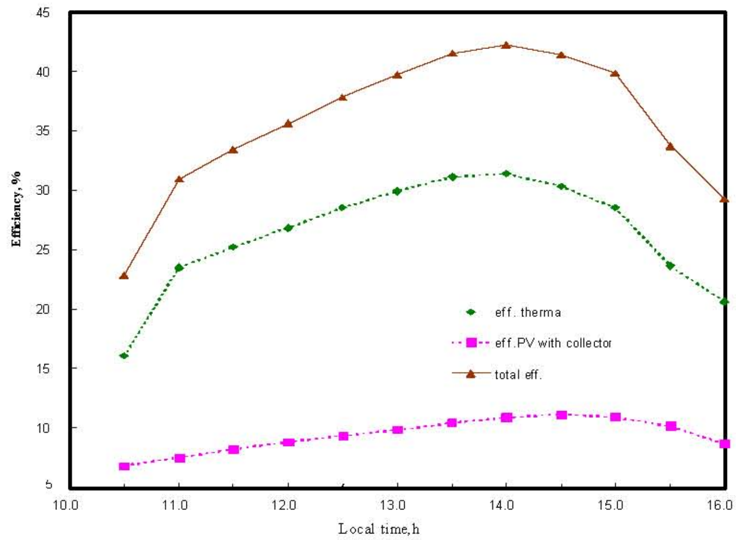

Fig. 5: Variation of the PV efficiency with collector, the thermal efficiency and the total efficiency of PV/T system.

temperature rise in the tank. Fig. 4 shows the variation of electrical power and efficiency of PV without and with collector with local time. The electrical power and efficiency of PV without collector are 10.7 w at local time = 14:0 h and 9 % at local time = 14:50 h, respectively as maximum values, also, with collector are 12 w at local time = 14:0 h and 11.05 % at local time = 14:50 h respectively as maximum values. It is observed that PV/T system is the preferred performance according to electrical power and efficiency of PV. The variation of the PV efficiency with collector, the thermal efficiency and the total efficiency of PV/T system with local time are shown in Fig.5. The total efficiency of PV/T system is the sum of the electricity efficiency of PV and the thermal efficiency. The thermal efficiency increases to reach 31.4 % as a result of the increased value of PV temperature. It is observed that the total efficiency of PV/T increases to reach 42.45 % at local time = 14:0 h as a maximum value.

CONCLUSIONS

The experimental investigations of the performance of PV/T system are performed. During whole operation period, the system can work stably. The system produces hot water in the tank that rises from 21.1°C to 46.2°C. The temperature of PV without collector decreases from 57.5°C to 47.6°C when it used PV with collector. The efficiency of PV is increased with collector about 2 %. The total efficiency of PV/T system increases to reach 42.45% as a maximum value. The PV/T system is very helpful in remote areas, where the primary requirements of use are electricity generation and hot water. 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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