An experimental study of combining a photovoltaic system with a heating system

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Abstract: Solar photovoltaic and thermal systems are potential solutions for current energy needs. One of the most important difficulties in using photovoltaic systems is the low energy conversion efficiency of PV cells and, furthermore, this efficiency decreases further during the operational period by increasing the cells temperature above a certain limit. In addition, reflection of the sun's irradiance from the panel typically reduces the electrical yield of PV modules by 8-15%. To increase the efficiency of PV systems one way is cooling them during operation period. In this experimental study combination of a PV system cooled by a thin film of water with an additional system to use the heat transferred to the water has been considered. Experimental measurements for both combined system and conventional panel indicate that the temperature of the photovoltaic panel for combined system is lower compared to the conventional panel. The results show that the power and the electrical efficiency of the combined system are higher than the traditional one. Also since the heat removed from the PV panel by water film is not wasted, the overall efficiency of the combined system is higher than the conventional system.

Keywords: *Cooling PV systems, Electrical efficiency, Combined system, Overall efficiency*

1. Introduction

Environmental problems due to extensive use of fossil fuels for electricity production and combustion engines have become increasingly serious on a world scale in recent years. To solve these problems, renewable energy sources have been considered as new sources of clean energy. Solar energy is one of the most important sources among the renewable energies. Generally, solar energy conversion systems can be classified into two categories: thermal systems which convert solar energy into heat and photovoltaic systems which convert solar energy to electricity.

Intensive efforts are being made to reduce the cost of photovoltaic cell production and improve efficiency and narrow the gap between photovoltaic and conventional power generation methods such as steam and gas turbine power generators. In order to decrease the cost of PV array production, improve the efficiency of the system and collecting more energy for unit surface area different efforts have been made.

The performance of the PV system is affected by several parameters including temperature. The part of absorbed solar radiation that is not converted into the electricity converts into thermal energy and causes a decrease in electrical efficiency. This undesirable effect which leads to an increase in the PV cell's working temperature and consequently causing a drop of conversion efficiency can be partially avoided by a proper method of heat extraction. PV/T solar systems consisting of photovoltaic modules and thermal collectors are applied to cool photovoltaic panel and use the heat generated by the panel and increase total energy output of the system. By proper circulation of a fluid with low inlet temperature, heat is extracted from the PV modules keeping the electrical efficiency at satisfactory values. The extracted thermal energy can be used in several ways, increasing total energy output of the system. Many researchers have investigated and proposed different methods for design and optimization of the PV/T systems to improve the system efficiency by cooling PV module and collecting more energy. The main concepts of hybrid PV/T systems have been presented by several researchers since 1978 [1-5]. Tripanagnostopoulos [6] studied hybrid PV/T solar systems experimentally and used water and air to extract heat from the PV module rare surface. He used a hybrid system with air duct under the PV module for heat extraction with air circulation and another hybrid system with thermal unit of water circulation through a heat exchanger. In the system he tested, water was circulated in pipes with the flat surface of a copper sheet placed at the rear surface of the PV module and in thermal contact with it. Kalogirou and Tripanagnostopoulos [7] proved analytically the potential benefits of PV/T systems compared to typical PV modules and presented justification of energy and cost results regarding system application. Their method could be considered as an estimation of the cost effectiveness of new solar energy systems in practice.

One method for cooling photovoltaic module is to flow a film of water over the PV module to decrease its temperature. By using this method reflection would also be reduced and therefore the electrical efficiency will improve. Krauter [8] studied the effects of cooling photovoltaic array surface with film of water on the power generated by the array. Abdolzadeh and Ameri [9] improved the operation of a photovoltaic water pumping system by spraying water over the front of the photovoltaic cells. Kordzadeh [10] studied the effects of nominal power array of 90 and 135 W on 16 m head of water pumping system on panel efficiency as well as the panel efficiency for 135W nominal power output on different heads of pumping system. A thin continues film of water was running on the top of the PV panel without water being recirculated. The advantage of the later system (thin water running on top of the photovoltaic array) is obtaining better electrical efficiency because of decreasing the reflection loss, in addition to decreasing temperature of the array. The disadvantage of this system is that the heat gained by the water running on top of the photovoltaic array is wasted.

The aim of the present experimental research is to consider the combination of a PV system equipped with cooling system consisting of a thin film of water running on the top surface of the panel with an additional system to use the hot (or warm) water produced by the system.

2. Experimental procedure

The experimental setup is composed of two similar but separate PV solar photovoltaic panels each with area of 0.44 m^2. The maximum output voltage and current are respectively 23V, 2.61A and with maximum power output of 60W. One of the panels is used in a combined system with a film of water running over its top surface without front glass and an additional fabricated system to use the heat generated by the panel. The other panel is a conventional PV as a reference panel. To produce a film of water over the photovoltaic panel, a tube with a slit along it has been installed on the top end of the photovoltaic panel (see Fig. 1). Water pumped to the feeding tube, leaves the slit and flows over the panel as a thin film. Power of the pump for circulation of water is 0.25 hp. The water collected at the lower end of the panel passes through a finned tube used as a heat exchanger and consumer of heat gained by the water. Another role of this finned tube is to dissipate heat to the environment and produce a constant low water temperature. Therefore when the water is pumped back to the feeding tube it would be at a desired temperature level to flow on the panel surface. The flow rate is 1 lit/min. Pumping system and the heat exchanger which are used in the combined system are shown in Fig. 2.

Fig. 1. Front view of solar photovoltaic panel equipped with water film producer.

Fig. 2. Pumping system and the heat exchanger of experimental combined Photovoltaic/Thermal (PV/T) system.

Maximum power output was obtained by utilizing an optimized ohmic load (8.7 Ω). Current and voltage were measured by Omega type multimeter with accuracy of 1 miliamper and 1 milivolt respectively. Both panels were facing south with an angle of inclination of 29°. Irradiance was measured by a Kimo SL100 solar meter installed on the corner of one of the panels with the same angle of inclination. Ambient temperature was measured in the shade at specified intervals. Patch type thermocouples (k type) were installed on the back surface of the two panels. Temperature of the top surface of the reference panel was occasionally measured by a surface probe and was almost $1.5\,^{\circ}C$ above the temperature of the back surface of the same panel. Therefore, the temperature difference between top and back surfaces of both panels was considered to be about $1.5\,^{\circ}C$. Standard thermocouples (k type) were used for measuring the temperature of the water before running over the panel and at the lower end of the panel. Temperature of the water coming out of the heat exchanger was also measured by installing a standard thermocouple (k type) at the end of the finned tube. Measurements have been performed simultaneously over 14 days during September, 2010 in Tehran (latitude 35° 41' and longitude 51° 25') and recorded every 10 minutes.

3. Results

In this section results of measurements on the 18th of September, 2010 have been presented and analyzed. Variation of irradiance received by the surfaces of the panels during the test day is shown in Fig. 3.

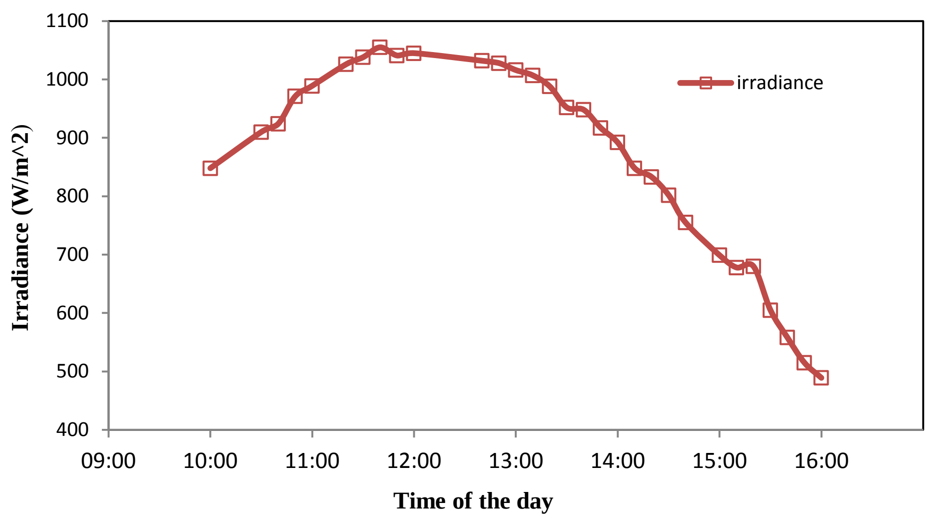

Fig. 3. Variation of irradiance during the test day.

Due to the water flow and additional cooling by water evaporation, the PV/T panel's operating temperature measured is much lower in comparison to the conventional reference panel. As could be seen in Fig. 4, maximum temperature difference of $18.7\,^{\circ}C$ is observed. This temperature reduction has caused a noticeable improvement for electrical efficiency as shown in Fig. 5, such that for some hours the relative difference is more than 33%.

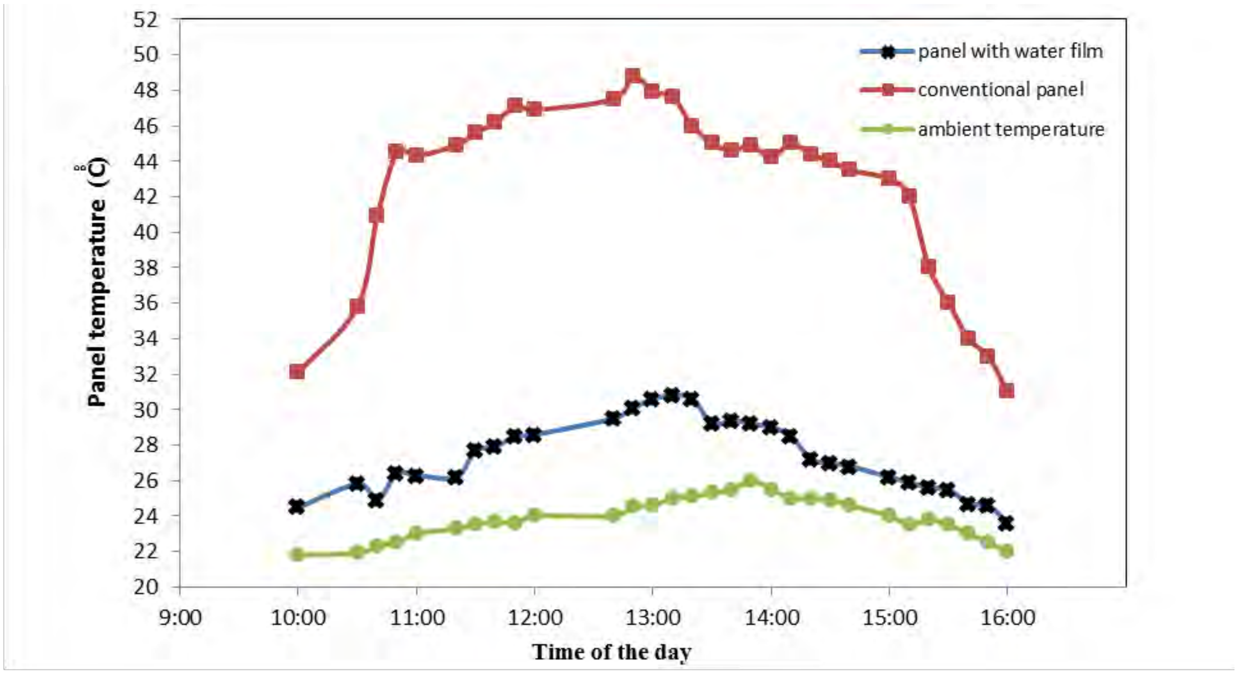

Fig. 4. Comparison of conventional photovoltaic panel temperature with the temperature of the panel in the combined system.

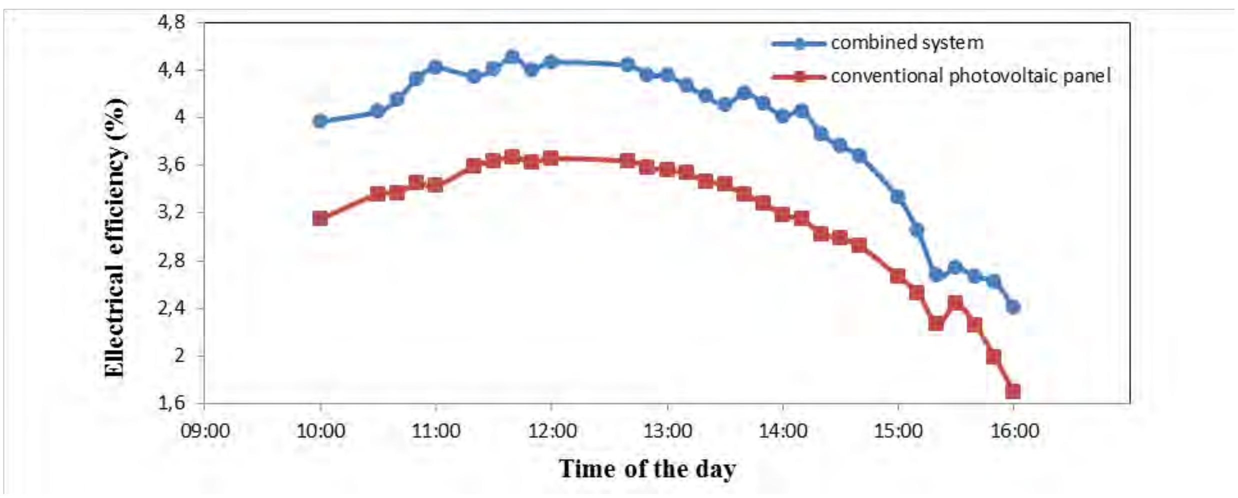

Fig. 5. Comparison of conventional photovoltaic panel electrical efficiency with the electrical efficiency of the combined system.

The experimental results showed that the continuous film of water on the surface of PV panel has two important effects on the operation of the system. First, it reduces the reflection of the solar irradiance. Second, it reduces the panel temperature by absorbing the heat generated by the panel. Temperature reduction is significant due to heat absorbed by the water. The heat removal from the PV panel by the water film increases the temperature of the water running over the panel surface and also causes evaporation. Calculations show that cooling is mainly by evaporation. In Fig. 6, temperature of the water before running down over the surface of the panel has been shown in comparison to temperature of the water collected at the lower end of the panel and temperature of the water coming out of the heat exchanger. As it is shown, the heat absorbed by the water when running down the panel is removed when passing through the heat exchanger and the temperature reaches more or less to the water temperature at the top end of the panel.

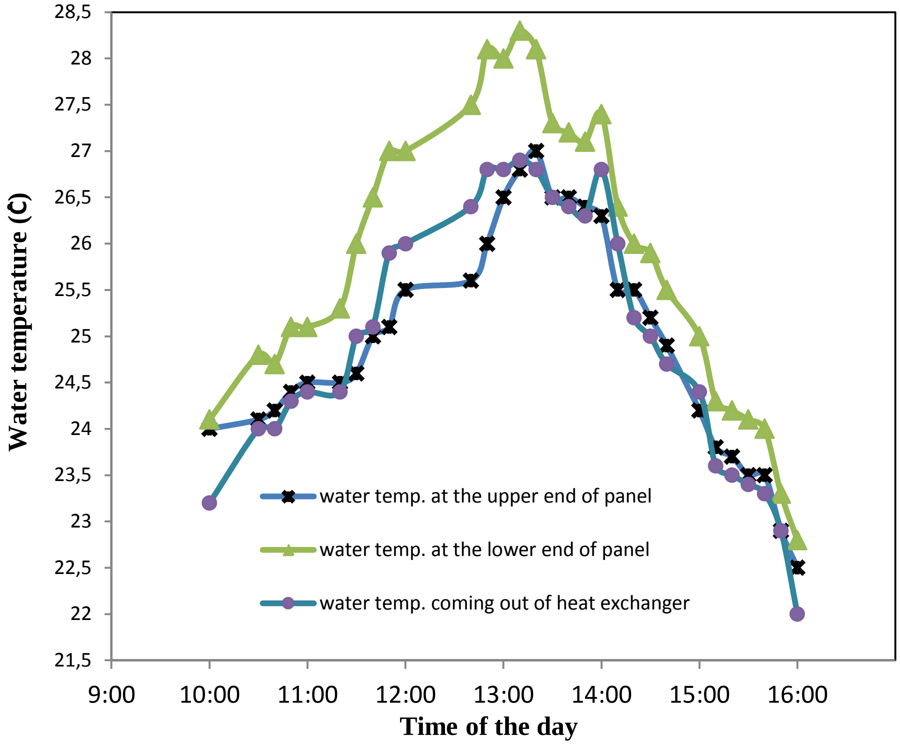

Fig. 6. Comparison of water temperature at the upper and lower ends of the panel and water coming out of the heat exchanger in the combined system.

Overall efficiency can be defined as the total energy output of the system compared to the radiant energy received by the system. For conventional system, total energy output of the system consists of electrical energy produced, but for the combined system it consists of both thermal and electrical energy produced. Thermal energy output is defined as the increase in the internal energy of the water running over the panel due to the increase in the temperature of the water ($m^{\cdot}\ c_p\ \Delta T$). Due to high specific heat of water the temperature increase is quite a bit. Also because of small surface area of the panel, the sensible heat added to water is a small amount. As could be seen in Fig. 7, there is a noticeable improvement in overall efficiency of the combined system in comparison to the conventional system.

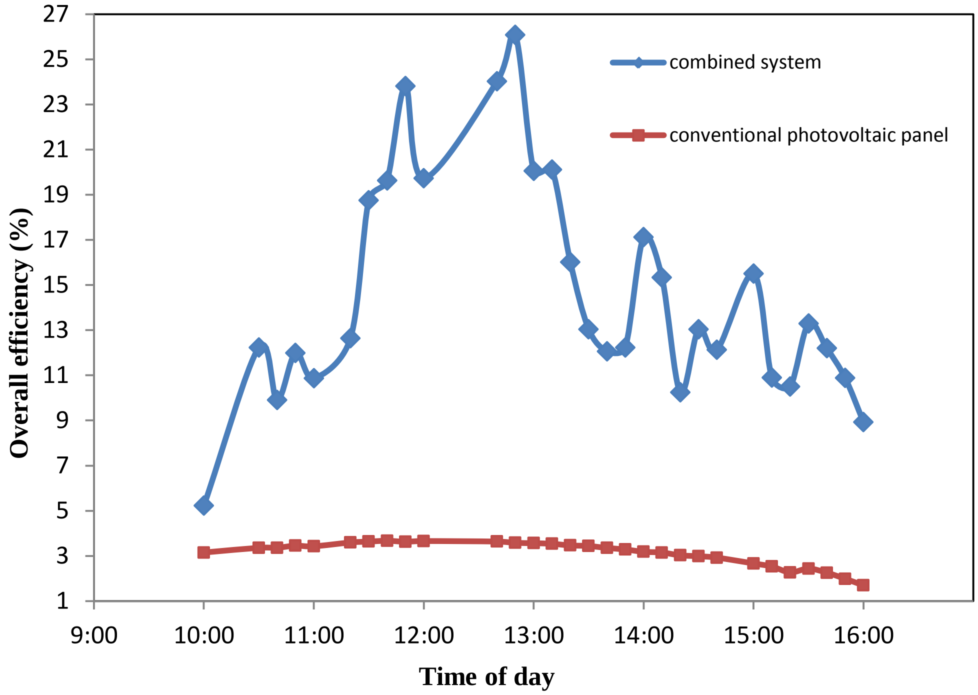

Fig. 7. Comparison of conventional photovoltaic panel overall efficiency with the overall efficiency of the combined system.

4. Conclusion

The photovoltaic panel efficiency is sensitive to the panel temperature and decreases when the temperature of the panel increases. One of the ways for improving the system operation is covering the panel surface with a thin running film of water which decreases both reflection loss and temperature of the panel. Results of present work showed that while the temperature of the panel could be controlled at a desired temperature level, the water collected at the lower end of the panel can be used as a utility for heating purposes. Therefore when the water is pumped back to the upper end of the panel it would be at a desired temperature level to flow on the panel surface. In the combined system tested in this work, aplying a film of water for cooling photovoltaic panel resulted in decreasing the temperature and reflection loss of the PV panel which increased electrical efficiency of the combined system. Also the heat removed by the water from the panel was used in a heat exchanger. Therefore, total energy output of the combined system (collected thermal and electrical energy for unite surface area) increased significantly compared to the electrical energy of the conventional photovoltaic panel. In this experimental study it has been shown that the overall efficiency of combined system at some hours is one order of magnitude more than the efficiency of conventional panel.

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