Improving of the photovoltaic / thermal system performance using water cooling technique

Hashim A. Hussien, Ali H. Numan, and Abdulmunem R. Abdulmunem
EletroMechanical Engineering Department, University of Technology, Baghdad-Iraq
E-mail: doctorhashim2004@yahoo.com , and ahnuman@uotechnology.edu.iq

Abstract. This work is devoted to improving the electrical efficiency by reducing the rate of thermal energy of a photovoltaic/thermal system (PV/T). This is achieved by design cooling technique which consists of a heat exchanger and water circulating pipes placed at PV module rear surface to solve the problem of the high heat stored inside the PV cells during the operation. An experimental rig is designed to investigate and evaluate PV module performance with the proposed cooling technique. This cooling technique is the first work in Iraq to dissipate the heat from PV module. The experimental results indicated that due to the heat loss by convection between water and the PV panel's upper surface, an increase of output power is achieved. It was found that without active cooling, the temperature of the PV module was high and solar cells could only achieve a conversion efficiency of about 8%. However, when the PV module was operated under active water cooling condition, the temperature was dropped from 76.8°C without cooling to 70.1°C with active cooling. This temperature dropping led to increase in the electrical efficiency of solar panel to 9.8% at optimum mass flow rate (0.2L/s) and thermal efficiency to (12.3%).

1. Introduction

Developing alternative energy resources with high efficiency and low emission has become of great importance with increasing concerns about fossil fuel deficit, high oil prices, global warming, and damage to environment and ecosystem [1]. In this concern, photovoltaic solar energy is a clean, renewable, energy with a long service life and high reliability [2]. A photovoltaic system converts sunlight into electricity, where, the basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules [3].

Performance of a solar-photovoltaic (PV) system not only depends on its basic electrical characteristics; maximum power, tolerance rated value %, maximum power voltage, maximum power current, open-circuit voltage (Voc), short-circuit current (Isc), maximum system voltage, but also is negatively influenced by several obstacles such as ambient temperature, relative humidity, dust storms and suspension in air, shading, global solar radiation intensity, spectrum and angle of irradiance [3-4].

There are several reasons which motivate the development of the PV/T system. One of the main reasons is that PV/T system can provide higher efficiency than individual PV and thermal collector system. With increased the efficiency, the payback period of the system can also be shorten [5].

The electrical efficiency reduction of PV modules due to their temperature increase can be partially avoided by water or air heat extraction. PV heating is mainly the result of the absorbed solar radiation that is not converted into electricity and PV cooling is considered necessary to keep electrical efficiency at a satisfactory level. Natural or forced air circulation is a simple and low cost method to remove heat from PV modules, but it is less effective if ambient air temperature is over 20°C, as it is usual for many months in low latitude countries. The operating temperature plays an essential role in the PV energy conversion process [6-7].

The performance of PV panels reduces with increasing temperatures. Therefore, most panels’ will not operate under ideal conditions due to different weather conditions or real ones. Since PV panels are more efficient at lower temperatures, PV systems have to design with active and passive cooling [8-9]. The water heat extraction is more expensive than air heat extraction, but it is considered practical for the above case, as the water temperature from mains is under 20°C almost all year. The
usual mode of PV cooling by water is the circulation of it through a heat exchanger in thermal contact with the PV module rear surface, to avoid pressure and electrical problems.

The theoretical cell electrical efficiency \((\eta_e)\) and this parameter are functioned of the cell temperature \([10]\).

\[
\eta_e = \eta_0 \left[ 1 - \beta (T_c - T_o) \right]
\]  

\[
\eta_e = \frac{\int V I \, dt}{A_c \int G(t) \, dt}
\]  

The electrical efficiency of the PV module can be described as following equation:

\[
\eta_\circ = \frac{V_{mp} \, I_{mp}}{G \, A}
\]  

The thermal efficiency can be computed with the following equation \([11]\):

\[
\eta_{th} = \frac{m \cdot C_p \int (T_{out} - T_{in}) \, dt}{A_c \int G(t) \, dt}
\]  

The total efficiency of the hybrid PV/T system is:

\[
\eta_{total} = \eta_{th} + \eta_e = \frac{m \cdot C_p \int (T_{out} - T_{in}) \, dt + \int V I \, dt}{A_c \int G(t) \, dt}
\]

The electrical and thermal efficiencies are presented in Eqs. (2) and (4). It can be seen that the solar irradiation is a function of time and those parameters which are affected by the solar irradiation, such as inlet and outlet temperatures, PV voltage and PV current, are also functions of time. That is the reason to integrate the equation with time.

2. Experimental methodology

In this experimental work a PV-array were cooled by made a cooling technique which is consist of heat exchanger and water circulating pipes are placed at PV module rear surface to reduce heat stored inside the PV cells during operation.

The aim of the suggested technique is to increase the electric current flow. Moreover, water circulating pipes should further decrease the panel surface temperature and increase power output, therefore, gaining better electrical efficiency.

2.1 System configuration

Figs. (1) and (2) presents the photograph and schematic diagram of the PV/T cooling system used in this paper. This system consists of seven pipes connected in parallel and placed in PV module rear surface. Solar irradiation was measured by the pyranometer, which was put at the same level as the solar panels. In this experiment, the mass flow rate was measured and the temperature of working fluid and PV module was obtained by using the k-type thermocouple directly connected to the data logger. The voltage and current of the solar panels were directly recorded by the data logger. The capacities of cooling system is 4 liters and the material of piping system is cupper with inner diameter 21mm and thickness 1mm and 7 parallel rows because cupper have high thermal conductivities to transfer the temperature from PV panels to working fluid.
2.2 Measurements

The measurements recorded during this work. The flow rate of water is measured by an ULTRASONIC FLOMETER-TDS-100H flow meter. AC to AC transformer is used to control the speed of motor to change the mass flow rate of working fluid. A 90 bulbs of (12V 50W) connected in series are used to simulate the sun light and controled by 3 AC to AC transformers to give different irradiation arrive up to 1000 W/m². The temperatures of inlet and water outlet, were measured to measure the temperature difference (ΔTw=heating rate). The maximum power point tracer is used to seek this point in order to maximize the power output of the panels under the different irradiation. PV temperature was measured using a k-type thermocouple. k-type thermocouples are suitable for measurements in the range at -180 to +1300 °C. K-type thermocouples comprise 2 wires, copper and constantan (copper-nickel alloy).

3. Results and discussion

The proposed water cooling technique contributes to considerably decrease the PV panel temperature and then leads to increase the output power from the PV system.

The thermal performance of the PV system using water as working fluid with difference mass flow rate (0.1, 0.2, 0.3) L/s is shown in Figs. 3&4. It should be noted that under lowest value of mass flow
rate (0.1L/s) a better thermal gain is obtained compared with increase of water mass flow rate due to at lowest mass flow rate the working fluid will take more time in absorbing heat from PV panel than that at highest mass flow rate.

Fig.3 Effect of water mass flow rate on thermal gain.

Fig.4 Effect of water mass flow rate on thermal efficiency.

Fig.5 show that the mass flow rate of water working fluid at (0.3L/s) give a better cooling for PV panel than others mass flow rates used in this test. This cooling process for all mass flow rate give an enhancement on PV power generated when increased from (0.1L/s) to (0.3L/s) because more heat dissipate in cooling system (radiator) with increasing mass flow rate of circulated of working fluid.

Fig.5 Effect of water mass flow rate on PV panel temperature.
Fig. 6 demonstrate that the mass flow rate of water working fluid at (0.3L/s) led to produce more maximum power and improve the PV panel electrical efficiency as shown in Fig. 7. The performance enhancements using cooling process in Impp & Vmpp is shown in Figs. 8&9. Compared with the process without cooling treatment because decreasing in PV panel temperature will increase in power generated.

Fig. 6 Effect of water mass flow rate on PV panel maximum power generated.

Fig. 7 Effects of water mass flow rate on electrical efficiency of the PV panel.
The MPPT have shown enhancement in electrical performance of PV panel under the cooling process with different water mass flow rate as shown in Figs. 10, 11 and 12 respectively at the end of each test.

---

**Fig. 8** Effect of water mass flow rate on Impp of PV panel.

**Fig. 9** Effect of water mass flow rate on Vmpp of PV panel.

**Fig. 10** MPPT trace at end of testing the effect of water cooling at (0.1L/s) on PV panel performance.
Fig. 11 MPPT trace at end of testing the effect of water cooling at (0.2L/s) on PV panel performance.

Fig. 12 MPPT trace at end of testing the effect of water cooling at (0.3L/s) on PV panel performance.

Figs. 13, 14, and 15 are theoretical relationships of water physical properties with time at different mass flow rate (0.1, 0.2, 0.3) L/s obtained by using MATLAB simulation program, we saw that no effect of mass flow rate on water physical properties as seen on start of these tests at the same temperature but rising of temperature with time led to changing of these properties.

Figs. 13 and 14 have shown that the density and specific heat, these properties are decreasing with increasing of temperature and the important role of mass flow rate in the change of absorbed temperature with changing of the mass flow rate, with increasing of water mass flow rate the range of absorbed temperature is dropped and that led to increase in both water density and specific heat and dynamic viscosity respectively as shown in Fig. 14 and Fig. 15 the rising of temperature led to increasing on thermal conductivities and thermal diffusivity respectively and the dropping on absorbed heat with increasing of mass flow rate led to decreasing of these ranges.
4. Conclusions
The increase in efficiency and the power output depends largely on reducing the temperature limit, which allows the greatest benefit from the whole system. Using cooling technique of water on the rear surface of PV/T system as a coolant cools it down enough to cause it to generate more power than one without water. Experimental results showed that the PV cells power is increased due to cooling water
for the photovoltaic cells. This can significantly increase the system efficiency. It was found that without active cooling, the temperature of the PV module was high and solar cells could only achieve a conversion efficiency of about 8%. However, when the PV module was operated under active water cooling condition, the temperature was dropped to (76.8°C at 0.1L/s), (74.5°C at 0.2L/s) and (70.1°C at 0.3L/s). This temperature dropping led to increase in the efficiency of solar panel to (8.6%, 9.1% and 9.6%) respectively, depending on water mass flow rate, and the thermal efficiency to (12.3%).

5. References

[1] Bari, S., Optimum slope angle and orientation of solar collectors for different periods of possible utilization, Energy Conversion. Management. Vol.41, (2000),pp.855-860.
[2] Yakup, M.A., Malik, A.Q., Optimum tilt angle and orientation for solar collector in Brunei Darussalam, Renew. Energ., Vol.24, (2001),pp.223-234.
[3] A.S.Joshi, A.Tiwari, G.N Tiwari, I. Dincer B.V.Reddy, Performance evaluation of a hybrid photovoltaic thermal (PV/T) (glass-to-glass) system, International Journal of Thermal Science, Vol.48, (2009), pp.154-164.
[4] Swapnil Dubey, G.S.Sandhu, G.N.Tiwari, Analytical expression for electrical efficiency of PV/T hybrid air collector, Applied Energy, Vol. 86, (2009),pp.697-705.
[5] T.T. Chow, A review on photovoltaic/thermal hybrid solar technology, Applied Energy, Vol.87, (2010),pp.365-379.
[6] B.J.Huang, T.H.Lin, W.C.Hung and F.S.Sun., Performance Evaluation if Solar Photovoltaic/Thermal Systems, Solar Energy, Vol.70, (2001),pp.443-448.
[7] Jie Ji, Jian-Ping Lu, Tin-Tai Chow, Wei He, Gang Pei., A sensitivity study of a hybrid photovoltaic/thermal water-heating system with natural circulation, Applied Energy, Vol.84, (2007),pp.222-237.
[8] C. H. Cox, III and P. Raghuraman, Design Consideration for Flat Plat Photovoltaic/Thermal Collectors, Solar Energy, Vol.35, (1985),pp.227-241.
[9] Fedele L, Colla L, Bobbo S, et al., Experimental stability analysis of different water-based nanofluids, Journal Article, Nanoscale Res Lett; Vol.6, (2011),pp.289-300.
[10] Rott N. Note on the history of the Reynolds number, Annual Review of Fluid Mechanics, Vol.22, (1990), pp.1–11.
[11] Gnielinski V., New equations for heat and mass transfer in turbulent pipe and channel flow, International Chemical Engineering, Vol.16, (1996),pp.359–368.