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Water cooled PV panel efficiency in Osmaniye environment

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ABSTRACT

In this study, the electrical and thermal efficiency of the natural convection water-cooled photovoltaic panel (PV) is compared with the standard PV module. PV modules are made up of polycrystalline solar cells. As it is known that, an increase in PV panel temperature results in a decrease in electrical efficiency. The aim of this study is to increase PV panel electrical efficiency. PV panel characteristic values such as air/PV panel temperature, solar radiation, voltage, current, and power are recorded for both panels to the computer simultaneously. The thermal and electrical energy performance of PV panels are analyzed comparatively. The results are presented in detail. The water circulation structure is mounted under the PV module by using a glue that has good heat conductivity. The structure contains an S-shaped pipe and a plate made of copper. The plate is used for better heat absorption from the PV panel which is mounted downside of the panel with glue. The efficiency of the PV module with having a proposed cooling system and normal PV module is analyzed. For the overall efficiency, it is observed that the water-cooled PV system is better than the standard PV module by % 6.2.

1. Introduction

Demand for alternative energy resources is increasing nowadays. Due to environmental concerns, renewable energy resources are taking more attention in recent years. Solar and wind energy production is the most popular and used renewable energy resources [1]. Two method is used for energy harvesting from solar system. The one is direct method by using PV panels. Whereas, in the other method solar energy is converted into thermal energy. In Concentrated Solar Power (CSP) technology, deploying parabolic mirrors connected to molten salt energy storage is used. After then the electricity production is obtained by use of this thermal energy. These systems are generally large scale systems [2]. CSP solar technology is widely used in large power facilities due to its storage ability. The storage ability is an important aspect since demand and production of power time do not coincide every time. That is power produced cannot be consumed simultaneously.

Solar PV systems has high initial investments costs. These can be reduced by improving PV cell efficiency. Efficiency increasing studies for PV panels can be divided into two areas. The one in PV cell semiconductor design technology. Sunlight harvesting of perovskites type solar cells are better than silicon solar cells. Perovskites type solar cells are attained power conversion efficiency of 27% [3]. Many papers have been written in intrinsic semiconductor PV design technology. For example, electricity production by using cadmium telluride (CdTe) photovoltaic module technology attained the lowest-cost electricity in the solar industry. This is obtained by alloying selenium into the CdTe absorber. As a result, PV cell efficiency is increased from 19.5% to 22.1% [4]. The second area is related with improving the working condition of PV cells. According to the PV cells inherent characteristics, PV cell efficiency can be increased, (1) by increasing the incident solar radiation falling on a PV cell, (2) by holding the temperature of PV cells at optimum temperatures, (3) by selecting an appropriate working point on I-V curve for maximum power harvesting. In this article 2[nd] method is conducted with a novel cooling

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approach. Different PV cooling techniques are used in literature [5, 6]. PV modules can not convert whole solar radiation into electricity. Only around 20-25 % of solar radiation could be converted. The rest of the energy is converted into heat [7, 8]. The temperature of the PV cell increases gradually by environmental conditions. This results in a decrease in PV cell electrical efficiency [9, 10]. For this reason, “PV cooling” is one of the main methods to increase electrical power generation in PV modules. [9].

Recycled cooling water can be used as hot water demands. For example, it might be used as hot water supply for homes [10].

Lifetime and Efficiency of PV cell is important. In literature, the electrical efficiency of PV cell is increased between 15% to 23% [11]. The effect of temperature raise is higher in polycrystalline and monocrystalline silicon solar cells which is about 0.45%/ºC, with respect to amorphous silicon cells which is about 0.25%/ºC. Moreover, amorphous silicon has lower thermal coefficient with respect to the other technologies. For this reason, it is widely used in thermal cogeneration applications [12, 13]. To reduce cell temperature different cooling techniques are used. These can be natural or forced type cooling. Also, different coolants are used such as air, water, oil and some chemical compounds [9, 14].

Different cooling techniques are used in PV cell cooling. Some of them are air based cooling (air channel, air gap), liquid based cooling (water flow, jet impingement, liquid immersion, submerging), phase change materials based (conductive) cooling. Matias et al., studied water cooling of PV panel with different coolant flow rate and compared the results [15]. They obtained efficiencies ranging from 5.30 % to 22.69% depending on the flow rate.

In this study PV cell cooling with naturel flow with a novel approach is experimentally analyzed. Cooling mechanism is mounted on back of PV panel. It consists of mainly two parts, copper sheet and copper pipe which is mounted on the sheet in S model. The gap between the pipes are approximately 2 cm. The gap between pipes is minimized to obtain a better cooling effect. Water circulation is achieved by natural flow. PV panel cooling performance and the overall heat transfer can be increased by increasing the circulation capacity. However, increasing water consumption used in cooling will increase cost of power production. This results in reduction of efficiency of overall system.

The experimental set up contains a PV module with the designed cooling system, two water tanks, and a DC load as shown in Figure 1. One of the tanks is used for hot water the other is for cold water storage. Water circulates from the cold water tank to the hot water tank by natural convection. The purpose of the DC load is to sample the I/V curve of the PV module. PV module is loaded with DC load by varying the load resistance to obtain I/V curve of the module.

In experiments, PV cell temperature, solar radiation, environment temperature, cooling water temperature, voltage and current values of panel are recorded. Two Tommatech brand 10W polycrystalline PV modules are used in experimental analysis. One of the panels is equipped with a copper plate that has pipes. The copper pipes are attached on a sheet of copper with a thickness of 0.5 mm which adhered to the back of the PV module. The second panel has no extra cooling equipment.

2. Solar Insolation Conditions in Osmaniye Environment for PV Energy Production

In this section insolation duration and sun radiation for Osmaniye province is tabulated. The data presented here is obtained from General Directorate of Meteorology of Turkish Republic website.

The monthly average solar radiation in the Osmaniye environment is above the Turkey average. Monthly global radiation for a long time period, 2004-2018, in Osmaniye environment is shown in figure 2. Also, average insolation duration in Osmaniye is above the Turkey average. Monthly insolation duration is given in figure 3. The whole data is obtained from General Directorate of Meteorology website. Longer insolation time and higher radiation means better PV output power. In Osmaniye province, the sun radiation and insolation duration suggest that PV energy production in this environment is efficiently sustainable.

3. Mathematical Model of Single PV Module

Although many models have been proposed in the literature, two types of PV cell models stand out. The first of these is the single diode model as shown in figure 4. The second is two diode models as shown in figure 5.

In this article, a single diode model is preferred due to its ease of use. The I/V characteristic of the model has been obtained by assuming constant temperature and solar insulation conditions. I/V relationship of the single diode PV can be defined as follows:

Figure 1 Experimental setup of the developed PV system.

$$I_D = I_0\left(e^{\frac{(V_D - R_s I_{pv})}{nV_T}} - 1\right) \text{ where } V_T = kT/q \qquad (1)$$

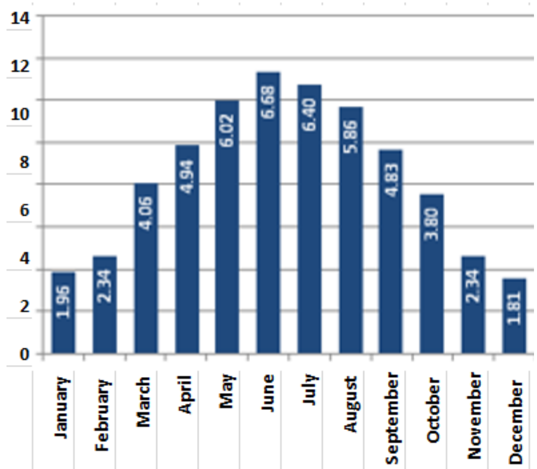

Figure 2. Global radiation for Osmaniye center. (kWh/m^2.day)

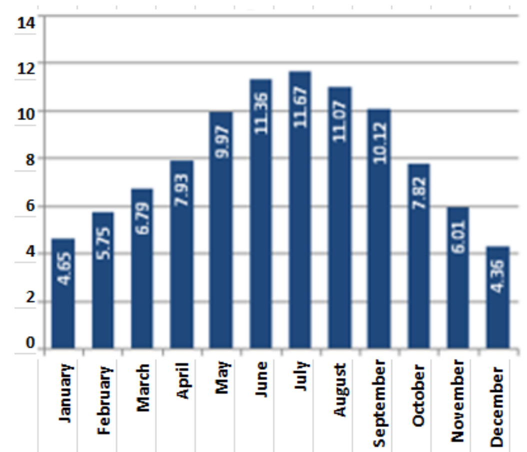

Figure 3. Insolation duration for Osmaniye city, hourly basis

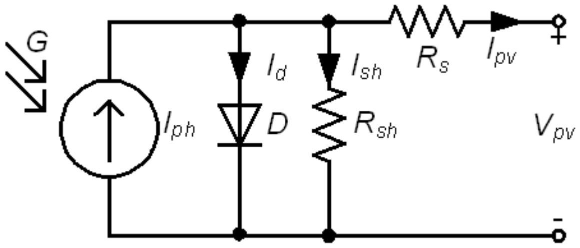

Figure 4. One diode equivalent model of PV panel.

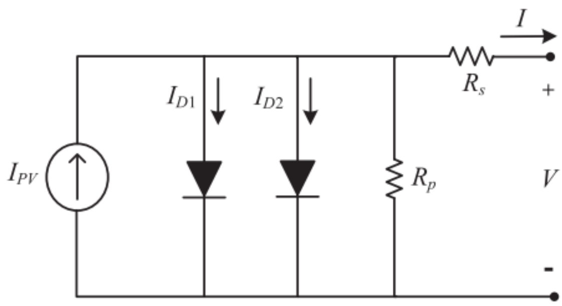

Figure 5. Two diode equivalent model of PV panel.

R_{sh} in the model stands for the p-n junction leakage current in the solar cell. There is a metal base between the semiconductor layers. This metal base has a contact resistance. This resistance is modeled in design with the existence of R_s [16]. The diode D assumed to have I-V characteristic of the Shockley diode model as shown in equation (1), where I_0 is reverse bias saturation current of the diode, I_D is the current that flow through diode D, V_D is the voltage across the diode D, k is the Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K), n is the diode ideality factor, the thermal voltage is represented by V_T, operating temperature of cell in degree Kelvin is represented by T and q is the electron charge ($1.60217646 \times 10^{-19}$ C).

PV module load current is:

$$I_{pv} = I_{ph} - I_{sh}\left(e^{\frac{q(V_{pv} - R_s I_{pv})}{NKT}} - 1\right) - \frac{(V_{pv} - R_s I_{pv})}{R_{sh}} \qquad (2)$$

Where I_{ph} is the main current produced by solar cell, the solar cell terminal current is symbolized by I_{pv}, the solar cell terminal voltage is symbolized by V_{pv}, the equivalent parallel resistance is represented by R_{sh} and the equivalent series resistance is represented by R_s. The resistances R_{sh} and R_s in equation (2) can be calculated by iteration. In iteration the constrained that the maximum power obtained from model should conform with peak power from the datasheet at MPP [17]. Table 1 shows some assumptions made for parameter estimation of PV panel.

At Maximum Power Point, voltage (V_{mp}) and current (I_{mp}) is used for calculation of the maximum output power (P_{MP}), as follows:

$$P_{mp} = I_{mp} V_{mp} \qquad (3)$$

The technical specification and parameters of the PV panels used in experiments are given in Table 2.

Table 1. Initial conditions for parameter estimation

At Short Circuit	$[dI/dV]_{sc} = -1/R_{sh,ref}$
At the Maximum Power Point	$[dI/dV]_{sc} = 0$
At Short Circuit Current	I = Isc,ref, V = 0
At Open Circuit Voltage	$I=0$, $V=V_{oc,ref}$
At the Maximum Power Point	$I= I_{mp,ref}$, $V=V_{mp,ref}$

Table 2. PV module technical parameters used in analysis

Parameters	**Symbol**	**Values**	**Units**
Solar irradiance	S	1000	W/m2
Temperature	T	25	ºC
Maximum power	P	10	W
Nominal open circuit voltage	V_{ocn}	21.5	V
Voltage at Maximum power	V_{mp}	17.3	V
Nominal short circuit current	I_{scn}	0.71	A
Current at Max. power	I_{mp}	0.57	A

To derive the following equations, PV module initial condition parameters are used in Equation (1) to find short circuit current of the model. Equation (3) represents short circuit current of the PV cell, Equation (4) represents PV cell load current, Equation (5) represents maximum current of the PV cell and Equation (7) represents current to voltage ratio of the model of PV cell respectively. The variables and their symbols used in equations while diode modelling is tabulated in Table 2.

$$I_{sc} = I_L - I_o\left[exp\left(\frac{I_{sc}R_s}{a_{rf}}\right) - 1\right] - \frac{I_{sc}R_s}{R_{sh}} \quad (4)$$

$$I_L = I_o\left[exp\left(\frac{V_{oc}}{a_{rf}}\right) - 1\right] - \frac{V_{oc}}{R_{sh}} \quad (5)$$

$$I_m = I_L - I_o\left[exp\left(\frac{V_{mp}+I_{mp}R_s}{a_{rf}}\right) - 1\right] - \frac{V_{mp}+I_{mp}R_s}{R_{sh}} \quad (6)$$

$$\left[\frac{dI}{dV}\right]_{sc} \cong -\frac{1}{R_{sh}} \quad (7)$$

$$\frac{I_{mp}}{V_{mp}} = \frac{\left(\frac{I_O}{a_{rf}}\right)exp\left(\frac{V_{mp}I_O+I_{mp,}R_s}{a_{ref}}\right)+\frac{1}{R_{sh,rf}}}{1+\left(\frac{I_OR_s}{a_{rf}}\right)exp\left(\frac{V_{mp}I_O+I_{mp}R_s}{a_{rf}}\right)+\frac{R_s}{R_{sh}}} \quad (8)$$

The maximum power point efficiency of PV module heavily depends on the cell temperature[18]. PV module efficiency dominantly depends on temperature of module. It is obtained as the following:

$$\eta_{mp} = \frac{I_pV_{mp}}{G_TA_M} = \frac{P_{mp}}{G_TA_M} \quad (9)$$

where, A represents the aperture area and G_T represents irradiance quantity that PV cell exposed, under standard test conditions; 25 °C, G_T=1000 W/m^2. In literature a number of correlations can be found for PV electrical power as a function of cell/module operating temperature and basic environmental variables. Some correlation equations are linear and some of them are nonlinear [19]. As an example, the following multivariable nonlinear regression equation can be shown.

$$P_{mp} = d_1 + d_2T_C + d_3(lnG_T)^m d_4T_C(lnG_T)^m \quad (10)$$

Here, $d_{j,}$ j=1…4 and m are model parameters.

4. Results and Discussion

The experimental set up of PV panel efficiency analysis for two different panel is conducted at Osmaniye Korkutata University roof of Engineering Faculty. Experimental data used in this paper are taken on 12 August 2019 at midday. In the experimental set up two PV module is used.

As previously stated, in this work two PV panels utilized. First one is unmodified panel, the other one is modified with copper cooling system which is consist of copper plate and pipes. The copper plate is attached back side of PV panel by using high heat transmission coefficient adhesive (Thermal Conductivity: 8.5 W/(m*K)). This type of adhesives can conduct heat from PV panel to copper sheet almost perfectly [20]. Water circulation through the pipes is supplied by natural convection flow. The data from PV panel with and without water cooling is collected simultaneously.

Current-Voltage and Power-Voltage characteristics of PV panels are depicted in figure 6 and figure 7 respectively.

As a result of experimental studies it has been shown that use of a water pipe system is comparatively inexpensive. The results of experiments show that output power of the PV solar system is effectively increased. Real time thermal images of PV panel were also recorded by using maximum ambient temperature. Thermal images shown in Figure 4 and Figure 5, at 13:30 the maximum temperature for a solar panel without and with water cooling 49^{0}C and 40.2^{0}C is observed respectively.

The temperature of the PV panel was varying from 35.2^{0}C to 40^{0}C depending on the sunniest (there were some mist). At the same time, temperature of the water-cooled panel was varying between 34.2°C to 40.2°C respectively. Drop in panel temperature is due to cooling water. The cooling water is supplied from water tank. It has an average temperature of 27 °C. At the beginning, water cooling of PV panel has reduced the surface temperature of the panel below the environment temperature.

As temperature is decreased on PV panel, the efficiency of the panel is enhanced. Power efficiency of water cooled PV panel with respect to non-cooled can be achieved by equation:

$$\eta = \frac{P\max with\ cooling - Pmax\ w/outcooling}{Pmax\ w/outcooling} \quad (10)$$

Water cooled PV efficiency varies between 5.8 and 6.5 %. During August, midday PV efficiency is measured and its average value is approximately 6.2 %.

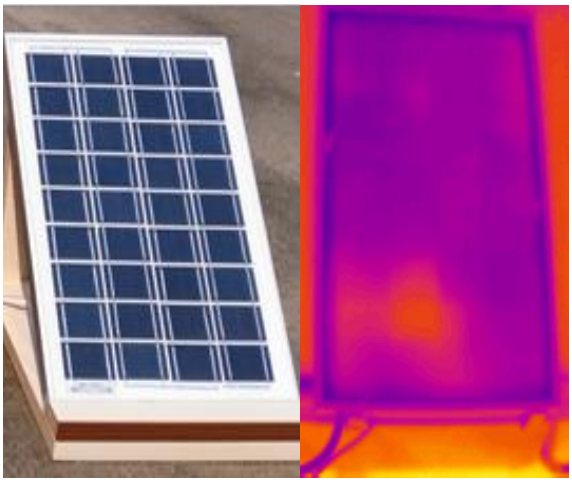

Figure 4. Front view of photovoltaic panel. (left side: Normal image, Right-side: thermal image)

Table 3. Temperature values of water cooled PV panel and environment

	PV with cooling	Environ ment	PV without cooling
Min temp(^{0}C)	34.2	35.2	51
Max temp(^{0}C)	40.2	40	63
Average temp(^{0}C)	37.5	37	56

Figure 5. Backside, normal and thermal view of developed PV module

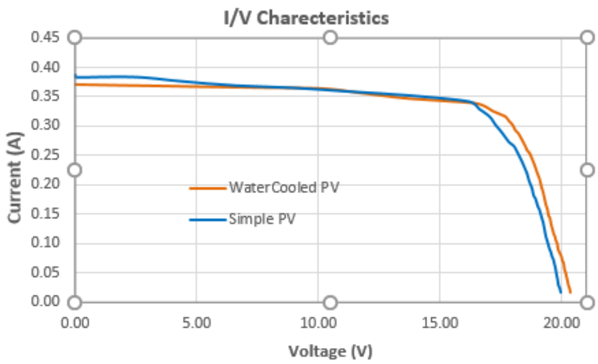

Figure 6. Voltage- Current PV module Characteristics

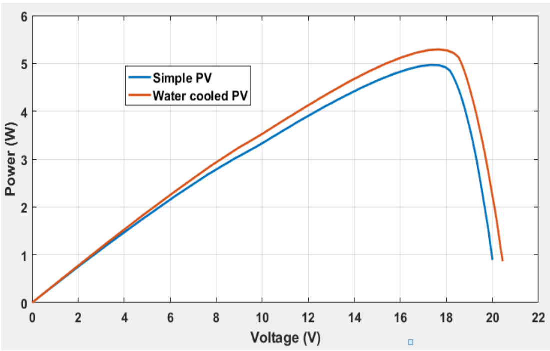

Figure 7. Voltage- Power PV module Characteristics

4. Conclusions

The electrical efficiency of PV panel with water cooling is compared with normal PV panel. The efficiency results of conducted experimental studies are promising. Better results are obtained with respect to previous studies. As a result of cooling, the temperature of panel decreases slightly. Thus, the PV panel maximum power (P_{mp}) and open circuit voltage (V_{oc}) increase slightly while short circuit current (I_{sc}) decreases slightly. If the overall efficiency of proposed system is considered, water cooled PV system is better than normal PV panel approximately by % 6.2 for experimental test conditions.

The efficiency of PV panel with proposed method is better than most of the results obtained in literature [9, 14].

Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

M. Uçman prepared experimental setup. All authors contributed to data collection phase. H. Erol wrote the manuscript. Z. Kesilmiş made proofreading of manuscript.

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