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Performance Enhancement of PV Panels by Back Cooling

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A B S T R A C T

The photovoltaic panel is a device of photochemical energy conversion. It produces electricity from the sun light by PV phenomena. There are many factors that negatively impact solar panel performance, with panel temperature being one of the most important. The cell temperature of the PV panel effects on its degradation rate and life time. So, it's very important to install a cooling system combined with PV system to enhance its efficiency. In this paper, the effect of back cooling for a PV panel was studied experimentally. The cooling system was carried out using water pipes installed under the PV panel. An experimental setup was installed to study the effect of water cooling from the back on the PV output. The panel temperature and open circuit voltage were measured. It was found that the open circuit voltage of PV panel enhanced from 33.92 to 34.66V when the panel temperature decreased by 5^{o}C.

1. Introduction

The demand for renewable energy has recently increased to avoid the problems of traditional fuels. In addition to the decrease in fossil fuels, it causes air pollution due to the emissions resulting from its use. Currently, in many applications, solar cells are relied upon as a renewable source for producing electrical energy, for example electric cars, communications systems, mobile networks, and irrigation applications in remote areas, … etc. Solar radiation and ambient temperature are among the factors that most affect the performance of photovoltaic (PV) panels. The performance of the solar panel is tested in factories at a temperature of 25^{o}C and a solar radiation of 1000W/m2, which is called standard test conditions (STC). Therefore, the output of solar cells changes significantly when any change occurs in the surrounding environment [1].

Any increase in the ambient temperature causes PV panel temperature to increase [2]. In addition, not all of the sunlight falling on the solar panel is converted into electricity. The remaining sunlight is converted into heat that affects the output of the solar panels. Therefore, the PV panels must be cooled to improve their efficiency. However, the appropriate cooling technology must be chosen for the climatic conditions in which the solar plant is installed to ensure the desired improvement is achieved.

Energy and water have always been independent sources that affect each other. Since water desalination does not occur without consuming energy (produced from fossil fuels). Water is also necessary to extract and purify fossil fuels. These processes produce greenhouse gas emissions as a result of the use of fossil fuels, which are expected to reach 0.4 billion tons of CO2 annually by 2050 [1]. Therefore, it was necessary to rely on clean energy

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for water desalination and constant research to improve its performance to preserve the environment and not harm it [2].

One of the main factors affecting the output of solar panels is temperature [3]. Therefore, it is necessary to properly cool the PV panels. There are many cooling technologies, some of which require external equipment to perform cooling, and some that rely on methods or materials with chemical and physical properties to remove heat [4, 5, 6]. Examples of systems that need external equipment are pumps, fans, etc. for cooling using water or air. Examples of other systems are phase change materials (PCM), heat pipe, heat sink, etc.

Water cooling (as an available and reusable resource) is one of the best cooling methods because it has two advantages: cleaning and cooling. It is achieving fast and effective cooling as well as providing uniform temperature profile distributed on the PV panel surface [7, 8]. Ahmed et al worked to improve the efficiency of a solar panel by reducing its temperature from the surface and back [9]. The panel was water-cooled and the efficiency improved by 2.7% compared to the non-cooled panel. Samaneh et al also worked on improving the efficiency of a solar panel by cooling and achieved an increase in electrical efficiency to 12.3% [10]. Yingbo et al presented an innovative cooling method for PVT system to improve the heat transfer rate [11]. The results showed that with the use of water cooling, randomly distributed holes can be made that have a significant impact on cooling performance. A higher overall efficiency of 4.7% was achieved when using a flow rate of 0.006kg/s at a solar radiation of 1000W/m2. The best result was achieved with a hole with a diameter of 0.005m.

2. Physical PV characteristics

Solar cells consist of semiconductor materials (PN junction) and produce electricity from sunlight without any pollutants [12]. Atoms of these materials absorb photons from sunlight. These photons cause electrons to move from the negative layer to the positive layer, passing through the external circuit. As a result, an electric current passes in the opposite direction, causing a potential difference between the ends of the cell. The solar cell produces from 0.5 to 0.8 volts, depending on the type of semiconductor and the technology with which it is made. The cells are connected together to obtain the required voltage.

The solar cell is represented by an equivalent electrical circuit [13]. This circuit consists of a current source called a photocurrent (Iph), a series resistor (R_s), and a parallel resistor (R_{sh}). The resistance in series is very small and the resistance in parallel is so large that they can be neglected to simplify the circuit [14]. The solar cell's voltage-current characteristic equation is as follows:

Panel photo-current Iph:

$$\mathrm{Iph} = \frac{\mathrm{Ir}}{1000} \times [\mathrm{Isc} + \mathrm{Ki} * (\mathrm{T} - 298)] \qquad (1)$$

Where, Iph: photo-current (A); Isc: short-circuit current; Ki: short-circuit current of cell at 25 °C and 1000 W/m2; T: operating temperature (K); Ir: solar irradiation (W/m2).

Panel reverse saturation current Is:

$$\mathrm{Is} = \frac{\mathrm{Isc}}{e^{\left(\frac{q \times Voc}{ns \times k \times N \times T}\right)} - 1} \qquad (2)$$

Where, q: electron charge, = 1.6 × 10−19C; V is the voltage across the diode; ns: number of cells connected in series; N: the diode ideality factor; k: Boltzmann’s constant, = 1.3805 × 10−23 J/K.

The PV cell equivalent circuit contains a diode, a current source, a shunt resistance, and a series resistance. As a result, the current to the load may be expressed as:

$$\mathrm{I} = \mathrm{Iph} - \mathrm{Is} \times \left(e^{\left(\frac{q \times (V + Rs \times I)}{N \times k \times T}\right)} - 1\right) - \frac{(V + Rs \times I)}{Rsh} \qquad (3)$$

As a consequence, the whole PV cell physical performance is related to Iph, Is, Rs, and Rsh, in addition to two external factors such as solar radiation and temperature. It is clear from Equation No. 3 that temperature is one of the factors that greatly affect the output of solar cells.

3. System and Results analysis of cooled PV Panel

The system includes a PV panel with open circuit voltage (Voc) equal to 38.1V at standard test condition (STC) of 25oC temperature and 1000W/m2 solar radiation. Cooling is done manually with water. As shown in figure 1, water sprayers were used through a network of pipes under the PV panel and covering all back. The pipes are distributed evenly under the panel, every 15 cm, so that they cover the entire panel from the back. Each pipe has holes every 10 cm, pointing upwards to allow the water to rush into the back of the panel. The solar panel has a temperature sensor installed on the back to measure its temperature, in addition to another sensor to measure the ambient temperature. A voltmeter was used to continuously measure the open circuit voltage of the panel.

Fig. 1: Water back cooling system for PV panel

The cooling system was operated for only one minute to study how this method effects on the panel temperature. Table 1 shows the measurements taken throughout the experiment. The ambient temperature at this time was 35oC while the panel temperature was recorded at 56oC before cooling began. The open circuit voltage of the panel before cooling was 33.92 V.

From the measurements in the table 1, and as shown in Figure 2, the panel temperature remained constant for 20 seconds then decreased from 56 to 51oC. As a result, the open circuit voltage increased from 33.92 to 34.66 volts with an improvement of approximately 2%. It is noticed from Fig. 3 that a slight decrease in panel temperature and thus a slight improvement in open circuit voltage. The reason for this is that the water does not stay enough on the panel.

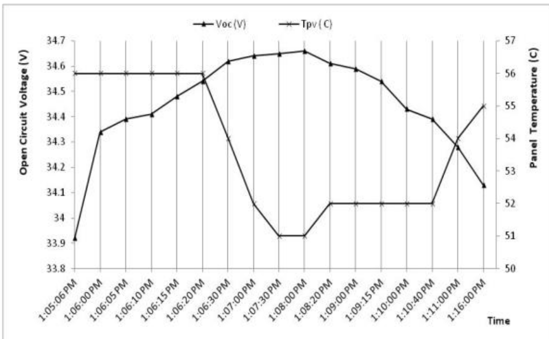

Fig. 2: Panel temperature and Voc vs. the time

Figure 3 shows the direct relationship between temperature versus open circuit voltage and the output power of the solar panel. It is clear that the voltage increases significantly as a result of the decrease in the panel temperature. The panel voltage reached 34.66V when it reached a temperature of 51oC, a difference of 5 degrees compared to before cooling. As a result of increasing the voltage, the power output from the panel increases, as the power is directly proportional to the voltage.

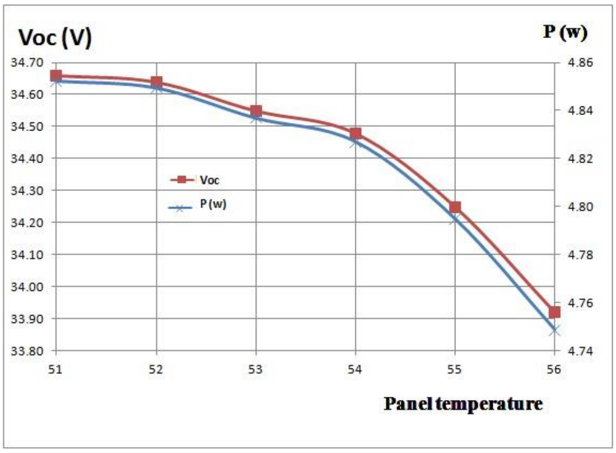

Fig. 3: Effect of panel temperature on Voc

It is clear that the efficiency of the solar panel is improved by improving the power output. This improvement achieved several advantages. The performance of the solar system was improved by cooling, which in turn reduced the rate of decay and increased its lifespan.

4. Conclusions

The use of photovoltaic as a means of producing clean electrical energy reduces the consumption of fossil fuels. To improve the performance and efficiency of solar cells, they must be cooled using a cooling technology. Among many cooling technologies, this paper studied the effect of using water for cooling PV panel back side. An experimental setup was installed to study the effect of water cooling on the PV output. It was found that Voc of PV panel enhanced from 33.92 to 34.66V when the panel temperature decreased from 56^{o}C to 51oC.

Table 1: Measurements of panel temperature and Voc

Time	Panel Temperature (^oC)	V_{oc} (V)	Notes
1:05:06 PM	56	33.92	Before cooling
1:06:00 PM	56	34.34	Cooling Start
1:06:05 PM	56	34.39	
1:06:10 PM	56	34.41	
1:06:15 PM	56	34.48	
1:06:20 PM	56	34.54	
1:06:30 PM	54	34.62	
1:07:00 PM	52	34.64	Cooling Stop
1:07:30 PM	51	34.65	
1:08:00 PM	51	34.66	
1:08:20 PM	52	34.61	
1:09:00 PM	52	34.59	
1:09:15 PM	52	34.54	
1:10:00 PM	52	34.43	
1:10:40 PM	52	34.39	
1:11:00 PM	54	34.28	
1:16:00 PM	55	34.13	

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