Enhancing the Energy Efficiency of Solar Panel Using Water: A Case Study in Sudan

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***Abstract*— Operating temperature has been considered a major factor that affects solar panel efficiency. The efficiency of the solar panel is influenced either by increasing or decreasing the panel temperature. The aim of this paper is to design a cooling system to improve the efficiency of the solar system by reducing the temperature of the panel. In this design, additional waterproof layer is added under the button of solar panel to provide more protection from any water leakage, then a region filled with water is added at the back surface of the panel to work as a cooling medium. This region of water exchanges heat between the solar panel and the water layer .The cooling system fixed on the bottom of the panel is almost about 5mm from the back surface. The liquid was fed from the top hole of the system, so if water is inserted from the top hole it can come out of the bottom hole, when there is a need to empty the water. The design ensured that there is no leakage of water at the sides so that the water could not reach the surface of the board. Water tube is connected to the top and bottom of the hole with two valves to control the inlet and outlet of water. The measured parameters of radiation, voltage and current which obtained at different times through the day were used to calculate the efficiency of the panel after and before using this system. The overall experiment results show that when the proposed cooling system was used, the average efficiency of voltage in the solar panel increased approximately by 1.2% and the average efficiency of current in the solar panel increased by 5%.**

***Index Terms*— Current; Efficiency; Solar Panel; Voltage.**

I. Introduction

Renewable energy refers to the use of natural flows of energy occurring directly in environment [1]. A significant impact of demanding energy exists, in particular the renewable energies due to the growth of power needed in the less developed countries [2], and solar technologies were helpful to make them the future of energy. These technologies can be classified as either passive, such as the use of sun energy in heating water or active, such as the solar panel [3]. Unlike solar thermal systems that supply heat by absorbing light energy, the photovoltaic systems produce electricity by absorbing light. The operation of photovoltaic (PV) is divided into three steps: absorption of light, separation of charge carriers and separate extraction of carriers. The first step produces hole- electron pairs [4]. The thickness of absorber is an important factor in the design of solar cell because it is important to increase the amount of the absorbing light and minimize the reflecting energy [5]. Many technologies, such as Nano scale improve the efficiency of the solar cell by increasing the light absorption [6]. In general, there are three generation of solar cells: the first generation made of crystalline silicon, the second one is amorphous silicon, while the third one is made of thin film technologies. The latest generation is still under research and has yet to be used commercially. The most common material used for manufacturing photovoltaic cell is the crystalline semiconductor; therefore it has high producing cost similar to the integrated circuits [7]. Solar energy has been used widely in different region in different temperature. Operating temperature is a major factor of solar cell efficiency. The efficiency of solar cell is influenced by either increasing or decreasing the temperature of the panel. This paper studied the effect of reducing the panel heat on the efficiency of producing current by the solar panel; the paper studied the use of water cooling system in enhancing the efficiency of solar panel.

II. Solar Cell

Solar cell is P-N semiconductor junction used to convert directly the incident light to electric current. The structure of the solar cell is shown in Figure 1. The working principle of the solar P-N junction based on the number of electron-hole pairs is created when the light energy strikes the junction.

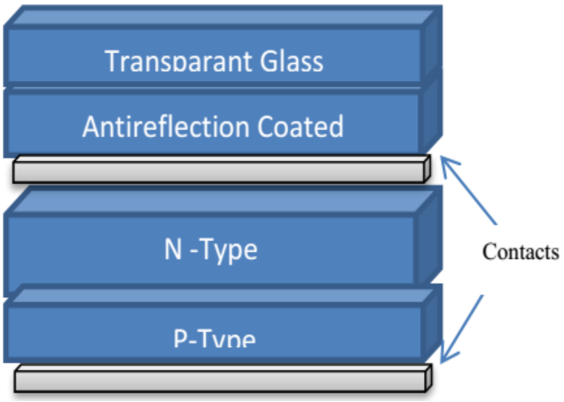

Figure 1: Solar cell structure

It consists of two layers of semiconductors connected to contacts planes. A transparent glass is used on the surface of the cell followed by an antireflection coated. The working principle of the solar cell is based on the photoelectric effect, which states that when a light strikes the surface of conductive materials, photons will interact with electrons, causes excitation of electrons, and jumps to a higher layer. The previous absorption process generates electron hole pairs. The next step is separating the opposite charges to the external circuit. The optimized range of light spectrum is set between 400 nm and 750 nm.

III. Related Works

Enhancing the performance has become an interest for many efforts around the world. Table 1 summarizes some of these efforts. Most of the publication works in this field has the common objective, which is to improve the efficiency of the solar panel. However, they have different scope of investigation, such as the place of experiment, which play important role in such studies due to the variation in the parameters of experiment such as ambient temperature, amount of radiation, etc. There are other differences such as the type of the operating medium and the techniques used to improve the efficiency of the solar panel, such as using heat sinks or using different types of dyes. A lot of works review the history of the solar panel progress.

Table 1
Summary of Related Works

Author	Year	Description
Chengyang Jiang [8]	2017	This paper worked on reducing the PV temperature by using refrigerant of propane (R290).
Mallikarjun [9]	2017	This paper studied the efforts to increase the efficiency of the solar cell.
Efsilon et al. [10]	2018	The study was conducted in Indonesia, and it used heat sink and cooling fan. The results lead to improving the open circuit voltage.
Cătălin G et al. [11]	2016	This paper studied the efficiency of the panel using cooling system based on air heat sinks; the paper studied the efficiency by using different positions of the heat sink.
Muhammad Bilal [12]	2016	Study the performance of PV with the use of reflecting mirrors.
Yunfei Shang [13]	2015	Reviewed the recent progress on varying types of efficient up conversion materials.
Nisith [14]	2015	Reviewed the history of solar cell development.
Ghania Azzouzia [15]	2013	This paper studied numerically the potential of the impurity PV effect in crystalline silicon solar cell doped with impurity PV.

IV. Methodology

The efficiency of a solar cell is determined as the fraction of incident power, which is converted to electricity and is defined as in equation (1) [16]:

$$P_{Max} = V_{OC}.I_{SC}.FF \qquad (1)$$

where: V_{oc} = Open-circuit voltage
I_{sc} = Short-circuit current
FF = Fill factor

The efficiency of the solar cell can be given by:

$$\eta = P_{Max} / P_{IN} \qquad (2)$$

where: η = Efficiency
$P_{Max:}$ = Maximum output power
P_{IN} = Solar panel input power

$$\eta = (V_{OC}I_{SC}FF)/P_{IN} \qquad (3)$$

It is known that the temperature reduces the efficiency of the solar cell. In this design, we designed a simple system to improve the efficiency of the solar panel by cooling the solar panel (cooling the panel through water). The solar panel was well insulated with an additive waterproof material (from all sides), then added water space closing to the solar panel in the back surface of the solar panel. The inner cavity was filled with water. The simple model of the cooling system is shown in Figure 2. The water region fixed on the back surface of the panel was about 5 mm from the back surface. The liquid was inserted from the top hole of the systems, as shown in Figure 2. If water is inserted from the top hole, it can come out from the bottom hole. For big systems, it is suggested that the upper water pipe to be connected to a water tank and a pump is used to return the output water to the tank.

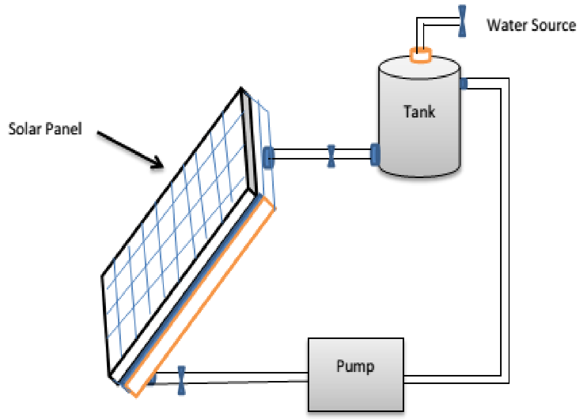

Figure 2: Design schematic

The system ensures that there is no leakage of water occurs in the sides so that the water does not reach the surface of the board, which prevents the absorption of light from the surface of the cell. The system was connected with water tube on the top and bottom holes. The upper water pipe can be connected to a water tank, in the case of the large system. Also in the case of the large system, the tank can be connected to a river. The bottom tube completes the loop of the cooling process (the resulting water has a temperature higher than the water inside).

The heat transports between the solar cell and the added water layer. Within the solar panel, the heat exchanges between the surface of the panel and water, where the heat from the surface of the panel to water reduces the temperature of the panel surface; thus, increasing the efficiency of the solar cell. The measuring steps are:

- Measuring the temperature of ambient air and solar radiation in all cases:
- Measuring the solar radiation provided by the sun at each reading.
- Measuring the ambient temperature at each reading.
- Measuring the output current of the cell at each read.
- Measuring the output voltage of the cell at each read.

The previous steps of measuring radiation, temperature, voltage and current were done in both two scenarios before applying the cooling system and after applying the cooling system.

Therefore, by applying the measurements results of the experiment, the efficiency of the solar cell was determined using equation (2). The amount of heat transferred between the panel and the water surface is relative to the amount of water and its temperature. This relation can be given by the following equation:

$$m_p \text{ x } c_p \text{ x } \Delta T = m_w \text{ x } c_p \text{ x } \Delta T \quad (4)$$

where: m_p = Mass of the panel
m_w = Mass of the water
$c_{p\,,}$ = Heat coefficient of panel
c_w = Heat coefficient of water
ΔT = Temperature difference between the panel and the water

The technical data of the used solar panel given by the manufacture company at standard test conditions are shown in Table 2.

Table 2
Solar Panel Specifications

Model Type	SYFDM10S-18
Short Circuit Current	0.68 A
Open Circuit Voltage (V_{os})	21.60 V
Max System Voltage	1000.00 V
Maximum power	10.00 W
Maximum Current	0.56 A
Maximum Voltage	18.00 V
Fuse Rating	15.00 A
Manufacture Country	Germany

V. Results and Discussions

The results illustrates the efficiency of the solar panel before and after cooling system application.

A. Results Without Cooling

In this scenario, the efficiency of the solar panel without using cooling system (normal case) was calculated using equation (2). The study measured the efficiency of solar panel at different times over the day and the results are shown in Table 3.

Table 3
Reading Before Cooling System

Ambient Temperature (C°)	Radiation (Mev)	Voltage (V)	Current (A)
40	71.0	19.50	0.50
41	67.8	19.10	0.45
44	68.0	18.10	0.50
42	67.0	19.20	0.40
34	62.9	19.34	0.36
36	63.7	19.55	0.37
39	60.2	19.34	0.45
48	63.2	19.30	0.35
40	61.7	19.21	0.35
40	62.8	19.28	0.35
38	55.1	18.19	0.38
41	50.5	19.17	0.34

As shown in Table 3, the average voltage and current are 19 V and 0.4 A respectively. The maximum level of voltage is 19.55 V and the lowest voltage level is 18.1 V.

B. Results After Cooling

In this scenario, the enhancement results in terms of voltage and current produced by the solar panel were measured after using the cooling system, the study reported the results in Table 4. The experiment was done at different times over the day.

Table 4
Reading With the Cooling System

Ambient Temperature (C°)	Radiation (Mev)	Voltage (V)	Current (A)
40	71.0	20.40	0.60
41	67.8	20.10	0.48
44	68.0	20.20	0.61
42	67.0	20.20	0.49
34	62.9	20.30	0.38
36	63.7	20.15	0.38
39	60.2	20.15	0.37
48	63.2	20.18	0.37
40	61.7	20.69	0.42
40	62.8	20.60	0.45
38	55.1	20.59	0.40
41	50.5	20.50	0.42

Table 4 shows that the results of the average voltage and current were 20 V and 0.45 A respectively. Figure 3 and Figure 4 show the differences of voltage and current before the cooling of the solar cell and after cooling. Different reading ratio occurred due to some factors, such as solar radiation, temperature, wind, humidity and angles. All the results of the experiment were done at the same time of the day; therefore, they have the same weather conditions.

The significance of this paper is the study of the effect of the ambient temperature on the average voltage and current produced by the solar panel. Therefore, this study is required in evaluating the efficiency of the solar panel in the tropical countries. As shown in Table 2 and 4, the overall results show that there is an increase in the average output current from 0.4 A before the use of water cooling to 0.45 A after the cooling system. Similarly, the average voltage increased from 19 V to 20 V.

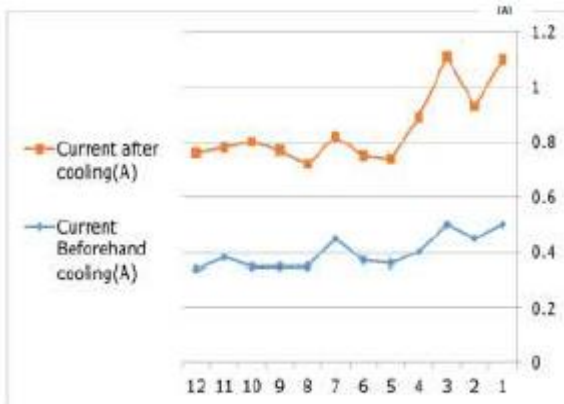

Figure 3: Results of current

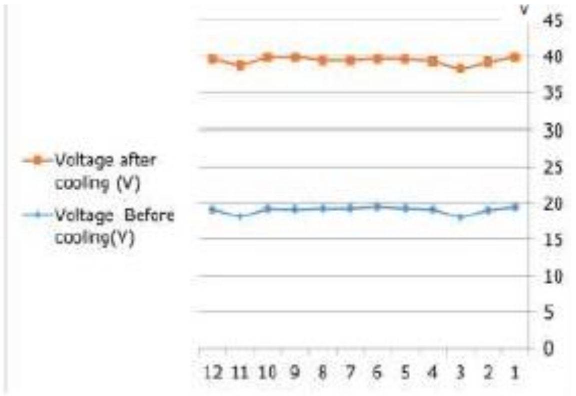

Figure 4: Results of voltage

VI. CONCLUSION

The solar panel heat reduces the efficiency of the solar cell. In general, an increase of the temperature leads to efficiency drops. Therefore, maximizing the solar panel efficiency basically depends on controlling its temperature, and it is considered the major factor to improve the efficiency. This paper work conformed this fact, and studied the effect of panel temperature. The experiment was done in Sudan, which falls on the hot weather region. Therefore, such studies are important to evaluate the efficiency of the solar panel. The paper proved that the efficiency of the cell can be enhanced by using cooling system based on water to cool the solar panel through the process of heat exchange between the water and the cell. The results showed an increase of the panel efficiency in terms of voltage and current after using the suggested cooling system. The maximum voltage was 19.55V without using the cooling system and 20.69 V after using the cooling system. Similarly, the maximum current was 0.5 A before using the cooling system and 0.61 A after using the cooling system. This result illustrates the importance of improving the efficiency of the solar panels by controlling its temperature; hence, this work achieves its goal to enhance the average output voltage and current.

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