



Investigation of water-cooled photovoltaic driven reverse osmosis desalination system

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ABSTRACT

The photovoltaic (PV) panel is a device of photochemical energy conversion. It produces electricity from the sun light by PV phenomena. The cell temperature of the PV panel effects on its degradation rate and life time. So, it's very important to installing a cooling system combined with PV system to enhance its efficiency. Among many cooling technologies, this paper reviewed two common techniques. These techniques use water as an active cooling and phase change material (PCM) as a chemical passive cooling. This paper studied the effect of using cooled PV driven reverse osmosis (RO) desalination system. An experimental setup was installed to study the effect of water cooling on the PV output. It was found that the open circuit voltage (V_{oc}) of PV panel enhanced from 32.1 to 35V when the panel temperature decreased by 19°C. The results showed that for PV driven RO, the PV output enhanced by cooling. So, the RO saline feed-water can be used to PV cooling in addition to preheating it to improve the desalination system productivity.

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°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

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

3. Water and PCM cooling

One of the main factors affecting the output of solar panels is temperature. Therefore, it is necessary to cool the PV panels with proper cooling. 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 [3, 4, 5]. 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 [6]. Ahmed et al worked to improve the efficiency of a solar panel by reducing its temperature from the surface and back [7]. 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% [8]. Yingbo et al presented an innovative cooling method for PVT system to improve the heat transfer rate [9]. 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.

Phase change material (PCM) is placed behind the photovoltaic panels in order to remove heat. When these materials change from a solid to a liquid state, they store a certain amount of heat, and lose it when they change from a liquid state to a solid state. Temperature stabilization is achieved due to the isothermal nature. The appropriate material and its quantity are selected to determine the amount of temperature change. Determining the material is not easy because it is placed in constantly changing and unpredictable climatic conditions. The states of phase

change materials change rapidly with changes in solar radiation, ambient temperature, panel temperature, and wind speed. Therefore, the physical and thermal characteristics of PCMs affect the effectiveness of the PV system cooled by PCMs. The amount of absorbed heat is dominated by heat capacity and fusion latent heat in addition to thermal conductivity. It is also affected by material density and quantity. Furthermore, as a construction material, it must meet explosiveness, flammability, and toxicity restrictions.

PCMs are classified into three types: inorganic, organic materials, and eutectics. The majority of phase change materials lack all of the functionalities necessary for storing [10]. Therefore, it is important to selecting the material which is nearest to the cheapest and required material characteristics. Three different cooling cases were devised by Ali et al [11]. Cooling in the first case is by water flowing through pipes. Cooling in the second case is by PCM flow in pipes. In the third case, cooling is done by flowing PCM/nano-SiC in pipes. The best case in terms of efficiency is when using nano-fluid and nano-PCM with an efficiency improvement value of 5.25%.

The efficiency and performance of a PV panel was also evaluated by Lippong et al [12]. The panel is cooled with paraffin as a PCM with melting point of 27°C. The results showed that the panel's efficiency increased by 5.39% when its temperature decreased by 15°C compared to the panel without cooling. Xiaojiao et al improved the efficiency of a PVT by 14% when cooled by PCM with a water flow rate of 2.5L/min [13]. A solar PV panel was cooled by a heat sink reservoir by Washington et al [14]. Palm Wax was used as a PCM because it is cheap compared to other types. Efficiency is improved by 5.3% when the temperature is reduced by 6.1°C.

4. Physical PV characteristics

Solar cells consist of semiconductor materials (PN junction) and produce electricity from sunlight without any pollutants [15]. 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 [16]. This circuit consists of a current source called a photocurrent (I_{ph}), 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 [17]. The solar cell's voltage-current characteristic equation is as follows:

Panel photo-current I_{ph} :

$$I_{ph} = \frac{I_r}{1000} \times [I_{sc} + K_i * (T - 298)] \quad (1)$$

Where, I_{ph} : photo-current (A); I_{sc} : short-circuit current; K_i : short-circuit current of cell at 25 °C and 1000 W/m²; T: operating temperature (K); I_r : solar irradiation (W/m²).

Panel reverse saturation current I_s :

$$I_s = \frac{I_{sc}}{e^{(q \times V_{oc}) / (n_s \times k \times N \times T)} - 1} \quad (2)$$

Where, q: electron charge, = 1.6 × 10⁻¹⁹C; V is the voltage across the diode; n_s : 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:

$$I = I_{ph} - I_s \times \left(e^{\frac{q \times (V + R_s \times I)}{N \times k \times T}} - 1 \right) - \frac{V + R_s \times I}{R_{sh}} \quad (3)$$

As a consequence, the whole PV cell physical performance is related to I_{ph} , I_s , R_s , and R_{sh} , 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.

5. Cooled PV combined with RO desalination System

The hybrid system is a system that combines more than one energy source. There are many advantages to combining energy sources in one system, including: increasing reliability and increasing the efficiency of the system as a whole, in addition to compensating for the weaknesses of each

system individually [17]. When combining traditional energy sources with renewable energy, it compensates for times of lack of renewable energy sources, in addition to reducing environmental pollution as a result of using traditional energy sources alone, in addition to improving the performance of the system as a whole [18].

All water desalination systems require one or more energy sources to operate. As previously mentioned, traditional energy sources have a negative impact on the environment, so it was necessary to search for a clean, renewable energy source for desalination plants [19]. For this reason, desalination plants combined with renewable energy sources have become widespread. Solar and wind energy are among the most promising sources globally for use in desalination plants. These sources can supply desalination plants with electricity in remote and desert places far from national electricity networks and areas that need clean water. Recently, these sources have become available with technologies that are cheaper than before and highly efficient.

PV Cooling is sometimes expensive and requires special equipment. On the other hand, in addition to its basic function as a cooling, the output of warm water resulting from cooling can be exploited in RO desalination plants [20]. Figure 1 shows cooled PV driven RO desalination system. Due to the problems of using fossil fuels and their high cost, it affects the economic evaluation of desalination plants that rely on them [21]. Therefore, the continuous trend has been to use renewable energy sources in desalination plants to avoid environmental problems resulting from the use of fossil fuels and traditional energy sources. Using fresh salt water to cool solar panels improves their performance. At the same time, reusing water after cooling the cells as warm water for RO desalination plants also improves the efficiency and productivity of desalination plants [22].

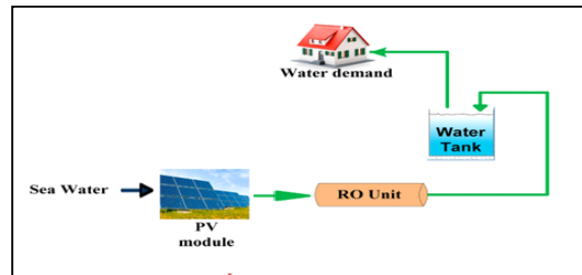


Fig. 1: Cooled PV plant combined with RO desalination system

6. System and Results analysis of cooled PV Panel

The system includes a PV panel with open circuit voltage (V_{oc}) equal to 38.1V at standard test condition (STC) of 25°C temperature and 1000W/m² solar radiation. Cooling is done manually with water, as it is better compared to PCM in terms of heat transfer. Water is poured along the highest edge of the panel and the water flows over it automatically. As shown in figure 2, using water has two benefits, cooling in addition to cleaning the panel from dust, which also affects the panel’s performance. 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. 2: Water cooled PV panel

Cooling was repeated more than once. Each time, both the panel temperature and voltage were measured. Table 1 shows the measurements taken throughout the experiment. The cooling was carried out 5 times, separated by 3 minutes between each time. The ambient temperature at this time was 40°C while the panel temperature was recorded at 64°C before cooling began. The open circuit voltage of the panel before cooling was 32.1 V.

From the measurements in the table 1, and as in Figure 3, the temperature decreases gradually as a result of cooling, and thus the voltage increases. In less than two minutes after cooling, the temperature rises again, affecting the voltage drop. With repeated cooling, the temperature continues to decrease until it reaches the lowest possible temperature at the time of the experiment. It is also clear from the measurements that this happened after the fifth time, as the temperature did not drop below 45°C. This depends on the solar radiation and the ambient temperature at the time of the experiment.

Table 1: Measurements of panel temperature and V_{oc}

Time	Panel Temperature (°C)	V_{oc} (V)	Notes
12:10 PM	64	32.1	before cooling
12:15:00 PM	62	32.3	1st cooling
12:15:20 PM	60	32.6	
12:15:40 PM	58	32.8	
12:16:00 PM	57	33	
12:16:20 PM	55	33.5	
12:16:40 PM	53	34	
12:17:00 PM	52	34.1	
12:17:20 PM	53	34	
12:17:40 PM	54	33.84	
12:18:00 PM	50	34.42	2nd cooling
12:18:25 PM	49	34.56	
12:18:50 PM	48	34.66	
12:19:15 PM	48	34.42	
12:19:40 PM	49	34.32	
12:20:05 PM	50	34.22	
12:20:30 PM	51	34.12	
12:21:00 PM	52	34	3rd cooling
12:21:30 PM	50	34.53	
12:22:00 PM	49	34.65	
12:23:00 PM	48	34.76	
12:24:00 PM	47	34.77	4th cooling
12:25:00 PM	46	34.9	
12:26:00 PM	45	34.95	5th cooling
12:26:30 PM	45	35	

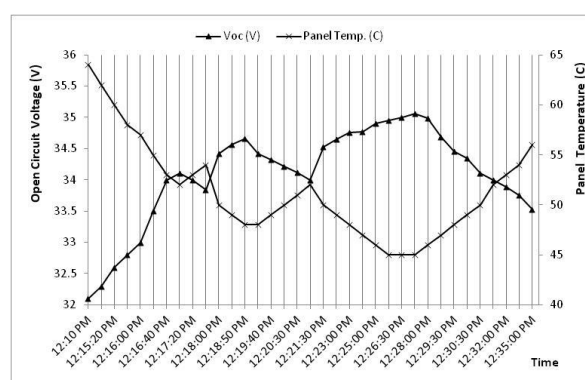


Fig. 3: Panel temperature and V_{oc} vs. the time

Figure 4 shows the direct relationship between temperature and the open circuit voltage 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 35V when it reached a temperature of 45°C, a difference of 19

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.

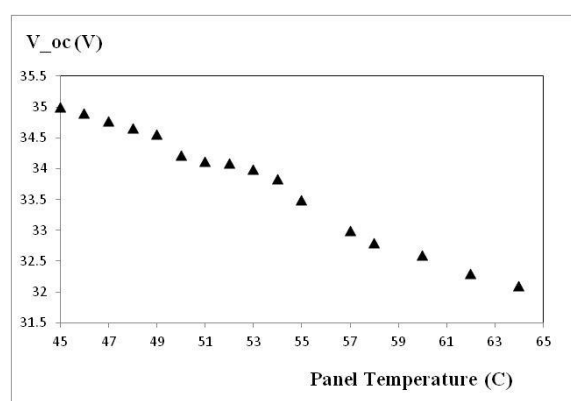


Fig. 4: Effect of panel temperature on V_{oc}

From Figure 4, it is clear that the efficiency of the solar panel is improved by improving the power output. This improvement achieved several advantages. In addition to the fact that it did not cost the solar system if it was integrated with the water desalination system, the performance of the solar system was improved by cooling, which in turn reduced the rate of decay and increased its lifespan. In addition, the brine feed-water entering the desalination system is warmed, which leads to an increase in its productivity.

7. Conclusions

The use of photovoltaic as a means of producing clean electrical energy reduces the consumption of fossil fuels. Desalination technology based on renewable energy has established a new trend by becoming a viable choice for freshwater production. To improve the performance and efficiency of solar cells, they must be cooled using a cooling technology. Among many cooling technologies, this paper reviewed two common techniques. These techniques use water as an active cooling and PCM as a chemical passive cooling. This paper studied the effect of using cooled PV driven RO desalination system. An experimental setup was installed to study the effect of water cooling on the PV output. It was found that the V_{oc} of PV panel enhanced from 32.1 to 35V when the panel temperature decreased by 19°C. The results showed that for PV driven RO, the PV output enhanced by cooling. So, the RO saline feed-water can be used to PV cooling in addition to preheating it to improve the desalination system productivity.

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