Experimental and numerical study on the effect of water cooling on PV panel conversion efficiency

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Abstract

The solar energy is available in a tremendous amounts around the world and the photovoltaic panels might be the solution global power problem. Put the use of PV panels is limited due to the low power conversion ratio. Along with the low conversion rate of the PV panels, its efficiency even drops with the rise of surface working temperature by 0.5% for each degree centigrade. This study investigate experimentally and numerically the effect of front face water cooling on the power production and efficiency. By developing a CFD and experimental module (cooled and conventional panel) for cooling the front face of the PV panel with 8, 6 and 4 LPM of water sprayed by 4 mm nozzle diameter. The results shows an efficiency increase up to 16.2% at 45 ºC ambient temperature compared to a conventional panel works at the same conditions.

Keywords: PV efficiency enhancement, photovoltaic cooling, PV power conversion, solar energy, water film cooling, efficiency enhancement.

1. Introduction

All the known sources of power are either limited or causes too many environmental pollutions, and on the other side it cost, time and effort required to provide it. One of the main problems that affected the power production by photovoltaic panels is the high working temperature due to the high solar radiation and ambient temperature (1). The PV panels designed to work from 0 ºC to 75 ºC with a power drop as shown (figure 1). The P-V diagram represent the Photovoltaic performance corresponding to the working temperature (2). And the P-V
diagram is the relation between the panel voltage drop and the produced power while the solar radiation, ambient temperature and the wind speed kept constant. The maximum power generated by the PV panel starts to drop as the panel surface temperature rises with a 0.5% for each 1 degree centigrade (3).

![Diagram of P–V relationship](image)

Figure 1: P–V represent power as Function of the temperature

1.1 Cooling technique

Cooling the front face with water flow over it is one of the most effective ways for cooling the PV panel. Stefan, Krauter (4) designed and investigated the front face water cooling and the experimental results show that the efficiency enhancement has increased as the working temperature decreased. Also, the cleaning process increased the absorbed radiation by 30% which was prevented by dirt. Also, a study presented by R. Hosseini (5) for cooling the photovoltaic panel with a thin film of water flowing on the front face for both reducing the working temperature and increasing the power output as well as decreasing the reflection effect that reduces the amount of energy absorbed by the photovoltaic panels. Cooling the front face was not the only methodology used for PV water cooling. Spraying water on both front and back faces for the same reason as S. Nizetic (6) presented in his experiment. Study also leads to efficiency increase up to 16.3%. Cooling the PV panels with collectors to extract the excess heat will also decrease the working temperature and increase the power output as the experimental study done by Erzat Erdil (7). For keeping the photovoltaic under a certain temperature the PCM might use as the numerical study done by Pascal Henry Biwole a (8). Using ANSYS software and Navier-Stokes momentum conservation equations to simulate the performance of a cell subjected to a
1000w/m² constant radiation. The results showed that the PV cell surface temperature could be maintain under 40 °C for more than 80 minute. Immersing the photovoltaic panels in water also drops it temperature, but at a certain depth as the study presented by G.M. Tina at al(9). The researcher study both analytically and experimentally the effect of submerging the PV panel in different depth and the evaluated results which shows that the temperature could be dropped from 70 °C to 30 °C and the efficiency increased by 2.5% and reached 15.5% at 4cm and start to drop as the depth increase due to the mirroring effect. Cooling the photovoltaic panels with air as a working fluid is also efficient for dropping the panels temperature and rising its efficiency as well as using the heat extracted in the air for other domestic uses like heating and drying as shown in the study done by Emad A. Sweelem (10) ware he manage to circulate the air around the PV panel by using a small DC fan for keeping a low power consumption. The cooling with air is depend mainly on convection therefor changing the air flow channel depth will change the flow characteristics as well as the thermal performance according to the experimental study done by R. Mazón-Hernández (11) . Along with the experimental studies a computer simulation using CFD software to simulate the air cooling for a PV panel under a 1000 w/m² with 50ºC and 25ºC without the wind speed effect and the study shows that the efficiency could be increased by 1.35% when the air flow rate kept at 8 g/s (12). Also a modified air cooling system is simulated using (ANSES-cfx) to determine the optimum number of air guides as well as the tilting angle and spacing position (13). The study conducted that the optimum air guide number for a 2 meter long PV is 18, positioned 70 mm from the cell base tilted with 45º from the horizon. The main purpose of this study is to develop a cooling system for cooling the front face of the PV panel with water spray and dissipate the excess heat by a water mesh also collocating the optimum flow rate and the time needed for cooling. As well as comparing the results with a normal panel works at the same time and location.

2 Mathematical modeling

2.1 Flow characteristics

In order to obtain the thermal performance for the PV panel to be cooled down and reach the steady state condition at a specific temperature some parameters must be calculated and other must be computationally simulated. As the water flow over PV panel is considered a flow over a flat plate therefor the flow velocity and the flow layer thickness can be calculated based on the Navier- stokes equation.

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + \omega \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \gamma s \sin \theta + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right)
\]

After simplifying the Navier- stokes equation for a flow over a flat plate flowing by the gravitational effect only the velocity magnitude can be calculated by the simplified equation as below.
\[ v = \frac{b^2\gamma h}{12\mu L} \quad \text{m/s.} \quad (1.2) \]

And the flow layer thickness should be obtained from the quantity equation.

\[ Q = Av \quad \text{or} \quad Q = bwv, \quad Q = bwv \frac{b^2\gamma h}{12\mu L} \quad (1.3) \]

And therefore the flow layer thickness can be calculated with the below relation.

\[ b^3 = \frac{12q\mu l}{bw^2h} \quad \text{or} \quad b = \sqrt[3]{\frac{12q\mu l}{bw^2h}} \quad \text{m.} \quad (1.4) \]

The type of the flow above must be identified either it’s a laminar, transient or turbulent. And the flow type will be recognized based on the Reynold’s number.

### 2.2 CFD module

A mathematical module has been developed to investigate the effectiveness of cooling the photovoltaic panel by water flow over the front face with the above calculated flow parameters. The CFD module has been developed using COMSOL Multiphysics 5.3 software with a variable boundary conditions to simulate different type of climate conditions. The computational module test run at a water input temperature of 25ºC, 8 LPM flow rate and 45ºC ambient temperature. The calculation take place with a mesh as shown in the figure 3 and the results shows that the PV panel could be cooled by a water flow of 4, 6 and 8 LPM and the panel surface could reach the study state condition within 3 to 4 minutes as shown in figure 4.

![Figure 2: Over panel flow film dimensions](image1)

![Figure 3: CFD mesh and temperature distribution across the PV cross section](image2)
3 Experimental setup

For experimentally investigate the effect of the water front cooling on the photovoltaic panel electrical and thermal performance an experimental module has been constructed located at Iraq- Najaf (31.97 °N , 44.36º E) . A two polycrystalline photovoltaic panel has been selected to study the effect of cooling on the average, local market available panels. And for study the cooling effect on the panels at the same environmental parameters at the exact time. The experimental module included two panels (modified and conventional) as shown in figure 5. Two panels with a break power of 330 W each and the electrical specifications as listed in the Table (1) below are selected for the study.

Table 1: PV panel specifications

| No; | Properties                          | Discreption                  |
|-----|-------------------------------------|------------------------------|
| 1   | Rated maximum power                 | 330 W +3%                    |
| 2   | Power sorting                       | 0~4.99 W                     |
| 3   | Voltage at P max                    | 37.8 V                       |
| 4   | Current at P max                    | 8.74 A                       |
| 5   | Open-circuit voltage (Voc)          | 46.9 V                       |
| 6   | Short-circuit current (Isc)         | 9.29                         |
| 7   | Maximum system voltage              | DC 1000 V                    |
| 8   | Mechanical load test                | 5400 pa                      |
| 9   | Weight                              | 24 kg                        |
| 10  | Dimensions                          | 1956x992x34 mm               |
| 11  | All technical slandered test conditions | AM=1.5 E=1000 w/m² Tc= 25 °C |
| 12  | Safety application class            | Class A                      |
The cooling system is consisted of water tank for store the cooling water also for heat dissipation. To provide the time needed for the water to dissipate the excess heat collected from the PV panel.

The water mesh is located above the water tank with a distance of 5 cm and work as evaporative part (figure 6 A&B) which contain 218 hole with a diameter of 2mm for water to flow down as droplets for more evaporation cooling down.

For circulate the water in the cooling system a centrifugal pump is used with a (20 W, 2000 LPH and 2.5 m max head) for cover all the required flow rates to be studied. With flow meter of 1 to 18 LPM range is used to measure the exact flow rate at the exact time needed.

A water distributer pipe is used with 20 nozzle to spray the water evenly on the front face of the PV panel with a nozzle diameter of 4mm distributed equally each 5 cm om the 1m long pipe.

The water collector tray is used to collect the water from the PV panel and returned it to the evaporation mish for further cooling.
Figure 6 A&B : the water evaporation mesh

The water pump is fixed on the upper level of the tank for two main reasons first is to reduce the pumping height as well as the pumping power required also, to avoid and dirt suction during the operation. Then the water goes through the water valve and the flow meter for flow rate control and then to the water distributor to spray it over the PV panel for cooling, then the hot water collected in the collected tray and returned to the tank.

3.1 Experimental working procedure

The cooling system has been investigated to study the effect of the excess heating and cooling on the photovoltaic cells performance. The experimental test has been done in the city of Najaf / Iraq (31.97°N, 44.36°E) in the 13th of June 2020 at 1:00 PM to investigate the effect of cooling in the hardest climate in the year so the effectiveness of the cooling system will be useful for the rest of the seasons. The system run at 8, 6 and 4 LPM to study the difference of the flow rate change as the flow rate is the main parameter that controls the pump type and the power consumption. And after calculated the evaporation rate of water it has been found the water losses is about 7.5% of the tank per month. That low water consumption indicate that is the cooling system could be used in the deserts and hot climates.

The power conversion in the polycrystalline panels depends on the type of materials used and manufacturing techniques. After all the exact conversion efficiency can be calculated from the flowing relation.

$$\eta = \frac{P_{\text{max}}}{I A}$$  \hspace{1cm} (1.5)

Where P_{\text{max}} is the maximum power that the panel can deliver at the standard condition. And I is referred to the incidence solar radiation fallen on the cells at the same inclined angle and A is the surface area of the entire panel.
The panel at the standard condition (1000W/m² & 25ºC) was tested and it can provide a 330 W of energy. And as the panel total surface area is (1.948 M²) therefor the panel maximum efficiency is 16.94%. And as the efficiency drops by 0.45%~0.5% for each 1ºC over 25ºC as a working temperature (3). The exact panel efficiency can be calculated based on the surface temperature according to the following relation.

\[
\eta = \eta_{std} (1-0.005(T_{surf} - 25)) \tag{1.6}
\]

The solar radiation is measured using a pyranometer type Tenmars TM-207 mounted on one of the panels to measure the exact amount of solar radiation fallen on the panels according to the sun radiation and panel angles. While the overall temperature of the panel is measured by 6 thermocouples distributed equally on each panel. Also the input, output, and the tank water temperature are all measured and recorded using a 32 channel data logger type Applent (AT-4532x). Also, the wind speed is measured using AM-4206M type anemometer. All the data are recorded on an excel file for further analyzing.

4. Results

The experiments are done on the 13th of June 2020 with an ambient temperature of 42ºC and wind speed of 2.9 m/s for three flow rates 4, 6, and 8 LPM with the same nozzle orifice diameter of 4 mm. The cooling rate is directly proportion with the cooling water flow rates and gathering the recorded data it has been found that the cooling rate for the 8 LPM was the most efficient with a 6 ºC/min. wheal the cooling rate for the 6 and 4 LPM was 5.4 and 5.1 respectively and as shown in (figure 7).

The experimental measurements shows that the panel efficiency drops as the temperature rises and also the opposite. The panel efficiency could be calculated according to the panel temperature and the standard efficiency. And as shown in the (figure 8). The increase in efficiency was from 13.72% to a 16.2% that means a 16.83% increase in total efficiency which is calculated by the relation

\[
\Delta \eta = \frac{\eta_e - \eta_c}{\eta_c} \times 100 \% \tag{1.7}
\]

Where \(\eta_e\) and \(\eta_c\) are the enhanced and conventional efficiencies respectively. The main purpose for design a cooling module is to enhance its power production as well as increasing its working lifetime. The proposed cooling system managed to increase the panel efficiency as well as the power output and as shown in (figure 9) the amount of power increased by the means of cooling. And for calculating the real value of enhancement. The pumping power required for that cooling system must be calculated and subtracting from the increased power. And as the power required for cooling the single pane with a head of 1.1m and flow rate of 8 LPM was 2.31 W as shown on the pump performance curve in figure 10. And by subtracting that from the added
power due to water cooling which is calculated to be 43.3 W. the net useful added power will be 40.99W.

![PV Panel Temperature](image)

**Figure 7:** PV panel surface temperature with and without cooling

![Reduced Power and PV Panel Efficiency](image)

**Figure 8:** the efficiency enhancement Compared with the conventional

**Figure 9:** the power delivered Compared with the conventional
5. Conclusion

The main objective of this research is to study the PV cooling with water film on the front face with the lowest amount of time and energy used. A water spray cooling system has been developed. A computational module has been also developed for estimating the amount of the flow rate and the time needed for reach the steady state condition based on a given parameters for simulating different types of climate along the year. Based on the results of this study it can be concluded that;

1- Cooling and cleaning the photovoltaic panel with the proposed cooling system is efficient.
2- The front water cooling can provide a cooling rate of 6 °C/min. which means that the cooling system will had to operate for three to four minutes to reduce the cell temperature by 24°C.
3- The panel operate with more efficiency when it cooled and reached 16.2% compared to 13.72% without cooling.
4- The power produced by the PV panel increased by 43.3 W compared by the PV panel without cooling.
6. Resources

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