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Photovoltaic Panel Cooling: A Review of Methodologies and Technologies

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Abstract. Energy production using photovoltaic panels seems to be the next promising technology. The only main problem is that the panel's efficiency has a negative relationship with its surface temperature. Moreover, the efficiency drops by 0.5% for each one-degree rising in temperature. In recent years, many attempts have been done to cool the PV panel surface temperature. Different technologies have also been proposed to achieve that purpose .mainly, most of the suggested cooling systems based on the water or air as a working fluid, and the conversion ratio could be enhanced by 22% and 13% when using water and air cooling. Others use Nano-particles to enhance that process, as well as the PCM was also investigated. All these technologies can increase panel efficiency by 3-5%. In this paper, different types of cooling technology are analyzed and categorized.

Keywords: cooling techniques, photovoltaics cells, renewable energy, PV cooling, PV water cooling. PV forced air cooling

1. INTRODUCTION

The majority of world power usage worldwide comes either from fossil or nuclear fuel, which has too many pollutions and environmental harms. Simultaneously, the sun delivers a tremendous amount of energy in the form of solar radiation, wind, and biomass energy. It is promising to be the main source of power as being renewable and sustainable energy.

That energy could be extracted in two forms thermal and electrical energy. The most valuable energy type is the electrical type because it is easy to transmit and transform into work. Moreover, the most efficient method to directly produce electrical energy from solar radiation is photovoltaic cells. However, the PV cells come with a conversion efficiency ranging from 5-20%. That conversion ratio is much more than the ratio in the wind and biomass technologies. However, it decreases dramatically with the rise of the surface temperature ranging from 0.45 to 0.5 % / ºC. for each degree Celsius **[1],** depending on the material used in PV manufacturing. It has been noticed that the high working temperature reduces the lifetime of the photovoltaic panel. Some Cooling mechanisms already have been proposed [2]–[6] .for cooling the PV pane, and the cooling techniques are continuously developing **[7]**. PV panels cooling's main objective is to increase the power output, and the maximum amount of energy that could be gained may reach up to 5%[8].

2. PHOTOVOLTAIC CELLS TYPES

The photovoltaic cell is a device that converts solar radiation into electrical power depending on the Photovoltaic effect phenomena proposed by Edmond Becquerel back in 1839, those phenomena was not used until the 1960s in space applications. Different types of PV cells were developed, and all of them mainly based on silicon semiconductors. The PV cells divided into main groups depending on the fabrication materials.

The monocrystalline photovoltaic cells made from slicing a single cylinder of crystalized silicon. It has the highest efficiency among the other types with a conversion efficiency of 15-17%, at the same time, they are difficult to manufacture and more expensive.

The polycrystalline photovoltaic cells made by cutting an ingot of melted and crystallized silicon. It is generally much easier to manufacture. Therefore, it is a bit cheaper. However, it had a conversion efficiency of 12-15%.

Another type known as the thin-film PV cells. It made from a less efficient alternative material. At the same time, it had a high power to weight ratio. It mainly used in space applications for its lightweight. Moreover, it has a conversion efficiency of around 10%.

3. COOLING TECHNIQUES FOR PV PANEL

Photovoltaic panel cooling may be used for heating, such as the PV/T application as mentioned in [9]. But the main reason for cooling the PV panel is to increase the electrical power output. For extracting the excess heat from the PV panel, a separated cooling system is required. That system construction and maintenance may cost more than the electrical power gained. Therefore, many studies tried to balance between the gained energy and the cooling requirement losses. And based on the cooling systems could be divided into two main technics. Passive, which requires no power to run, and active cooling systems with the help of pumps, fans, extra.

3.1 Active Cooling Systems

All cooling systems that consume power are called active cooling systems. It uses air or water as a working fluid for transferring the excess heat from the PV panel for dissipation using pumps and fans for circulating the fluid. The active cooling systems are more efficient and could help the PV cells to produce more power, but at the same time, it consumes power to maintain the fluid circulation. Therefore, the power consumption to production ratio must be consecrated to get the advantage of the cooling system. Lee et al. [10] investigate the effect of cooling the back of the PV panel using an array of ducts for a uniform air distribution with input and output manifold designed with the help of CFD simulation to determine the shape. The experiment runs with and without the cooling system. The PV cell efficiency ranged from 8-9% without the cooling system while it ranged from 12-14% with the mains of forced air cooling. While a study done with the same methodology could achieve cell efficiency of 13.5% when cooling with 0.74 m^3/s of air passing on the panel back surface and reduce the temperature to about 15 ºC leading to an overall efficiency increase of 2% as in figure 1.

Figure 1. Forced Air - Cooling

Farhana at el [11]. Study the PV cell backside air-cooling. The experiment conducted two PV panels with 0.924 m^2 covered with aluminium casing to form airflow channel, to compare the PV performance with and without forced air-cooling. The experimental results show that airflow with a mass flow rate of 0.035 kg/s managed to reduce the PV back surface temperature by 12 °C, which records a relative efficiency of 8.9%. Z Syafiqah [12] Investigate the effect of both water and air cooling systems, using ANSYS CFX and PSPICE software to simulate the cooling cases for PV panel subjected to radiation 1173 w/m² and the ambient temperature of 36.5C°. The result shows that the maximum surface temperature on the PV panel was 63.5 without cooling, and the temperature drops to 31.3 C°. Also, the temperature difference between the water and the air-cooling was about 12.7 C°. Arcuri [13] uses a special design for a duct made of 1 mm aluminium sheet, wooden frame, and a 3.6 w helical fan. He established an airflow rate of 0.016 kg/s to cool the Polycrystalline panel's back surface and increase its efficiency by 0.6%. Ahmed Mohsin [14] presented a numerical study to investigate the effect of using air guides to enhance the thermal performance in the PV panel air cooling system. It has been found that the optimum number of air guides is 18 displaced 70 mm far from 2 meters long PV panel.

Cooling with water as a working fluid was also efficient and prove that this technology was able to increase the panel output power. Cooling back, front, or both sides are investigated. Hosseini [15] manage to reduce the temperature of the front face of a monocrystalline photovoltaic panel of 0.44 m² by 20 ºC using a 0.25 Hp pump for creating a thin film of water for extracting the excess heat of the PV panel and increasing its overall efficiency by 1%. Concentrating the solar energy to produce more electrical power within a relatively small area using concentrated photovoltaic panels facing the panel-overheating problem. R. Hussein et al. [16] studied the effect of the front face water cooling on the PV panel thermal performance numerically and experimentally. A comparative study on two PV panels was made to compare the experimental results for the same environmental conditions in addition to the numerical simulation. Both numerical and experimental results have agreed that cooling the PV panel with 8 LPM reduces the working temperature and improves conversion efficiency by 22%. Du et al. [17] experimentally investigate the ability to use water for CPV cooling. Using 0.035 PLM of water flowing inside two aluminium pipes, mounted on an aluminium base of a 0.152 m². A CPV with a concentration ratio of 8.5, and he maintained the cell temperature of 60 ºC with an efficiency increase of 0.8%. Another design for PV water cooling is presented by Bahaidarah [18] by developing water pockets on the back of the photovoltaic panel and establishing a water flow inside it for removing the excess heat with a flow rate of 0.06 kg/s using a 0.5 Hp pump. A monocrystalline panel of 1.24 m² is used, and the temperature drop was 10 ºC and that reduction in temperature increase the efficiency by 2.8%.

Dorobantu [19] presented an experimental study to investigate the water cooling system. A front face washing methodology is used to decrease the front and back panel surfaces by 12 and 8 ºC, respectively. The increment in power production was covered the pump losses and an addition of 4 w. In contrast, Moharram [20] uses the time interval method for cooling. He manages to establish a water flow over the front face of the PV with a flow rate of 0.48 kg/s using a one hp pump for Colling and cleaning the panel surface at the same time. By cooling for 5 minutes followed by 15 minutes system off to conserve power, he reduced the temperature with a redaction rate of 2 ºC/min. And improve the total efficiency by 1.5%, as shown in figure 2.

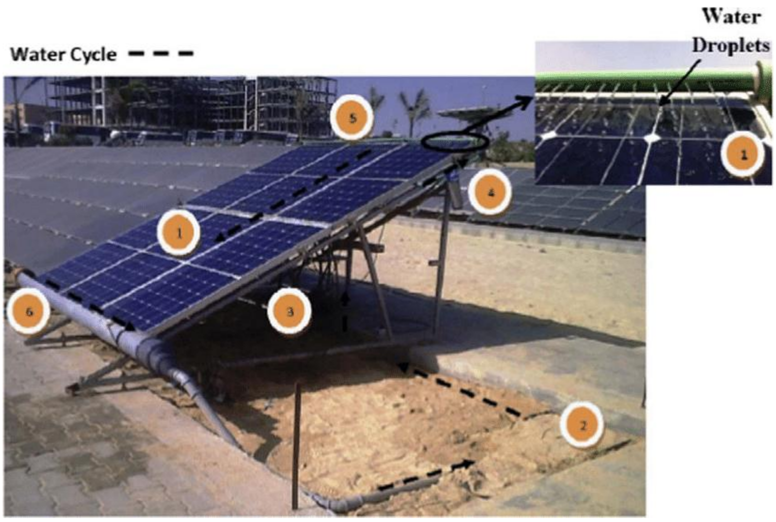

Figure 2. Front Face Water Cooling

1. **PV Panel,**
2. **PV/T System,**
3. **Water Tank,**
4. **Control Valve**
5. **Distribution Pipe,**
6. **Collecting Tray**

Sun et al. [21] investigate using oil as a working fluid, using dimethyl silicone oil with a flow rate ranging from 0.19 to 0.95 kg/s for cooling a concentrated monocrystalline photovoltaic panel with an area of 0.014 m^2 illuminated by 9.5 suns. The cooling system manages to keep the panel temperature between 20 ºC to 30 ºC corresponding to the flow rate and the efficiency ranging between 12.5% to 13.74.

Another study investigates the effect of cooling by water spray over the front face of a concentrated monocrystalline PV using iced water under 2.5 ºC with a flow rate of 0.116 kg/s. The power production was improved by 24% utilizing cooling and concentrating at the same time Smith [8]. Front face water cooling has many benefits for handling the thermal drift of the photovoltaic panels. However, the front cooling water layer reduces the pass radiation to the PV panel due to the optical losses. Tina et al. [22] investigate the effect of optical losses and the thermal draft reduction benefits. The study proves that the front face water cooling is not sufficient for small radiation while the power production improvement Overcomes the optical losses with high radiation. The efficiency increment was 1.2% for higher radiation. A cooling system is also based on the water jet on the front, back, and photovoltaic panel sides. [23]. The electrical power was increased by 16.3% with a total conversion efficiency of 14.1%when applying front and back water jet. The same technique was applied by [24] with a varying flow rate and 0.0625 kg/s, and the efficiency also varied with the flow rate, and it was 14.8 %, 19.1 %, and 20.4 %, respectively. While the same system heat dissipation was described in [25]**.** While M. Abdolzadeh [26] Studied the effect of spraying water on the front face of the photovoltaic panel for both reducing the dust and reflection and reducing the surface temperature to enhance the performance of the photovoltaic pumping systems. The experimental results show a positive effect on total system performance. The efficiency was improved by 12.5%. Salih [27] study the direct effect of spray cooling and power production. Developing a cooling system depending on the jet spray method reduced the surface temperature by 4 degrees, and the power production was enhanced to be 7 w/ºC.

3.2 Passive Cooling System

The main objective of photovoltaic panels cooling is to improve its conversion efficiency to produce more power. The passive methods require no power source there for it eliminate the power consumption. Three major passive cooling techniques are used, water cooling, air cooling, and conductive cooling.

Conductive cooling eventually depends on the air passing naturally. A study presented by Cuce et al. [28] experimentally investigate the effect of using an aluminium heat sink attached to the back of a polycrystalline. The experiment was conducted using two photovoltaic cells under controlled environmental conditions. One PV panel was equipped with aluminium fins connected by a thermal base for increasing the conductivity. The radiation varied from 200 to 800 w/m2. The experimental results showed a relative increase in the conversion efficiency with about 9%.while R. M.Hernandez et al. [29] investigate the effect of using passive air channel under the PV panel. An experiment was conducted using a large PV panel with 1.95 $m^{2,}$ and an air channel with an aspect ratio length-to-depth of 0.085 has a negative effect compared with the regular mount. It raises the PV panel at about 6 °C, proving that not all passive cooling types effectively reduce the PV panel surface temperature. Other researchers investigate the effect of using PCM for reducing the PV panel temperature, using a 65 w PV panel with a 50 mm PCM in the back of the PV panel with aluminium fins to improve the heat transfer between the panel and the PCM. The improved panel was subjected to 1000 w/m² for five hours, and it manage to be 12.5 °C less than the other conventional PV panel with the same specifications while the power output was enhanced by 9.7% [30]. Maiti and others [31] used a v-through reflector to concentrate the solar radiation on a PV panel with 0.133 m^2 and 10 w power output. Using 5.5 PCM mixed with sawdust to reduce the PV panel temperature. The PCM managed to reduces the temperature from 85 °C to 65 °C, and the efficiency was enhanced by 55%.as in figure 3.

Figure 3. PCM Mixed with Sawdust

Using water in passive cooling systems produces more efficient results than air and PCM due to water's high thermal characteristics. Rosa-Clot et al. [32] submerged a PV panel in water in order to reduce its temperature. The submerged panel managed to maintain at a temperature of 30 °C with a relative efficiency of 20%. However, as the solar intensity drops with the depth and exact efficiency of 11% was recorded at 4 cm depth.

3.3 Heat Pipe Cooling

The heat pipe method is a combination of the PCM and convection in a cooling medium. The main principle is that the PCM expands on the hot side of the pipe, absorbing the heat while it condenses on the other side, releasing the heat. As in figure 4.

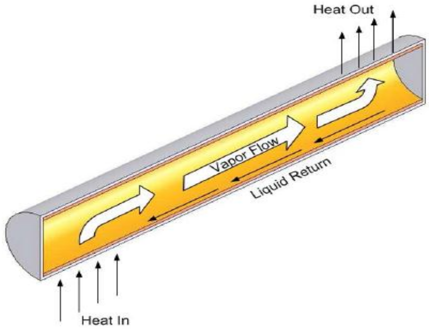

Figure 3. Heat Pipe Cooling

Gang et al. [33] investigate the effect of heat pipes on a PV panel's produced power. The study was done on a PV panel of 1 m^2 with a solar radiation intensity of 800 w/m^2. The heat pipes manage to reduce the PV panel temperature and maintain it stable at 48 °C by circulating 200 L. Tang et al. [34] study the hot pipe cooling experimentally on a 0.0625 m^2, used a heat pipe with the same size as the PV cell, the maximum conversion efficiency increased by 2.6%. At the same time, the temperature increment was only 4.7 °C. Now et al. [35] examine the effect of a set of heat pipes on the backside of a monocrystalline panel of 0.15 m^2. Using water boxes at the condensing side improves the heat pipe cooling by being heat storage for the extracted heat. The backside surface temperature was reduced by 13 °C while the efficiency increased by 6% with 1.2 w of power.

3.4 Nanofluids Cooling

Nano-fluid is a mixture of water and nano-particles. Usually, metal oxides are used, such as Al2O3 or CuO extra. Water and nano-particles are mixed according to a weight percentage ratio, and they are usually ranging from 0.1-3.0 %. Nano-fluids are more efficient than normal water in cooling due to the higher thermal conductivity.

Xu and Kleinstreuer [36] studied the difference of PV panel cooling numerically with normal water and a nano-fluid. The study showed that nano-fluid cooling is much more efficient than water-cooling due to the higher conductivity. The numerical results showed an improvement of 1% of the total efficiency when using nano-particles**.** Karami et al. [37] Cooled a 0.059 m2 polycrystalline PV panel expectantly using Boehmite nano-fluid. Using two different shapes of ducts for cooling the backside of the PV panel. The results proved that even a small amount of nano-fluid could enhance the cooling rates. A 0.1% wt of nano particles with a flow rate of 0.006 kg/s managed to reduce the back surface temperature by 4.5 °C compared to the water-cooled PV panel. The study shows that the cooling rates depends strongly on the nano content and the local flow rate.

Sardarabadi et al. [38] studied two types of silica nano-particles and copper tubes to cool down the backside of a 40 w PV panel of 0.35 m^2. The nano-particles concentration was ranging from 1.0% up to

3.0%. The experimental results show that using 3.0% wt nano-fluid with a 0.011 kg/s flow rate enhances the pre-mentioned PV panel's efficiency by 1.5%.

3.5 Thermoelectric Cooling

Thermoelectric cooling generally depends on the Peltier Phenomena. Peltier Phenomena is that heat energy flows in a certain direction from one side to another side in an electrified junction, creating heating and cooling effects. The amount of heat transferred is strongly related to the voltage/current intensity. Najafi and Woodbury [39] prove that using Peltier elements is not useful for cooling standard PV cells. It may be used just in high concentration PV cells to produce a high amount of power that maintains the cooling system works.

4. CONCLUSIONS

The studies have proven that reducing the Photovoltaic panels' surface temperature directly affects the PV cell performance. In this paper, different PV cooling types have been reviewed and classified according to the cooling methodology. According to the above cooling techniques discussion, some conclusions could be conducted as below.

1- Active cooling techniques are more efficient in reducing the PV panels temperature and improving its electrical performance, and in some cases, the electrical performance was enhanced by 22% utilizing water cooling and 13% using forced air cooling system. However, these techniques have some disadvantages like power consumption, maintenance cost, and the fabrication cost
2- Passive techniques require no maintenance, neither consuming any power to reduce the PV panel temperature. Moreover, in some cases, the passive cooling technique improves the cell performance by 11% using the water submerging.
3- Using a heat pipe for dissipating the excess heat from the PV panel could be an effective way to reduce the PV pane surface temperature, and this technology could improve the PV cell efficiency by 6%.
4- Utilizing the nano-fluids in the PV cell cooling technologies directly affects the PV panel temperature reduction. On the other hand, it requires much power to circulate the nano-fluid with reducing the relative efficiency, and in some cases, it records a 1% improvement.
5- The thermoelectric cooling technique is not useful for standard PV cell cooling due to its high power consumption. However, it may be used in the highly concentrated PV cells for being able to cover the required power.

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