Passive Cooling Module to Improve the Solar Photovoltaic (PV) Performance

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Abstract: - Solar energy is a renewable clean energy. Photovoltaic (PV) cells or solar panels use the sun light as the main source to produce electricity. However, the operating temperature has a significant impact on the PV conversion process and its performance. PV cell technology performance is sensitive to the operating temperature. Increasing cell temperature causes a significant reduction in the output voltage which in turn leads to reducing electrical efficiency. In other words, when the temperature rises, the output current rises exponentially which leads to output voltage to fall. Therefore, PV efficiency decreases. This paper aims to develop a new PV panel passive cooling system that enhances the efficiency of the panel and improves its performance. The design is based on air channels and air chimneys. Overall, cooled solar panels are efficient and cost-effective as their performance is better and their efficiency is higher than the non-cooled solar panels. Our project is designed to serve UAE's 2021 vision (increased dependence on clean energy and green development), reduce pollution in the environment, and save energy for the next generations. The goal of this research is to lower the temperature of the PV panel., therefore, enhancing the efficiency as well as improving the performance by cooling the PV panel. So, It has the potential to alleviate the problem of overheating solar panels.

Key-Words: - Cooling, Energy, Solar, photovoltaic cells, power.

Received: June 24, 2022. Revised: January 2, 2023. Accepted: February 11, 2023. Published: March 1, 2023.

1 Introduction

Renewable energy sources including sunlight are clean, alternative, sustainable energy, and do not run out unlike traditional energy which are available in limited amounts, costly, noneconomic, endangers the environment. Solar power is the energy from the solar energy turned into electricity with no noise, no greenhouse gases, and no pollution making it reliable and long-lasting. Further, solar, or photovoltaic (PV) cells transform sunlight directly into electricity, it is a straightforward way of harvesting the sun's energy, [1], [2], [3], [4].

Electricity has become an essential and indispensable part of our life. As the population increased, the electricity demand increased. Consequently, the rate of burning of conventional fuels increased, which led to an increase in pollution in the atmosphere in addition to the greenhouse gases, [5], [6].

UAE plans to turn into a sustainable country with environmental elements that are clean, healthy, and sustainable. The solar energy system is the most promising renewable energy source since the country has a desert climate and is blessed with plentiful sunlight. Furthermore, it plays a major role in generating electricity as it is used as an additional and a second source of generating electricity in the UAE. According to environment and government agenda "According to Vision 2021 and the national plan, the UAE must generate 27 percent of its energy needs from clean energy sources and cut its per capita greenhouse gas emissions", [7]. Dubai Electricity and Water Authority DEWA have launched the following solar challenge statement "We call for a proposal for a proof-of-concept of a new or significantly improving the existing mechanism/type/materials to bring PV modules' temperatures down".

In the UAE, the weather is extremely hot with temperatures around 45 °C, however, the operating temperature is critical to the efficiency and effectiveness of photovoltaic conversion. When the temperature rises, the output current rises exponentially, causing the output voltage to fall. Therefore, the performance decreases, [8].

Moreover, the cooling of a photovoltaic module topic is one of several problems that faces the performance of PV and needs to be improved. PV cooling may be accomplished using a variety of approaches. Our design can be the most powerful and reliable that could be used to increase the electrical efficiency of the panels.

There are three types of cooling methods as follows: the first one is the universal smart window made of a material that controls the light and heats passing through it. This window is set in 3 modes by applying a small amount of voltage. It is switched into a cool mode to allow the light to pass through the glass and prevent the heat from passing, thereby protecting solar cells from high temperatures and improving their efficiency, [9]. The second is air channel/chimney which is an effective passive solution that utilizes a channel or chimney to force the natural air to pass and circulate through and dissipate the heat, [10]. The third is the radiator which is a heat exchanger that transfers the heat from the fluid inside to the air outside, it controls the temperature used by water flow control and air flow control.

2 Design Concept and Conditions

A passive method is adopted as a new idea to enhance the efficiency as well as to improve the performance by cooling the PV panel. An air channel and chimney method are selected to be utilized for the PV cooling system, which is simple, effective, and cheap. The main idea of our solution depends on the airflow mechanism. Many factors affect air flows such as air temperature, pressure, density, and the area that air flows through. The pressure difference can let the air flow from one area to another from high pressure to low. This factor (pressure difference) is directly proportional to air quantity, when the difference increases, the amount of airflow increases too. When the hot/warm air inside the air channel has lower pressure than the cold air which is outside, the cold air transfers to the air channel. Then, the air rises to the upper level when it becomes warm since it has a lower density than the cold air and increases the positive pressure at the chimney. In positive pressure, the inside air pressure (hot air) has higher pressure which is pushed out of the chimney, [11].

This solution works as the air enters through the air channel and leaves from the chimney which is in the middle of the panel. Hotter air is lighter, so it leaves the solar panel through the chimney. The cold air will remain in and cool the panel. Which will lead to a decrease in the solar panel temperature. Another way to force more hot air to leave the panel is to increase the height of the chimney. The design is selected and evaluated to have a good cooling system with the highest efficiency. Furthermore, it can be improved by having two air channels above and below the PV module instead of one channel for several reasons.

There are some factors to be considered in the design which affect the PV performance such as the rate of air flow, and the position of channels (placed above or under the PV panel). On the other hand, to increase the efficiency, the below air channel could be another entrance for air to cool the PV. It is suggested to have another air channel under the PV with an air flow channel to cool the PV from the below side too. So, the air could be delivered from above, below, or on both sides of a PV. The design consists of one air inlet, one air channel placed above the PV panel, one air chimney, and an air flow channel that is placed under the surface of the panel to reduce the temperature and as a result, increase the efficiency of the panel. Hence, two air channels are placed from both sides, above and under the PV panel as shown in Fig. 1. Adding those two channels reduces the temperature more than installing only one air channel. Thus, the efficiency will be enhanced.

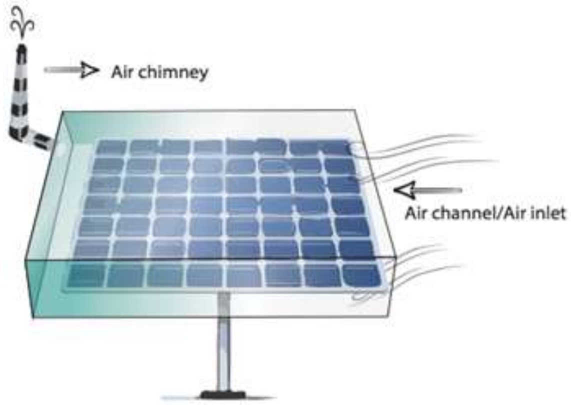

Fig. 1: The design sketch

This passive cooling technique design is mainly based on passive air channels and a chimney and does not need any energy for operation with low cost since only natural air is needed to decrease the temperature of the PV panel which in turn will increase the efficiency. For monitoring and controlling purposes, temperature sensors are used that help to read the temperature of the panel.

The material of the design is very important and should be selected with properties that do not affect the performance or the reliability requirements. In addition, the material should be easy to manufacture and design. A list of criteria is developed for material selection. as follows: cost, availability, weight, and manufacturing. The focus is on the cost and the availability where the selection of the components will be the least cost to make the system cost-effective. For the channel's material, there are two options either to use glass or acrylic. Both materials are transparent and withstand high pressures and can be used for several applications. However, acrylic is chosen so that will not affect the performance of the solar panel and because acrylic weighs less than half that of glass, is not affected by water and air, is stronger than glass and not easily breakable, and is cheaper and easier to deal with and manufacture with better thermal insulation. The transmittance of acrylic is higher than normal glass reaches 92%.

Several experiments were conducted to identify the maximum output power in each case of the non-cooling method and cooling with air and chimney. The electrical properties and characteristics of the tested PV panel are provided by the manufacturer data sheet, [12], and are shown in table 1. While the dimensions of the PV panel are 67×42cm.

Table 1. Electric Parameters of PV, [13].

Parameters	**Units**	**Values**
Maximum power	[W]	60.00
Maximum voltage V_{mp}	[V]	18.1
Maximum current I_m	[A]	3.32
Module efficiency	[%]	17.49
Nominal operating cell temp.	[C]	44.0
Temp. coefficient of Pmax (the decrease in the output for each 1°C increase in temperature)	[%/C]	0.43
Open Circuit Voltage Voc	[V]	22.1
Short Circuit Current Isc	[A]	3.69
Power Tolerance Range	[%]	±3
Weight	[Kg]	3.91
Dimensions	[mm]	630×540×25
All technical data at standard test conditions: Temp. = 25 C		

As the temperature in the UAE is very high in summer and reaches approximately 50°C (assuming the ambient temperature increases to 46°C), the solar panel temperature will be 70°C, [14]. The NOCT is the temperature attained by the panel in the lab when exposed to 800W/m^2 of irradiance (moderate sun) at a temperature of 20°C, [14]. This shows that the temperature of the PV panel is hotter than the ambient temperature by approximately 24°C. This, will affect negatively on the PV panel performance as below:

$$46℃ + 24℃ = 70℃$$
$$70℃ \times 0.43\% = 30.1\%$$
$$panel\,power\,loss = 30.1\% \times 50W = 15.05W$$
Therefore,
$$panel\,power = 50W - 15.05W = 34.95W$$

When adding an air channel and a chimney to the system, the panel power has been affected a lot, where the output reduced by 15.05 W. Hence, to avoid the power losing, an air channel and a chimney were added to the design to increase the efficiency of the design by 2.6% and reduce the PV panel temperature by 4.7°C, [15].

$$70℃ - 4.7℃ = 65.3℃$$
$$65.3℃ \times 0.43\% = 28\%$$
$$panel\,power\,loss = 28\% \times 50W = 14W$$
therefore,
$$panel\,power = 50W - 14W = 36W$$

The height of the chimney plays a role in increasing the produced voltage. By increasing the height of the chimney, the pressure difference between the solar chimney's input and outflow increases hence, the velocity of the air in the solar cooling chimney increases, and more air enters inside the air channel, which reduces the temperature of the PV panel and increases the produced voltage. Therefore, for a temperature of 55°C and the height of the chimney of 0.9 m, the improved PV panel voltage is equal to 0.4 v. While when the height of the chimney is 3 m, the improved PV panel voltage is equal to 0.9 v.

The functionality of this design is tested experimentally. Multiple prototypes have been made, each design consists of two air channels one is placed above the PV and the other under the PV. In addition, there are two different air chimneys used along with each design. In each prototype, one of the chimneys is kept constant in size while varying the other chimney in size and height. An important point to mention is that for each chimney there is a cover. This cover will be used to cover the chimney hole whenever the chimney needs to be eliminated. So, the two prototypes are different in the acrylic thickness of the upper acrylic layer, the number of chimneys used and chimney's height, and the chimney's cross-section area. These variables, parameters and factors that affect the final design and results of the prototype are tested and examined experimentally as will be explained in later sections.

The first prototype (Prototype 1) is designed as shown in Fig 2. It is like an acrylic box that has a thickness of 4 mm for all the sides of the prototype except for the top layer which has a thickness of 2.8 mm. The prototype is open sided from the front for the air inlet. The acrylic box has the following dimensions (66 × 57× 9.5) cm. The upper and lower air gaps between each of the acrylic layers and the PV panel are 3.5 cm, whereas the panel has a height of 2.5 cm. The dimensions of the first chimney 1 is (2×2×20) cm while chimney 2 is (3 ×3×15) cm. The second prototype (Prototype 2) is designed as shown in Fig 3. It is similar to the previous one with the same dimensions (66×57×9.5) cm but differs in thickness and chimney's dimensions. It has a thickness of 4 mm for the whole design. The dimensions of the first chimney 1 is (2×2×20) cm while Chimney 2 is (1×1×10) cm as shown in Fig 3.

A voltmeter is used to measure the volts and an Ammeter, IR laser point infrared gun thermometer is used to measure the PV temperature. A resistance box 1051 (rheostat) is connected as circuit terminals with connecting wires. The PV is adjusted under the sun then after 30 minutes, the temperature measurement of the PV is read using the IR laser point infrared gun. Then the PV panel is connected to the ammeter and the Ammeter is connected to the variable load (rheostat). The voltmeter connected across the variable load (rheostat) where the voltage and current values were registered according to the varying of the load to calculate the output power and then calculate the efficiency.

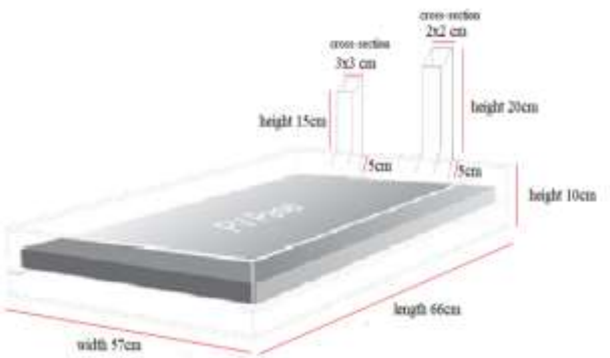

Fig. 2: prototype 1.

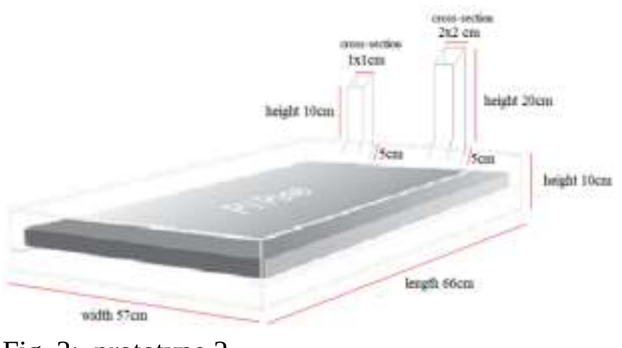

Fig. 3: prototype 2.

The IV characteristic curve of the PV module is used to analyze the PV performance with and without cooling and to study the effect of temperature on the PV panel with variable loads. The first case is PV without cooling. The second is for Prototype 1 and the third cases are tested for prototype 2. The IV curve is obtained to provides the important parameters such as the open-circuit voltage (Voc), the maximum voltage where resistance is infinity and zero current, the short-circuit current (Isc) which is the maximum current where resistance is zero and the voltage across the load is zero, the maximum power point (Pmp) produced by solar cell, and the efficiency (η).

To have accurate results, the experiments were repeated many times and for several days under the same circumstances and conditions, and at the same time (noon) to get the same sun radiation in all cases. The weather temperature is ranging from 38 to 40º Celsius.

Comparing both results it has been noted that the thinner the thickness the higher the output.

Table 2. Thickness comparison

	Thickness 2.8 mm	**Thickness 4mm**
Maximum output power P_{out}	10.7×2.35= 25.54 W	8.66×2.43= 21.04 W
Electrical efficiency	$n = \frac{25.54}{60} \times 100$ 42.56 %	$n = \frac{21.04}{60} \times 100$ 35.0 6%
Temperature	67° - 62° = 5 degrees	58.1° - 55.4° = 2.7degrees

Table 3. Thickness result

Number of chimneys	**Cross sectional area of chimney**	**Thickness of upper layer**	**Max output power**	**Efficiency**
1	2×2 cm^2	2.8 mm	25.54 w	42.6%
		4 mm	21.04 w	35.1%

Number of chimneys used

Both prototypes include two chimneys for cooling purposes. One chimney is fixed and normally open whereas the other chimney is adjustable to be opened and closed easily. The result shows that using two chimneys at the same time for cooling has a positive effect on reducing the temperature of the module as shown in Table 4.

Using a single chimney is not as effective as using two chimneys, this is because by using two opened chimneys, the hot air output is doubled which in turn reduces the PV temperature significantly. Moreover, the output peak power of the PV while using two chimneys is higher than that of a single chimney, thus, greater efficiency was obtained. Consequently, using two chimneys at a time leads to a lower temperature and higher efficiency. The results show that by using two chimneys, the efficiency is higher than that with a single chimney by about 4% and the temperature reduction level of two chimneys is 4 times the reduction level of the single chimney.

Table 4. Number of chimneys comparison

	Single chimney (2×2×10 cm^2)	**Two chimneys**
Maximum output power P_{out}	10.7×2.35= 25.54 W	11.2×2.48= 27.776 W
Electrical efficiency	$n = \frac{25.54}{60} \times 100$ 42.56 %	$n = \frac{27.776}{60} \times 100$ 46.293 %
Temperature	67° - 62° = 5 degrees	67° - 46° = 21 degrees

Cross-sectional area of the chimney:

As the cross-sectional area of the chimney increases, the power increases, the efficiency of the PV increases, and the temperature reduces as shown in Table 5. prototype 1 has the highest cross-sectional area in chimney 2 which is (3×3×15) cm. The maximum power produced by PV in prototype 1 and chimney two is 26.2W, and the PV temperature was 50.4°C. The maximum efficiency achieved is 43.667% Hence, the higher the cross-sectional area of the chimney (in the case of squared shape chimney), the more the temperature reduces.

Table 5. cross sectional area result

	Prototype 1 Chimney 1 (2×2×20) cm	**Prototype 1 Chimney 2 (3×3×15) cm**	**Prototype 2 Chimney 1 (2×2 × 20) cm**	**Prototype 2 Chimney 2 (1×1×10) cm**
Power	25.54	26.2	21.0438	20.038
Temperature	$62°C$	$50.4°C$	$55.4°C$	$56.8°C$
Efficiency	42.567%	43.667 %	35.073%	33.397%

As a result, DEWA or/and other customers can get benefits of our design of (66×57×9.5) cm, 60-watt PV panel with a cost-effective, environmentally friendly, and a unique cooling system that is designed with the optimized materials and components which makes our design a high-quality product also, that withstand the weather conditions in the UAE. See also some relevant ideas and applications of the photovoltaic systems in [16], [17] and [18].

3 Conclusion

A passive cooling technique is designed to decrease the temperature of the PV panel hence increase the efficiency and improve the performance of the PV panel. The design is mainly based on two air chimneys and two air channels to circulate the air motion for the purpose of cooling. One chimney is fixed and normally open whereas the other chimney is adjustable to be opened and closed easily. The effect of different parameters and variables such as the number of chimneys, chimney cross-section area, and acrylic thickness was studied and tested experimentally under the same weather conditions for all prototypes. Then the efficiency, output power, and module temperature were identified. The results are summarized as follows:

1- The thinner the thickness of the upper acrylic layer, the higher the sunlight absorbed by the PV photons. Subsequently, the higher the output power, the higher efficiency. When 2.8 mm acrylic thickness is used, the temperature is reduced by 5 degrees, which is almost twice as compared with 4 mm thickness which is reduced by only 2.7 degrees.

2- Since the temperature is reduced 11 degrees with two chimneys and 5 degrees while using a single/one chimney, it is obvious that two chimneys are more effective in reducing the temperature of the

PV panel, which means a higher output is obtained that will increase the efficiency. The efficiency is higher than that with a single chimney by about 4% and the temperature reduction level of two chimneys is 4 times the reduction level of the single chimney.
3- Based on the Cross-sectional of the chimney, the result shows that the higher the cross-sectional area of the chimney (in the case of a squared shaped chimney), the more the temperature reduces. A higher cross-sectional area of (3×3×15) cm dimensions reduces the temperature from $67°C$ to $50.4°C$ which is about 16.6 degrees.
4- Our design shows the best available solutions, cheaper compared to other solutions, and easier to work with. It helps to increase the efficiency and the performance of the PV panel under some weather conditions.

In conclusion, it is recommended to use two chimneys with a higher cross-section area and a lower acrylic thickness of the channels to achieve better efficiency. Overall, cooled solar panels are efficient and cost-effective as their performance is better and their efficiency is higher than the non-cooled solar panels.

Acknowledgement:
This paper was funded by Internal Research Grant. No. (238421). Students Undergraduate Research Fund (SURF), HCT.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The author contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This paper was funded by Internal Research Grant. No. (238421). Students Undergraduate Research Fund (SURF), HCT.

Conflict of Interest

The author has no conflict of interest to declare that is relevant to the content of this article.

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