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Improving PV Module Efficiency and Power Output by Using Water Film Cooling Technique with MPPT Controller on the PV Panel Front Surface

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ABSTRACT: The operating temperature of the cells may be significantly impacted by the electrical performance of the photovoltaic modules due to the characteristics of the crystalline silicon used in solar panels. This research aims to increase electrical conversion efficiency by reducing the solar cell's temperature. The PV module, which consisted mostly of a small glass channel fixed on the front of the PV panel, was linked to a water-cooling system. A water flow rate of 0.089L/s was used in the experiment. The experimental findings show that convective interaction between the cooling fluid flow and the PV plate's front surface, which is brought on by heat dissipation, increases output power. The module temperature drops by 17° C when the water-cooling method is used. The system's ability to increase the solar panel's output capacity is demonstrated by the approximately 62% improvement in electrical power when compared to the uncoiling state of the panel.

KEYWORD: Pv System; Pumping System; Cooling Method; Maximum Power Point Tracking (Mppt Controller); Matlab Simulink; Fuzzy Logic

1. INTRODUCTION

The primary energy source for human progress and life on Earth is solar energy. In addition to the fact that converting sunlight into heat or electricity is necessary for a variety of uses, a dependable method of storing this energy is also very helpful, as many applications need to store the solar energy harvested to match specific consumption patterns. Without the constant consumption and consequent supply of energy, society cannot exist. The world's requirement for energy is rapidly increasing due to both rapid population growth and technological progress. For this reason, it's critical to use sustainable, affordable, and renewable energy sources in case future energy demands arise. One viable and readily available energy source for addressing long-term problems in the energy crisis is solar energy, among other renewable energy sources. Due to extensive and rigorous research conducted to hasten its development, it is now cost-effective and has become a tool for improving the economic standing of developing nations and sustaining the lives of many impoverished people. Given its superiority over other renewable energy sources in terms of availability, affordability, accessibility, capacity, and efficiency, the solar industry is unquestionably the best choice for meeting future energy demands. The most fascinating and promising energy source is solar energy, which is essential for supplying the growing need for energy and saving the finite supply of fossil fuels. It can be used for a wide range of purposes, including pumping, irrigation, space vehicles, solar home systems, and integrated construction systems.

2. LITERATURE REVIEW

A quickly developing renewable energy technology that turns sunlight directly into electricity is the solar photovoltaic panel. One of the most notable issues facing contemporary photovoltaic technology is the decrease in conversion efficiency that occurs when panel temperature rises. This phenomenon is tightly linked to rising sun intensity and surrounding panel temperatures. Module temperature is a crucial factor for solar energy systems since variations in it have an impact on the systems' efficiency. There are many cooling control systems that provide precise measurements of the solar panel temperature, reducing excess heat that results in energy loss.

This is an assortment of current studies pertaining to the subject matter of the research paper.

Moharram et al. (2013) [1] In desert and dry areas in Egypt, a cooling spray device has been used to reduce the amount of water used to cool solar panels. It developed a cooling model to determine the time it takes for solar panels to cool down to their normal operating temperature 35C°. When the solar panel starts to cool down, they find that the plate produces the highest energy when the plate temperature reaches the maximum permissible temperature (MAT) of 45 C°.

Mehrotra et al. (2014) [2] The solar panel immersion technique was used in a different depth of water and was found at a depth of 6 cm that the efficiency increased 11% and at a depth of 1 cm the efficiency was 17.8%.

Raad A. 2014 [3] Used copper pipes as channels for water flow and heat dissipation from the cold side of the TEM to which the pipes are linked by heat conductive glue to improve the electrical performance of the PV module to counteract the rise in the operating cell temperature. It was observed that before the cooling process, the electrical efficiency does not exceed 8 per cent. The cell temperature decreased at an optimal water flow rate of 0.2 L / s, thereby increasing the electrical efficiency by more than 9.6 percent and achieving a thermal efficiency of 12.3 percent. temperature decreased at an optimal water flow rate of 0.2 L / s, thereby increasing the electrical efficiency by more than 9.6 percent and achieving a thermal efficiency of 12.3 percent.

Yakub et al. (2015) [4] To cool the solar panels from behind, a passive heat exchange system was used based on natural convection, called thermos phonic, which circulates fluid without a mechanical pump. Small amount of sun radiation energy received by the PV surface directly converted into electricity by solar cells, the great remaining value of this energy is transformed into waste heat and this waste heat is extracted by a heat exchanger attached to the back of the panel to extract heat from it. The result showed an increase in electrical and thermal output in a sunny day which reached 11.4% and 41.6% respectively.

Irwan et al. (2015) [5] Investigated PV panel performance using water cooling system. The water panel was flowed over the front surface of PV panel to cool the PV. To generate the irradiance a halogen lamp bulb was used. The results indicated that the decrease in operating temperature increased the PV module's output power. Additionally, the PV panel reduced the reflection of the absorbed solar radiation by using the water flow above its front surface. The experimental results showed that maintaining the operating temperature between 5 and 23 C resulted in a 9-22 percent increase in the PV panel power output.

Rasha Ali (2017) [6] Proposed an increase in the efficiency of the PV panel by designing and implementing a PV solar tracking system that was paired with a cooling system. In this work, Water flow double glazing (WFDG) cooling technique has been used to cool the front surface of the PV module panel in a near loop cooling system where the water flows through an underground heat exchanger to cool the water. In this work, the Taguchi method was used as an optimization method for obtaining the better water mass flow rate and thickness needed to design the (WFDG) cooling system. The average PV temperature reduction was (35 percent) which resulted in an increase in electrical efficiency (16 percent).

Hasan and Sumathy (2017) [7] A cellulose pad have been added to the back surface of the solar panel in order to preserve the state of moisture with water droplets flowing through the cellulose pad. The pad is filled with water constantly. Water evaporation from wet side (pad) has had a signifying impact on performance of the photovoltaic panels. A comparison of the experimental results with and without an evaporative cooling system was made for PV panels and it showed which one has the better effective. The experimental results showed a decrease in the overall solar panel temperature with cooling system, the average daily temperature of the photovoltaic panel decreased by about 10 ° C, resulting in an increase in the performance of the solar panel by around 20.8%.

Fabio Schiro et al. (2017) [8]: Developed method for cooling the PV model by spray water. In the steady-state and dynamic model the cooling behavior of the PV system was investigated. The model is used to calculate the temperature module at fixed ambient parameters, such as wind speed, solar radiation, and ambient temperature. The transient model represented response time of thermal mass of the PV module to external parameters of the ambient. Water nozzles were mounted to the top edge of the PV module at a flow rate of 0.02 L / s.m2 at an angle of 90o to the air. The gap between cooled and non-cooled steady state temperature is within the range 8-24C°.

Duha Adil (2018) [9] used various methods of cooling to improve the performance of the PV module. Heat sink, moist wood wool pad and humid pad together with heat sink were proposed as cooling systems. It was found that the moist wood wool cooling system, whether used alone or in combination with a heat sink, gives the PV module the highest thermal and electrical performance improvements. The electrical output of the PV panel with the use (rear, front, and both) of the cooling chamber is improved by 9.1%, 13.04%, and 14.20% respectively.

Mah et al. (2019) [10] in a tropical climate site, a retrofitted rooftop PV system with water-film cooling was installed on the front surface of the solar panels. Quality improvement of 15 percent was found.As can be seen from the preceding sections, the majority of the published studies employed various techniques to increase the electrical efficiency and cool solar panels. This study aims to examine, using experimental means, the impact that water flow directed in front of a photovoltaic panel has on the panel's performance and output power. The panel is intended to be inexpensive and efficient.

3. A SOLAR PHOTOVOLTAIC (PV) PANEL

is an apparatus capable of directly converting solar energy into electricity. But the thermal energy that builds up in PV panels will always cause the temperature to rise, which will lower the already low efficiency of the panels. The amount of light that the semiconductors receive determines how much power they produce. In general, photovoltaic systems are thought to be costly ways to generate electricity. The installation of a novel and more ecologically friendly power supply system is greatly attracted to the photovoltaic system. Semiconductors in solid materials have a high efficiency in converting solar energy into electrical energy, and almost all photovoltaic devices have a P-N junction in a semiconductor across which the photovoltaic voltage is developed. The photovoltaic effect can be produced in solid, liquid, and gaseous materials. Another name for these gadgets is solar cells. Solar cells are bundled into modules for practical usage, and depending on the application, these modules may be connected in parallel or series, though series connections are more common in the commercial world. The module provides a higher voltage than a single cell while shielding the solar cells from the environment. Additionally, modules frequently include a structure that facilitates handling and transit. The DC current produced by the module is usually converted into AC current by an inverter, which is an electronic device. This allows the electricity to be used in electrical devices or stored in batteries.

4. FACTORS INFLUENCING ON PV PANELS

The degradation of solar panels' effectiveness is mostly caused by a number of variables, including the climatic and ambient conditions, improper handling of the panels during transit and deployment, and the location of installation and maintenance. Even though the field of photovoltaic systems has advanced significantly over the past few decades, designers are still confronted with a substantial difficulty related to the impact of climate conditions on the efficiency of PV systems. The PV module performs significantly worse in outside operations than it does in controlled laboratory settings. Significant meteorological factors that impact the output of photovoltaic modules are temperature, solar radiation, dust, wind direction and speed, and relative humidity. Generally speaking, air temperature and solar radiation influence PV power output more than wind speed and humidity do. The most challenging impediments that lower PV module efficiency are temperature and dust. The excessively high ambient temperatures and solar radiation cause photovoltaic panels to overheat during operation. Panel performance is drastically decreased by overheating.

5. COOLING METHODS

The main cause of PV heating is solar energy that is absorbed but not transformed into electricity. An essential component of solar cell operation and design is cooling in PV panels. The cooling procedure ought to be designed to maintain the lowest possible cell temperature with a uniform distribution. Many cooling methods have been tested, most of them were based on air and water cooling. These days, one of the most often used techniques for cooling solar panels is the hybrid photovoltaic/thermal (PV/T) solar system. A cooling system and solar photovoltaic panels make up the hybrid system. Warm water or air that exits the PV panels can be used for home purposes like heating since the cooling agent, which is water or air, is circulated around the panels to cool the solar cells. It has been discovered that utilizing water as a coolant works better than using air. Therefore, the goal of this research is to develop a water-based cooling system that uses the least amount of energy and water possible to address the overheating issue with solar cells. Many cooling methods have been tested, most of them were based on air and water cooling. In cooling systems, the cooling approaches are divided into two categories: active cooling systems and passive cooling systems. Systems for removing and reducing heat absorption from PV plates that don't require extra electricity are known as passive cooling systems. Heat is transferred from the location of production to the atmosphere during the process. There are many different passive cooling techniques. Some of the more straightforward ones involve applying metal solids with high thermal conductivity, such as copper and aluminum, or using fins or other extruded surfaces to facilitate the transfer of heat to the atmosphere. The more sophisticated systems make use of heat pipes that efficiently transfer heat through a boiling-condensation cycle, phase-change materials (PCMs), and other natural circulation systems. On the other hand, active cooling systems use devices that remove heat, such as water pumps or ventilators that force air into the panels to remove heat. These systems work by utilizing energy to transmit heat in a variety of ways, most often by conduction and convection. Even though they demand more energy to operate, active systems are typically employed when the efficiency of the panels outweighs the energy needed to power the apparatus. When there are additional benefits, such as when waste heat recovery is needed to heat domestic water, these devices can also be utilized. Air and water are the most often used cooling media in both active and passive cooling systems. One of the most important techniques for cooling solar modules is water-cooling. The air is less effective as a refrigerant due to its thermal characteristics.

1. Construct a PVT panel system to produce both electrical and thermal power.
2. Solar cooling system production and evaluation.
3. Conducting experimental research on the electrical and thermal characteristics for the operation of cooling and solar systems

6. ANALYTICAL THEORY

6.1 Electrical Efficiency

$$\boldsymbol{PM = VMIM} \quad \textbf{(1)}$$

The electrical efficiency (ηe) of the solar PV module is an important criterion for the performance of the PV module, the ratio of the maximum output of electrical power provided by the PV module to the solar radiation product by module area, as Eq.

$$\boldsymbol{\eta = \frac{M}{AcG}} \quad \textbf{(2)}$$

6.2 Useful Gain of Thermal Energy

Useful energy gain that is carried away by fluid
in the glass channel of the PV/T system can be represented by the following equation

$$Qu = MCp(Tfo - \mathrm{Tfi}) \quad (3)\ [11]$$

Where:

Q: is heat transfer rate (J/s).
ṁ: is mass flow rate in the glass channel of PV/T system (kg/s).
Cp: is heat capacity of working fluid (J/kg. C°).

6.3 Thermal Efficiency and Overall Thermal Efficiency

The thermal efficiency of the PV/T system is described as follows.[12]

$$\eta th = Qu/GAc$$

The thermal efficiency is calculated by equation [12]

$$\eta th = \frac{\dot{m}Cp\ (To\ - T_i)}{A_c\ G}$$

where:
ηth: is the thermal efficiency.
M: is mass flow rate (kg/s).
Cp: is heat capacity of working fluid (J/kg.C°)
To and Ti: inlet and outlet temperatures of working fluid.
AC: Area of PV panel.
While the overall thermal efficiency is:

$$\eta overall = \eta th + \eta e$$

The design parameters of photovoltaic thermal (PV/T) water collector are given in Table 1, and the PV panel parameters are shown in table 2.

Design parameters of photovoltaic panel and glass channel

Layer	Thickness ,L (m)	Thermal conductivity k, (W/mK)	Absorptivity (α) and Transmittance, (τg)	Emissivity (ε)
Glass	L_g = 0.0032	K_g = 1.0	αglass= 0.05 & τg = 0.95	0.91
EVA1	L_{VA} = 500 * 10-6	K_{VA} = 0.35		
Cell	L_{cell} = 180*10-6	K = 148	αc =0.85	0.9
Tedlar	L_t = 0.0001	K_t = 0.2	0.5	

Photovoltaic panel parameter specifications, at STC

Model	TTN-P 50 W
Open circuit voltage(Voc)	21 V
Peak voltage (Vm)	17.7V
Short circuit current (Isc)	3.039A
Peak current (Im)	2.8 A
Maximum power (Pm)	50 W
Module efficiency (ηo)	12.8%
Module area (*Ap*)	0.378m²
The packing factor (*PF*)	92

7-Theoretical work:

Using BI Controller, the theoretical part of the experiment was designed by the MATLAB program, where we were able to control the tank, which is part of the cooling hypnotic and is related to the solar system. Due to the results, the system was able to reduce the temperature and increase efficiency, and the design was done using pole placement and looking at the results obtained from the MATLAB, we note the decrease in the temperature of the board and increase the **efficiency and thus increase the output of current and voltage. On the other hand, the experimental results from the laboratory experiment prove the success of the operation.**

MATLAB simulation:

the sensor was added to the PV system to track the temperature on the surface of the PV panel to detect when the temperature is higher than 50 ℃ ,in ths case the cooling system starts to operate until the temperature reaches 25 degree. Finally, the simulation shown Fig (8-1) shows the circuit of the PV panel connected with the MPTT and the water tank.

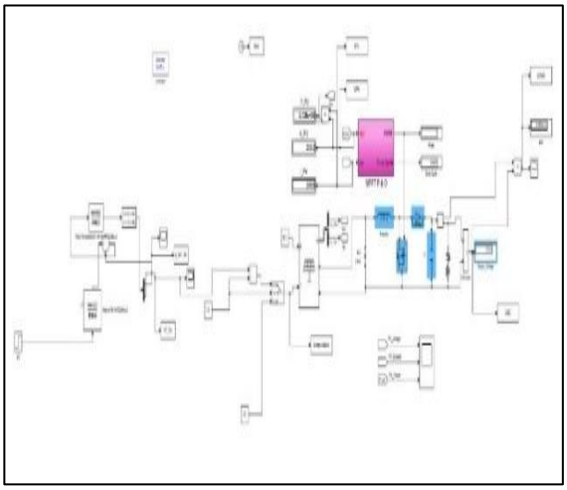
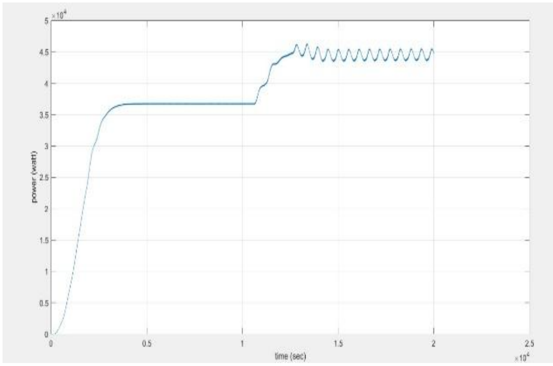
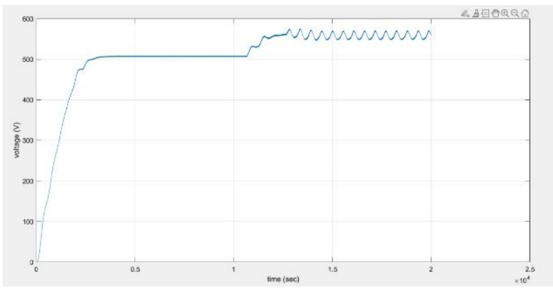


Fig (7-1)

When operate this circuit, it will give reading for the output power and shows the enhancement during the cooling process. The output power will increase until it remains constant.

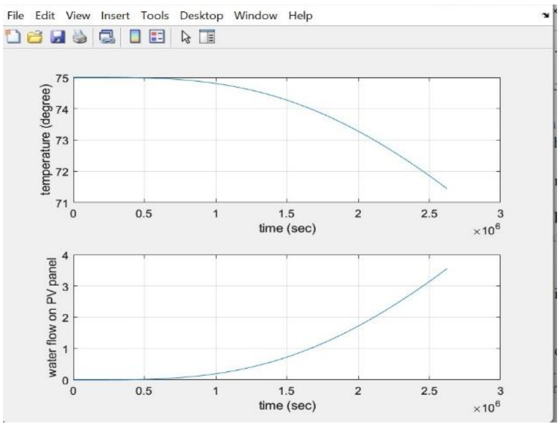


Fig(7-2) power –time chart



Fig(7-3) voltage –time chart.

The enhancement of the output power means the output voltage and current will also enhance as shown in Fig(7-2) and fig (7-3).



Fig(7-4) this figure shows the temperature decrease as the water flow increase on the surface of the panel ,The flow rate stay constant on 4(ml/s) until the temperature drop

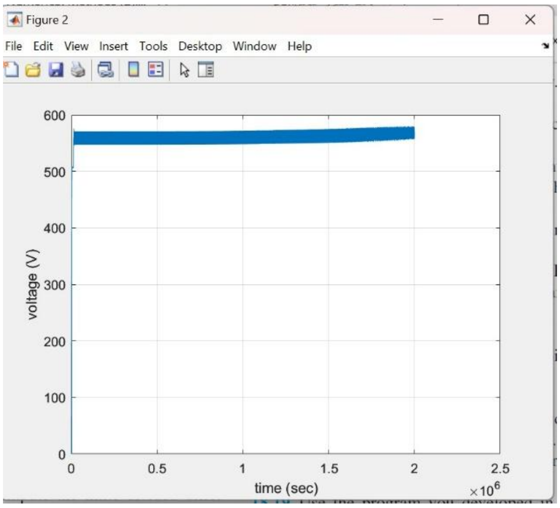
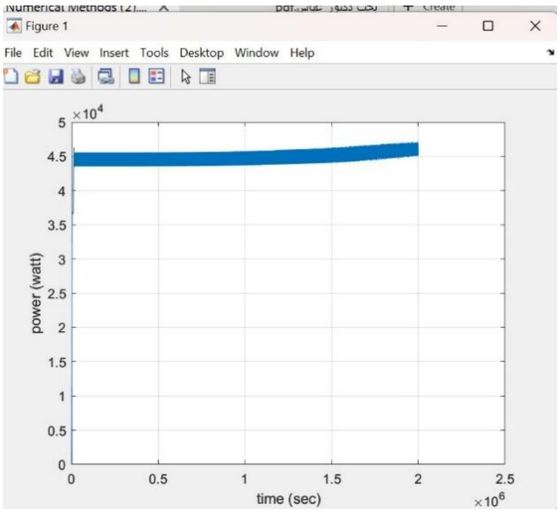


fig (7-5)



Fig(7-6)

Fig (7-5) and fig (7-6) shows the voltage and the power performance as numbers

8. *EXPERIMENTAL SETUP*

The following section explains the PV/T system prototype. All experimental investigations of the effects of heat and electricity on system performance, as well as recommended enhancements, are conducted using a water cooling system. The PV panel, load, perforated plastic pipes mounted on the front edge of the panel's upper edge, and a water circulation pump make up the configuration.

Fig. (8-1) Shows the schematic depiction of the supplied water pumping system and the suggested PV/T system. The PV/T system's overall experimental configuration. In Fig(8-2), a supplied water pumping system is displayed.

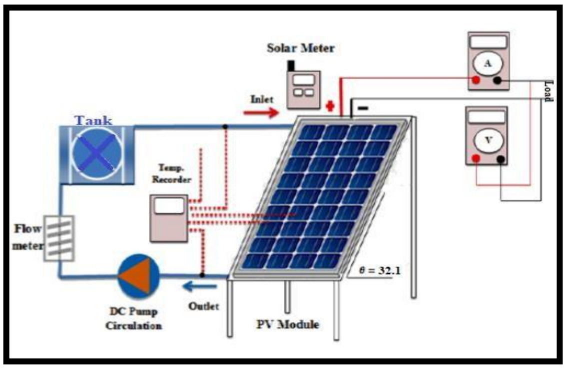


Figure (8-1) The schematic representation of the proposed PV/T system

Figure (8-2): The overall experimental setup of PV/T system and supplied water pumping system.

9. PV WATER PUMPING SYSTEM

In this experiment, we used a monocrystalline panel that has a constant water layer pouring on its working surface to cool it. In addition to cooling the panel, this system's benefits include the ability to remove dust or dry leaves from the panel's surface and the reduction of radiation reflectivity (water's refractive index is 1.3, which is in the middle of glass's value of 1.5 and air's at 1.0). This PV panel's technical specifications are displayed in table (9.1). The design of a PV/T hot water collector system makes it suitable for use with existing equipment. Water cooling systems are among the most straightforward and ideal for solar energy applications. The system used in this work consists of an AC water pump, load, tank, and photovoltaic (PV) module. Direct current (DC) electricity produced by the photovoltaic (PV) panel is the main element of the experiment setup. As seen in figure (9.2), TTN-P PV panels composed of monocrystalline semiconductors have been used in this work. The PV panel's maximum power output under Standard Test Conditions (STC) was 50 Watts.

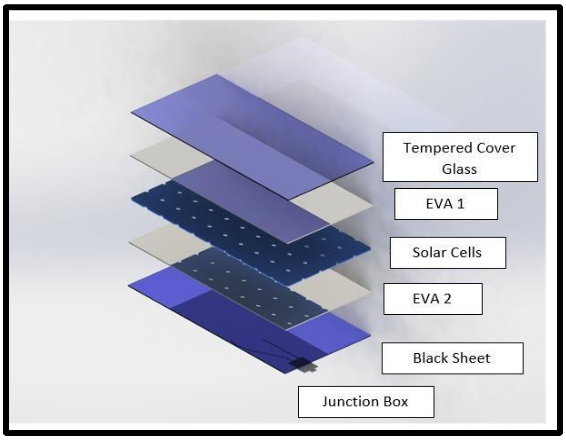


Figure (9.1): The PV panel layers.

To deliver water to a small glass channel, the pump is attached to the water tank. The cooling system design includes a horizontal plastic tube with a diameter of 25 mm that is positioned at the upper edge of the module's active surface. Figure (9.2) shows a line of holes with a diameter of 3 mm and an 8 mm pitch. Because of this arrangement, water was able to trickle out of the tube at a steady flow rate (4 Ipm), covering the active surface of the module in a homogenous layer. Thermal contact resistance is reduced when the cooling water comes into direct touch with the module surface. Water spraying across the module front to cool it theoretically, cooling via a water film running across the front of the module should enable operation at even lower temperatures than the device mentioned above: The water's rapid flow means that the temperature rise should be kept to a minimum. Furthermore, the water evaporating should lower temperatures even more, increasing electrical yields. A perforated pipe was affixed to the upper edge of the PV panel in order to feed cooling water inside the channel. As the hot water exits the tube at its lower

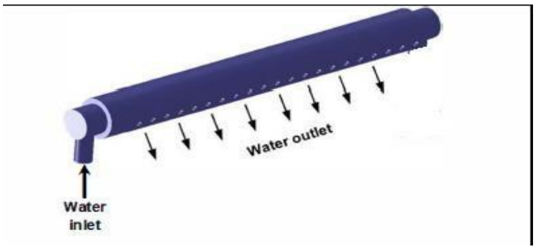


Figure (9.2): perforated supply pipe

10. EXPERIMENTAL MEASUREMENTS EQUIPMENT

Parameters that must be measured for the experimental work include the following: solar radiation (G), flow rate (Q), ambient temperature (Tam), intake and outlet water temperatures (Ti, To), and the current and voltage of the PV panel (power). These measuring tools and gadgets are part of the experimental setup.

Figure (10.1): Flowrate meter

Fig. (10.2): Multimeter device

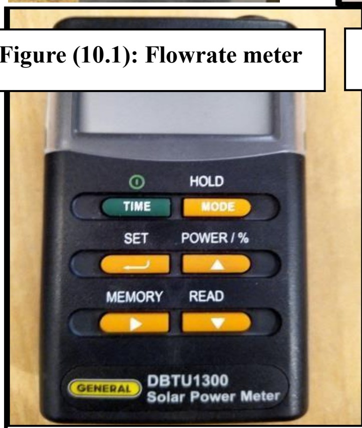


Figure (10.3) : digital solar-meter

Figure (10.4) Digital thermo-meter

10.1 Solar Meter measurement

The Solar Power Meter Type TES 1333R is used to measure the variation in solar radiation. The accuracy was within ±10 W/m2 and a resolution of 0.1 W/m2.it positioned on the panel's plane. the digital solar meter shown in Figure (10.3)

10.2 Temperature Measurements

The next step is to use a digital thermometer to measure the temperature at various locations. Different sites are equipped with six thermocouples (K-Type) for temperature measurement. On the front side of the PV panel, three thermocouples are located. The temperatures of the cooling fluid at the cooling fluid's inlet and exit are measured by the other three thermocouples. Measurements are also taken of the uncooled panel's front surface. the device showed at fig (10.4)

10.3 Flow Rate Measurements

Using a flow rate meter, the mass flow rate of the working fluid employed in this project was determined. As seen in Figure (10.1), it has been utilized to measure the water flow rate in the PV/T collector. The accuracy of the flow rate meter is 4% at full scale, and its range is 0.5–4 l/min. as showed in Figure (10.1): Flow rate meter

10.4 Digital Multimeter

Digital multimeter type (Excel DT-9205A) as illustrated in Figure (10.2) is used to measure maximum current (Imp) and maximum voltage (Vmp) .

10.5. Test Steps

1. Every PV panel was oriented southward and inclined at a 31.2-degree angle.
2. It is established that the water flow rate is 4 Lpm.
3. Attaching the solar modules to the multimeter equipment.
4. Using a solar power meter to measure solar radiation every 30 minutes.
5. Monitoring the ambient, inlet/outlet water, and two PV panel temperatures every 30 minutes.

11. PRACTICAL RESULTS

11.1 Ambient Conditions

Efficiency of the solar panel is affected by a number of factors. These variables include the ambient temperature as well as the direction, angle, and solar radiation. Given that the slanted angle is fixed at 32.1° and the direction is fixed to the south, the primary influencing factors that affect the photovoltaic system's ability to generate energy are temperature and solar radiation. The sun radiation and ambient temperature on May 15, 2021, are displayed in Figures (11.1). Figure (11.1) illustrates how solar radiation gradually rises over time before beginning to fall. This chart also displays additional climatic conditions.

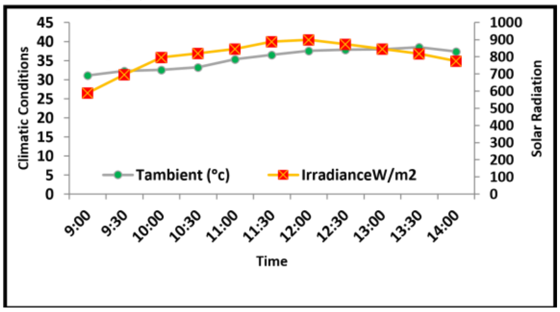


Figure (11.1): Climatic Conditions

11.2 Effect of cooling process on performance of PV/T system

The solar cell's electrical output is greatly impacted by its high temperature. The solar panels can be cooled to overcome this issue. The PV module's cooling process causes its temperature to drop, which improves the module's performance.

11.3 Electrical Performance

The cooling of solar cells affects the electrical performance of the PV module. In the current study, this leads to an increase in the electrical productivity of the panel due to a temperature decrease brought on by the thin water layer flows on the PV panel.

As the standard panels operational time increases, its temperature rises and its productivity is impacted. In contrast, the cooling panel's production rises as a result of both the direct water-cooling process and the evaporative cooling process. As seen in the following image, another advantage of this cooling method is the efficient production of hot waters.

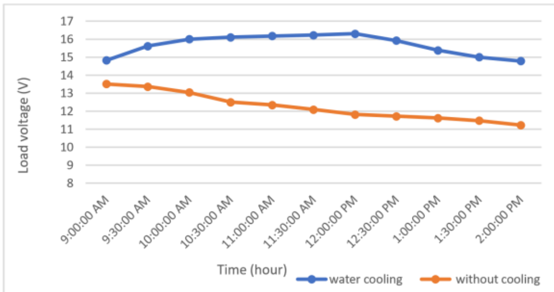
The impact of cooling on load voltage and load amp at constant water flow rates (4 l/m) is depicted in Figures (11.2) and (11.3). There is a 27% and 29% increase in load voltage and load ampere, respectively. Only 15% of the solar light is absorbed by the solar cells; the remaining 15% is converted to heat, which raises the temperature of the cell. Because of this, as solar radiation increases, the voltage drops. The output power and electrical efficiency for panels without water cooling and panels with a 40% and 62% improvement, respectively, are displayed in Figures (11.4) and (11.5).

11.4 Thermal Performance

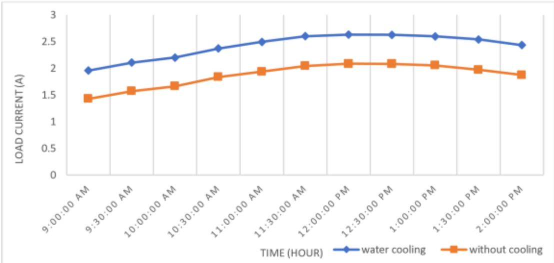
The temperature of the panels is shown over time in Figure (11.6). The maximum temperature of the PV panel was measured at 66.89 C°, which was its greatest temperature prior to cooling. Even yet, with water cooling, the cooling PV panel's maximum temperature was 42 ℃. The average temperature has increased by almost 16.5 ℃ . It is clear from Figure (11.7) that usable heat has a mean value of 230 W and rises as solar radiation intensity rises.

The cooling panel's thermal efficiency is displayed in Figure (11.8) when solar radiation is at its highest, from 9 a.m. to 2:00 p.m., it is evident that efficiency is constantly rising. At 2:00 PM, the estimated thermal efficiency was 36%, and the average mass flow was 4 liters per meter. The water's temperature drop during evaporation placed a restriction on the amount of thermal efficiency improvement.

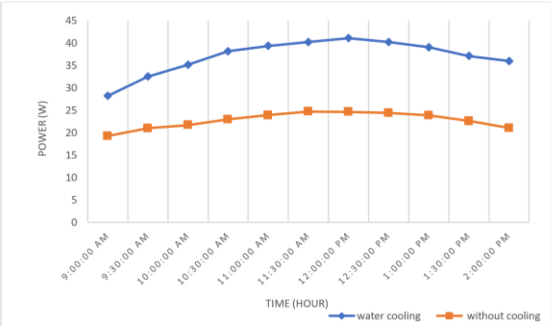
As seen in Figure (11.9), which shows the total efficiency, the decrease in PV surface temperature had improved the PVT device thermal output till noon and electrical and thermal output after midday.



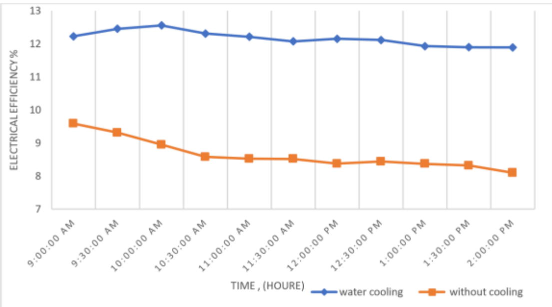
Figures (11.2): Comparison between load voltages at different operation conditions



Figures (11.3): Comparison between load current at different operation conditions



Figures (11.4): Output power compares



Figures (11.5): Electrical efficiency comparison

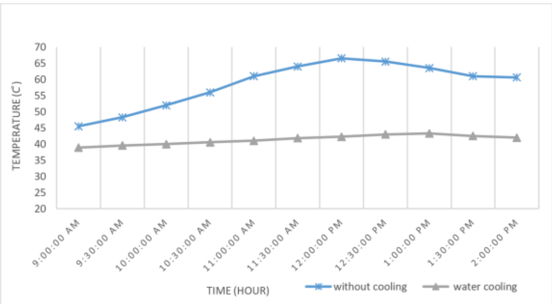


Figure (11.6): Temperatures of PV panels

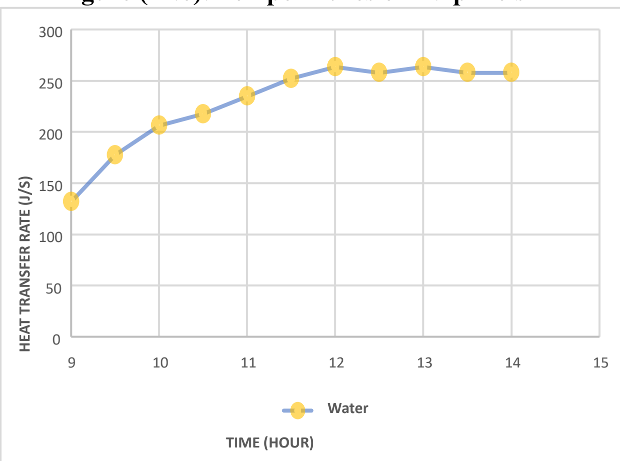


Figure (11.7): heat transfer to the cooing fluid (water)

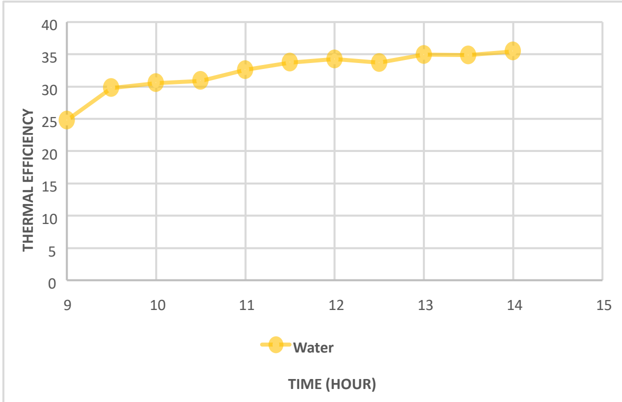


Figure (11.8): Thermal efficiency of cooling process

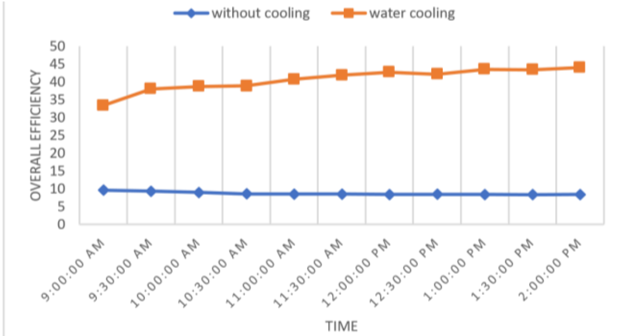


Figure (11.9): Overall efficiency of cooling process and uncooled panel

12. CONCLUSION

1. The main ideas of the paper can be summed up as follows:
2. Power was also decreased in tandem with a decrease in radiation. Radiation is the primary factor influencing the PV panel's ability to produce electricity. The generation of PV-modulated power is inversely proportional to rising cell temperature. The power reduces as the temperature rises.
3. Although solar radiation is an uncontrollable natural source, the module's output can be enhanced by lowering the daytime temperature.
4. By lowering the PV module's working temperature to a certain point, the cooling approach is the most effective way to increase electrical efficiency. However, the current cooling method maintains the PV module's performance at low temperatures by using an integrated hot water production system in conjunction with a cooling system to cool the module's front surface.

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