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Research Article

Changes in the Electrical Output Power and Efficiency of a Photovoltaic Panel Cooled by a Hybrid Method

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ABSTRACT

This study examines two cooling methods for photovoltaic panels to counteract efficiency loss due to high temperatures and radiation. The first method employed active cooling with water, while the second combined active and passive cooling using an aluminum heat sink with water as the medium. Three identical 100 W monocrystalline photovoltaic panels were analyzed, with one serving as the reference. The second panel utilized active cooling with transformer oil in a liquid reservoir and copper pipes, covered by a thin metal plate. The third panel, prepared for the hybrid method, featured a similar setup but with a rectangular finned aluminum heat sink. Transformer oil was used in both methods for insulation and thermal conduction. The copper pipes, connected to a radiator and pump, formed a closed circuit for water circulation. The experiment measured temperature and liquid flow using various sensors. The data showed that the hybrid method increased electrical power and efficiency by 4.7% and 0.84%, respectively, compared to 2.94% and 0.52% in the active method. The study's energy consumption was powered by wind energy.

1. INTRODUCTION

The interest in renewable energy sources has increased due to the rapid depletion of conventional energy sources, environmental concerns, and energy security issues. Solar energy emerges as a significant energy source due to its unlimited and clean nature [1]. Photovoltaic (PV) technology offers several advantages, including various power options, low operational and installation costs, and lower maintenance costs compared to other renewable energy technologies. However, PV systems are adversely affected by factors such as shading, hail, humidity, dust accumulation, and heating.

Factors like wind speed, ambient temperature, relative humidity, dust accumulation, and solar radiation affect the surface temperature of PV panels. Due to the increase in temperature, PV cells cannot convert all solar energy into electrical energy. To adhere to the law of energy conservation, the remaining solar energy is converted into heat [2]. The heating of PV cells increases the current while decreasing the voltage, resulting in decreased output power and electrical efficiency [3]. Additionally, non-uniform heating in PV panels can lead to hotspots due to uneven temperature distribution. This condition can cause damage to the PV panel, reducing its lifespan and safety [4,5].

Solar energy systems can be categorized into three main groups: solar thermal systems, solar PV systems, and combined photovoltaic/thermal (PV/T) systems [6]. In PV systems, efforts are made to increase electrical power and efficiency, while PV/T systems also aim to harvest thermal energy in addition to electricity. Studies have shown that, despite higher cell temperatures in PV/T systems, they produce more electricity compared to traditional PV systems. Therefore, improving the physical properties of materials and integrating PV and thermal systems can enhance electrical efficiency [7].

PV panels can overheat due to factors such as high ambient temperatures, intense sunlight exposure, and partial shading, leading to hotspots and reduced energy efficiency. Continuous heating of PV cells over extended periods can also shorten their operational lifespan [5,8].

Various cooling techniques have been developed to address the overheating issues of photovoltaic panels. Active cooling methods involve using energy to cool panels with air, water, or nanofluids. This process employs fans for air cooling and pumps for water or nanofluid cooling. Passive cooling, on the other hand, is an energy-free method. Passive cooling methods can include passive air cooling, passive water cooling, and conductive cooling [5]. Additionally, liquid immersion cooling, phase change materials (PCM) cooling [9,10], Peltierbased thermoelectric cooling, and microchannel evaporative foils have been used as different approaches [2,11,13].

Air cooling methods can be both active and passive, with some cooling techniques involving no energy consumption. Increasing the air gap behind the panel or attaching finned metal materials to the back surface of the panel can provide cooling without energy consumption [14]. In addition, in some cooling methods, a reservoir created on the back of the panel with aluminum fins is used to transfer heat from the panel to a liquid, and this liquid is circulated to provide cooling through a high-surface-area element. The use of nanofluids has been prevalent in recent PV panel cooling studies [8,15,18]. However, the cooling capacity of nanofluids depends on the appropriate mixture of nanoparticles and base fluids, and over time, the efficiency of the cooled panel decreases, negatively affecting its lifespan [5]. Studies have also explored cooling methods involving fans with various structures and air blowing [13,14,21].

Liquid cooling methods include forced water circulation, water spraying, liquid immersion cooling, and combinations of water and air spraying [2,11,22]. Additionally, simultaneous application of water spraying and air blowing has been tested in some methods [23].

Power transformers are used in power generation, transmission, and distribution systems, where voltage levels are changed. They operate at high power levels and can heat up. Transformer oils are used as cooling fluids in transformers. In addition to having high electrical insulation properties, transformer oils also possess reasonably good thermal conductivity properties. The thermal conductivity of transformer oils ranges from approximately 0.13 to 0.17 (W/m K) at temperatures around 20°C [24].

In this study, two different setups were created. In the first setup, active cooling was achieved by passing copper pipes through a reservoir filled with transformer oil, located behind the panel and sealed with a metal plate. The copper pipes were connected to an automotive radiator for heat dissipation. In the second setup, aluminum heat sinks with a rectangular geometry replaced the metal plate in the same configuration. In the first panel, the performance of active cooling was measured, while in the second study, the effect of aluminum fins was also evaluated. PV panel performance analysis was conducted based on electrical power increase and electrical efficiency increase. All measurements in the experiment were automated using sensors. Values such as solar radiation, wind speed, ambient temperature, liquid temperatures, surface temperatures, humidity, radiation, and water flow rate were automatically measured and recorded using suitable sensors.

2. MATERIALS AND METHODS

2.1. Experiment Setup

The experiment setup was installed on the terrace of the Technical Sciences Vocational School building at Dicle University, Diyarbakır province, Turkey, located at GPS coordinates 37° 55' 5" North and 40° 15' 47" East. The mounting platform used for the panels was adjusted to have a 360-degree orientation, considering local conditions in Diyarbakır, which has a high solar radiation potential.

Three identical 100 W monocrystalline photovoltaic panels were used in the study, with one serving as a reference. The reference panel remained unchanged, while the other two panels had a 1.5 cm high liquid reservoir created on their rear surfaces for transformer oil, with copper pipes installed inside. The first panel served as the reference panel, the second panel had active cooling (AC) applied, and the third panel had a hybrid cooling (HC) method applied.

In the AC method, a liquid reservoir was created on the rear surface of the panel to fill it with transformer oil. The oil reservoir was sealed with a flat metal plate with a thickness of 2 mm. A 0.5-inch copper pipe was placed inside the oil reservoir and connected to an automotive radiator with appropriate converters. Approximately 1.5 liters of water in the radiator was circulated through the copper pipe placed on the back of the panel using a 27W electric combination pump. The circulating water continuously absorbed heat stored in the transformer oil and transferred it to the connected radiator, where it was cooled. This process was repeated in a loop, with part of the heat being dissipated from the radiator's large surface area fins through air convection. This effectively removed heat from the oil reservoir. The radiator was cooled by a fan, which also cooled the water inside it. Thus, active cooling was achieved by cooling the heated water in the reservoir on the rear side of the panel.

In the HC method, the liquid reservoir on the rear surface of the panel was covered with a rectangular aluminum heat sink with fins, unlike the AC method that used a flat metal plate. The active cooling part was the same for both panels. This allowed for separate observations of the effects of active and passive cooling. Active cooling was achieved through the radiator, while passive cooling occurred with the assistance of the aluminum heat sink. Therefore, this method was named the hybrid system.

In both methods, transformer oil was used on the back of the panel to ensure both electrical insulation and heat conduction between the panel and copper pipes. Transformer oil is widely used in transformers for cooling purposes due to its excellent electrical insulation properties.

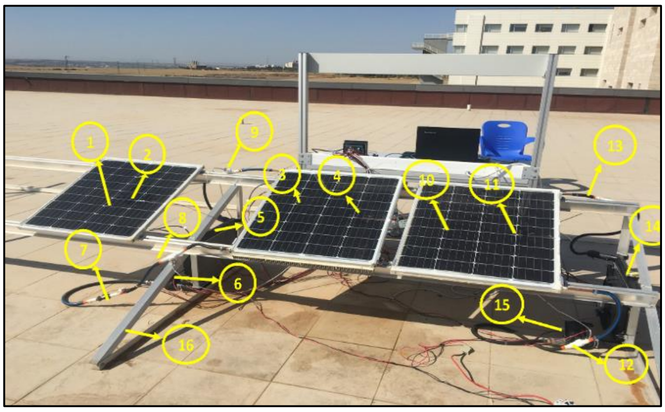

Figure 1. Front View of the Experimental Setup (*1-Reference panel 2-Ref. panel surface sensor 3-HC panel 4-HC panel surface sensor 5-HC radiator and fan 6-HC pump 7-Liquid flow sensor 8-HC panel liquid inlet temperature sensor 9- HC panel liquid outlet temperature sensor 10-AC panel 11-AC panel surface sensor 12-AC panel liquid inlet temperature sensor 13- HC panel liquid outlet temperature sensor 14-AC radiator and fan 15-AC pump 16-Mounting platform*

In the AC method, the rear side of the panel was sealed with a metal plate, while in the HC method, it was covered with an aluminum heat sink with a rectangular fin geometry to create a reservoir for transformer oil. The preparation process of the solar panel covered with the metal plate and the heat sink is illustrated in Fig. 3. The purpose of using transformer oil is to benefit from its electrical insulation and thermal heat conduction properties. Moreover, the use of transformer oil ensures a relatively homogeneous heat distribution on the backside of the PV panel.

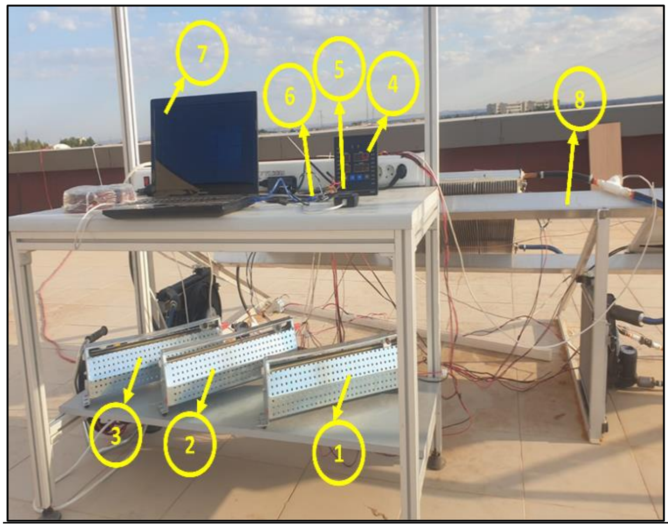

Figure 2. Back View of the Experimental Setup. *1-Refrans panel electrical load 2- HC Panel electrical load 3- AC Panel electrical load 4- SCN 100 data transfer device 5- USB-RS485 Converter 6- Arduino UNO R3 7-PC(laptop) 8-Mounting platform*

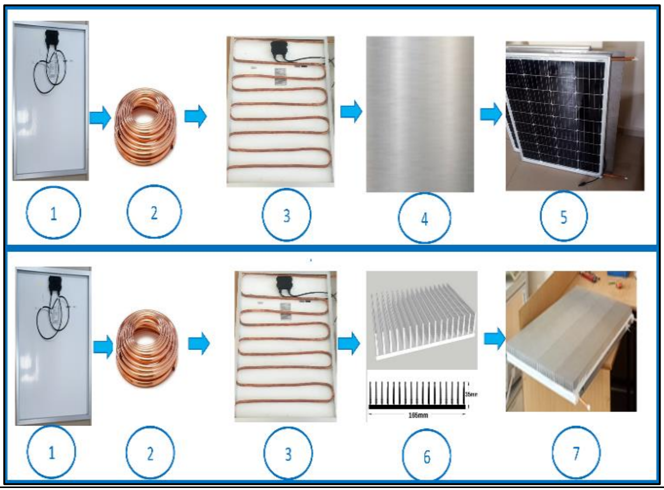

Figure 3. Preparation Process of Panels with Cooling. *1-PV panel 2-Copper tube 3-Copper tube mounting behind the panel 4- Metal plate 5-AC panel 6-Aluminum led heatsink 7-HC panel*

In the experimental setup, an electric pump commonly used in electric boilers was employed for the circulation of water. For the cooling process, an automotive radiator, radiator fan, adjustable electrical load (rheostat) for consuming electrical energy, hoses, a pump, converters to connect the radiator and copper pipes to hoses, and various sensors for measuring data such as current, voltage, and temperature were used. Sensor data was transferred to a PC via a USB-RS485 converter using an SCN 100 Scanner and Alarm Device. Data was processed using the OPiK 2016_scn 100 data transfer software on the PC. A liquid flow sensor and Arduino were used to measure the liquid flow rate. The block diagram of the cooling and measurement elements used for the HC panel in the experimental setup is shown in Figure 4. Data on radiation, ambient temperature, wind, and some meteorological data were collected from a meteorological solar data station, as seen in Fig. 5.

In the conducted experiment, one liquid temperature sensor was used to measure the inlet and outlet temperatures of both the AC and HC methods. Surface temperature sensors were placed approximately in the middle of each panel's surface, taking care to avoid shading from the sensors. A liquid flow sensor was positioned between the pump and the inlet sensor to measure the flow rate of the water.

In this study, the energy required was sourced from a previously established 0.4 kW wind energy system, as per our previous research. During periods of insufficient wind, an adjacent 1 kW solar power plant was utilized.

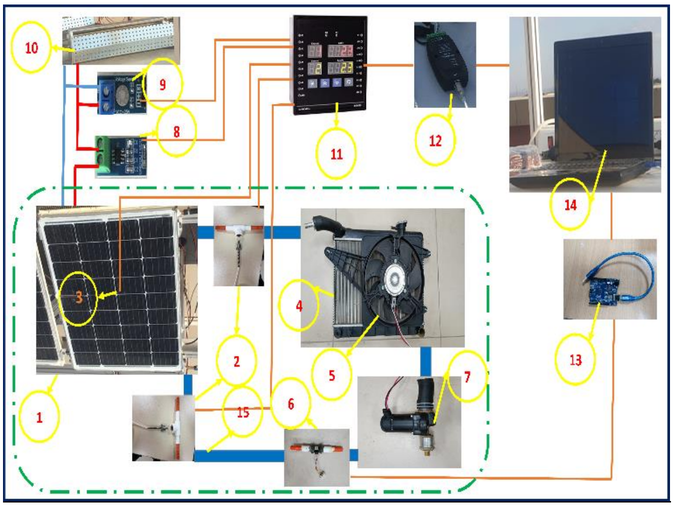

Figure 4. Experimental Setup Cooling and Measurement Block Diagram. *1-PV panel 2-Liquid temperature sensor 3- Surface temperature sensor 4-Radiator 5-Radiator fan 6-Liquid flow sensor 7-Pump 8-Current sensor 9-Voltage sensor 10-Adjustable electrical load (rheostat) 11- SCN 100 data transfer device 12- USB-RS485 Converter 13- Arduino UNO R3 14-PC(laptop)*

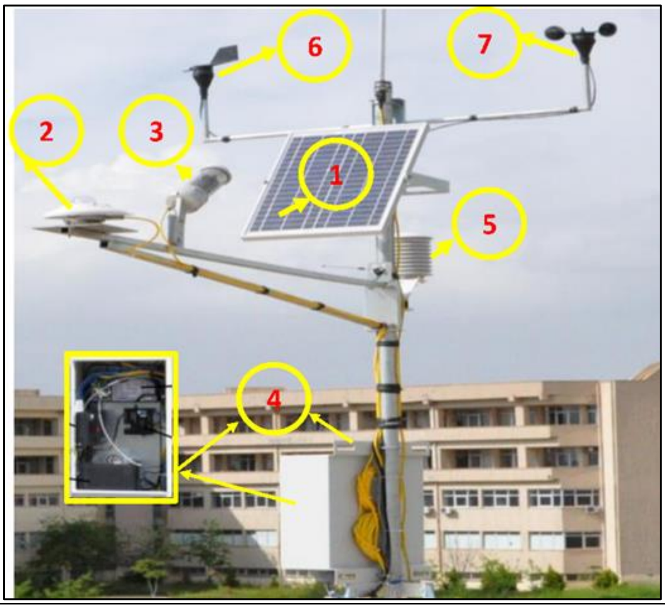

Figure 5. Image of the Meteorological Measurement Station. *1-Solar panel 2-Solar radiation sensör (Pyranometer) 3-Sunshine duration sensor 4-CR800(Datalogger), battery, Solar charge controller 5-Air temperature and relative humidity meter 6- Wind direction meter 7-Wind speed meter*

2.2. Materials Used in the Experiment

In the study, three identical 100 W monocrystalline photovoltaic panels were used, one of which served as a reference while the other two had a 1.5 cm high liquid reservoir created on the back surface to accommodate transformer oil, and copper pipes were placed inside these reservoirs. The first panel was taken as the reference panel, the second one was subjected to active cooling (AC), and the third one was subjected to hybrid cooling (HC) methods. In the AC method, a liquid reservoir was created on the back of the panel to fill transformer oil, and the reservoir was sealed with a 2 mm thick flat metal plate. Copper pipes with a diameter of 0.5 inches were placed inside the reservoir and connected to an automotive radiator using suitable converters. Approximately 1.5 liters of water was circulated through the copper pipes using an electric combi pump (27W) connected to the back of the panel. With the help of the pump, the circulating water in the oil reservoir continuously absorbed the heat and transferred it to the radiator connected to the system, where it was cooled. A portion of the heat was dissipated through the large surface radiator fins in contact with the air. Thus, the heat in the oil reservoir was removed from the system. Active cooling was achieved by cooling the water inside the reservoir. In the HC method, the liquid reservoir was covered with an aluminum cooling plate with a rectangular fin geometry instead of a metal plate. The active cooling part was the same in both panels. Therefore, while active cooling was achieved through the radiator using a fan, passive cooling was achieved through the aluminum cooling plate. For this reason, this method was named the hybrid system.

In both methods, transformer oil was used to ensure both electrical insulation and heat conduction between the panel and the copper pipes on the back. Transformer oil is commonly used for cooling purposes in transformers due to its excellent electrical insulation properties. Additionally, transformer oil has reasonable thermal conductivity properties, with thermal conductivity coefficients ranging from approximately 0.13-0.17 (W/m K) at 20°C.

In this study, a circulation pump commonly used in electric combi boilers (capable of continuous operation and resistant to high temperatures) was used for the circulation of water in the cooling system. The experiment also utilized an adjustable DC power supply capable of supplying 0-50 Ohm resistance and a power of 1000W for the electric load, copper pipes with a length of approximately 7 meters and a diameter of 1.5 inches for each panel, a liquid flow sensor for measuring liquid flow, an Arduino for processing the measured liquid flow data and transferring it to a PC, and a triangular-type adjustable panel mounting platform with an adjustable angle for mounting the panels (the panel angle was set to 36 degrees for the conditions in Diyarbakır). Approximately 8 liters of Hyvolt Power Oil 60 UX (inhibited transformer oil) were used for transformer oil. Additionally, a meteorological measurement station was set up to measure parameters such as radiation, relative humidity, air temperature, wind speed, wind direction, and sunshine duration.

All measurements were automatically recorded using appropriate sensors in the experimental setup.

TABLE I
CHARACTERISTICS OF THE SOLAR PANELS USED

Specifications	Value
Tipi	Monokristal
Power	100W
Number of Cells	36
Open-Circuit Voltage (Voc)	23,8V
Maximum Voltage (Vmp)	20,70V
Short-Circuit Current (Isc)	5,07A
Maximum Current (Imp)	4,83A
Maximum System Voltage	1000V
Module Dimensions (mm)	791*679*25

(Standard Test Conditions: Am=1.5 E=1000W/m2 Tc=25°C)

2.3. Photovoltaic Panel Electrical Circuit

The electrical equivalent circuit of the PV cell is modeled as shown in Fig. 6. This PV equivalent circuit consists of a current source, a diode in series, and parallel resistors.

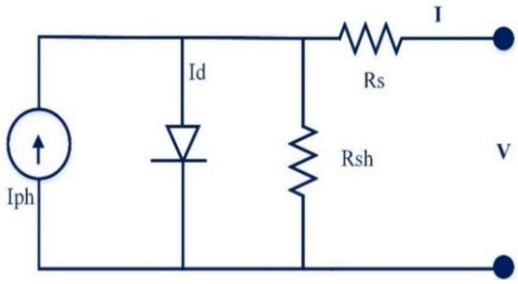

Figure 6. Equivalent Circuit of the Photovoltaic Cell

The output current of a PV cell;

$$I = I_{ph} - I_0\left(e^{-\frac{q(V+IR_S)}{nkT_c}} - 1\right) - \left(\frac{V+IR_S}{R_{sh}}\right) \quad (1)$$

It is found with the formula. In PV systems, PV cells are connected in parallel to increase current, and in series to increase voltage. If the PV panel current is rearranged based on N_s, the number of series cells on the PV panel, and N_p, the number of parallel cells used on the panel

$$I = N_p I_{ph} - N_p I_0\left(e^{-\frac{q\left(\frac{V}{N_S}+\frac{IR_S}{N_p}\right)}{nkT_c}} - 1\right) - \frac{1}{N_p}\left(\frac{V+IR_S}{R_{sh}}\right) \quad (2)$$

The R_{sh} parallel resistance, which represents the effect of leakage currents in the equivalent circuit, is much larger than the R_s series resistance that represents the voltage drop at the output. In the equivalent circuit of the PV cell, when $R_{sh} = \infty$ is taken (open circuit), the PV cell current and voltage;

$$I = N_p I_{ph} - N_p I_0 \left(e^{-\frac{q\left(\frac{V}{N_S}+\frac{IR_S}{N_P}\right)}{nkT_C}} - 1 \right) \tag{3}$$

$$V = \frac{nkT_c}{q} \mathrm{Ln}\left(\frac{I_{ph}+I_0-I+N_p}{I_0}\right) - R_s I \tag{4}$$

Here; I is the cell output current, Iph is the current generated by photons, R_s is the series resistance, the voltage drop at the output, R_{sh} is the parallel resistance, n is the ideality factor, V is the cell output voltage, k is the Boltzmann constant (1.380622×10-23 J/^{0}K), I_0 is the reverse saturation current of the diode, q is the charge of an electron (1.6021917×10-19 C), T_C is the cell temperature (Ambient temperature: 25 (°C), Irradiance value: 1000 (W/m^2), Wind speed: 1 (m/s)).

2.4. Energy analysis

The calculated current and voltage-dependent electrical power output of the PV panel;

$$Pe = V * I \tag{5}$$

Here, V corresponds to voltage, I to current, and Pe to electrical power.

The power generated by the PV panel varies depending on the angle of incidence of incoming sunlight, the degree of pollution on the panel surfaces, and whether the weather is clear or cloudy. The calculation of how much of the sunlight falling on the solar panel is converted into electricity is expressed as efficiency.

Efficiency;

$$\eta e = \frac{Pmax}{G*S} * 100 = \frac{Imax*Umax}{G*S} * 100 \tag{6}$$

ηe electrical efficiency (%) can be expressed as follows, where Imax is the maximum panel current (A), $Imax$ is the maximum panel voltage (V), $Pmax$ is the maximum power generated by the panel (W), G is the irradiance (W/m^2), S is the panel surface area (m^2);

$$FF = \frac{Imax*Umax}{Ioc*Uoc} \tag{7}$$

When expressed as V_{OC} (open-circuit voltage) and I_{SC} (short-circuit current), FF (fill factor) is defined as the fill factor.

In the study, the electrical power increase (P_inc) was calculated as follows by comparing the cooled panel power (P_col) with the reference panel.

$$\text{P\_inc} = \frac{\text{P\_col}-Pref}{Pref} 100 \tag{8}$$

Similarly, electrical efficiency increase (ηe_{inc}) can be expressed as the difference between the efficiency of the cooled panel (ηe_{col}) and the efficiency of the reference panel ηe_{ref}.

$$\eta e_{inc} = \eta e_{col} - \eta e_{ref} \tag{9}$$

2.5. Effect of Temperature and Irradiance on PV Panel Power, Current, and Voltage

The mathematical model of the PV panel, as described earlier, was simulated in MATLAB Simulink to calculate the maximum current, voltage, and power. The intended model is presented in Figure 7.

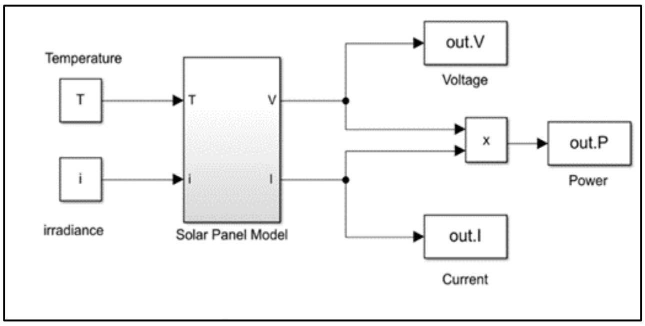

Figure 7. Solar panel MATLAB Simulink model

The impact of temperature is shown in the obtained I-V and P-V characteristics in Figures 8 and 9. When examining Figures 8 and 9, it can be observed that an increase in temperature, with constant irradiance, slightly increases the current while decreasing the voltage. Therefore, an increase in temperature reduces the power output.

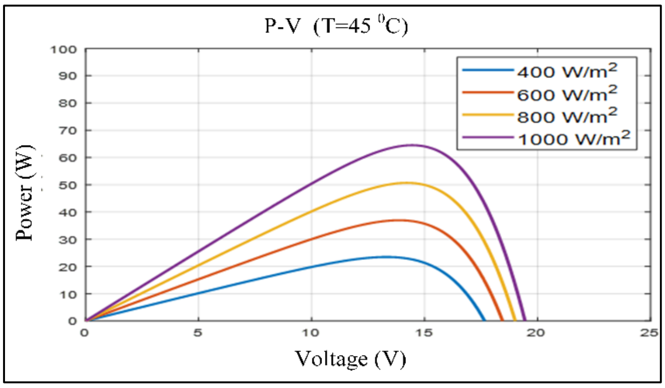

Figure 8. I-V characteristic of the panel under constant irradiance conditions (Irradiance = 1000 W/m^2 at temperatures of 20, 40, 60, and 80 °C)

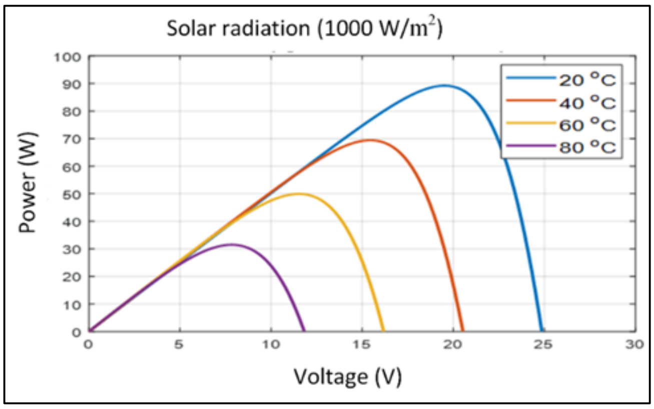

Figure 9. P-V characteristic of the panel under constant irradiance conditions (Irradiance = 1000 W/m^2 at temperatures of 20, 40, 60, and 80 °C)

When observing the effect of irradiance, the temperature was kept constant at 45°C, and changes in current, voltage, and power due to irradiance were investigated. While keeping the temperature constant, current, voltage, and power values were calculated for different irradiance levels (i = 400, 600, 800, and 1000 W/m^2). The I-V and P-V characteristics obtained to observe the effect of irradiance are presented in Fig.10 and Fig.11. When examining the figures, it can be observed that, under constant temperature conditions, an increase in irradiance slightly increases voltage and significantly increases current, thereby increasing power.

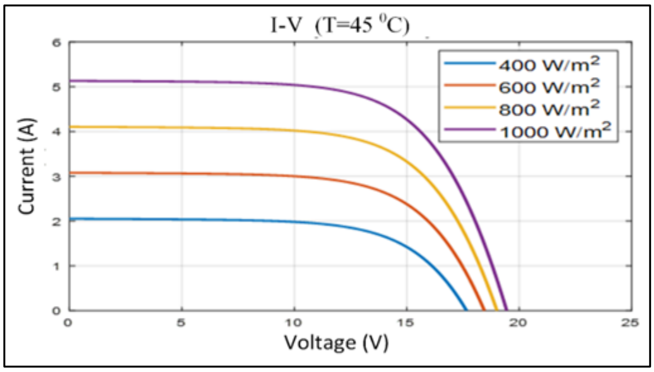

Figure 10. The panel I-V characteristic under constant temperature conditions (T=45°C) for irradiance levels of 400, 600, 800, and 1000 W/m^2

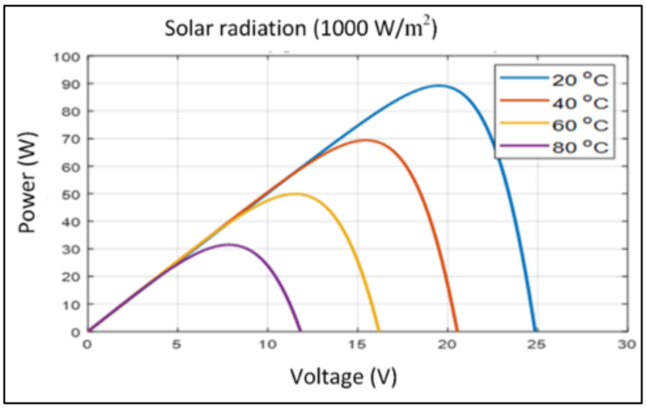

Figure 11 presents the panel P-V characteristic under constant temperature conditions (T=45°C) for irradiance levels of 400, 600, 800, and 1000 W/m^2.

3. DISCUSSION AND RESULTS

In this experimental study, instant measurements were taken for two days from 11:00 AM to 4:00 PM. Since the results for both days were very close to each other, data from a single day were used. During the experiment, temperature sensors were used to measure the inlet and outlet temperatures of the water passing through the copper pipes behind the panels, as well as the temperature of the transformer oil. Surface temperature sensors were used to measure the panel surface temperatures. Current and voltage sensors were used to measure the maximum current and voltage values of each panel. Sensor data were recorded on a computer using the SCN 100 scanner and alarm device.

Measurements were taken for aluminum AC panels and HC panels, including water inlet and outlet temperatures, transformer oil temperature, surface temperatures, and electrical parameters (current and voltage). For the reference panel, only surface temperatures and electrical parameters (maximum current and voltage) were measured. The measurements are presented in Figures 12-22.

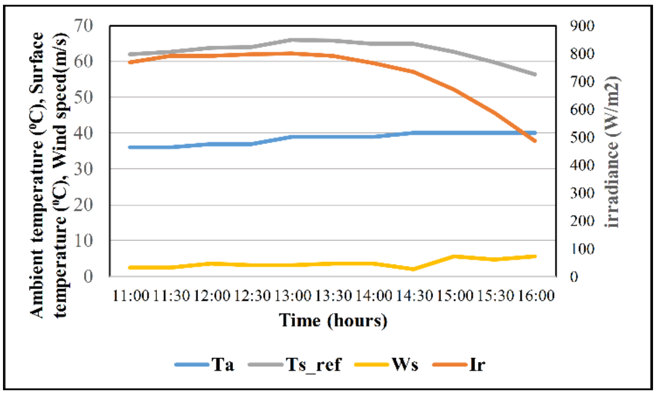

Figure 12. Variation of Ambient Temperature, Wind Speed, Irridance, and Reference Panel Surface Temperature

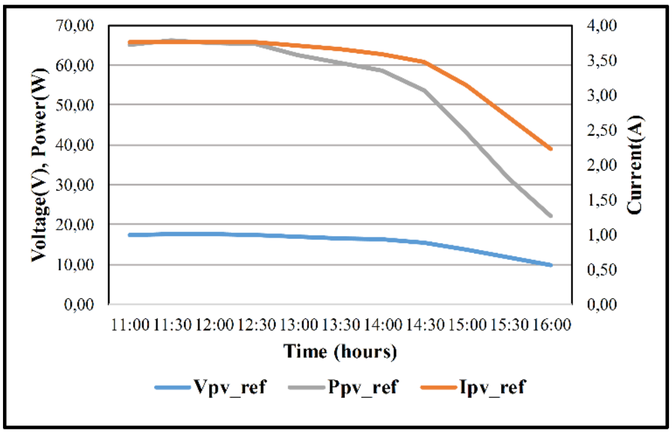

Figure 13. Maximum Current, Voltage, and Power of the Reference Panel

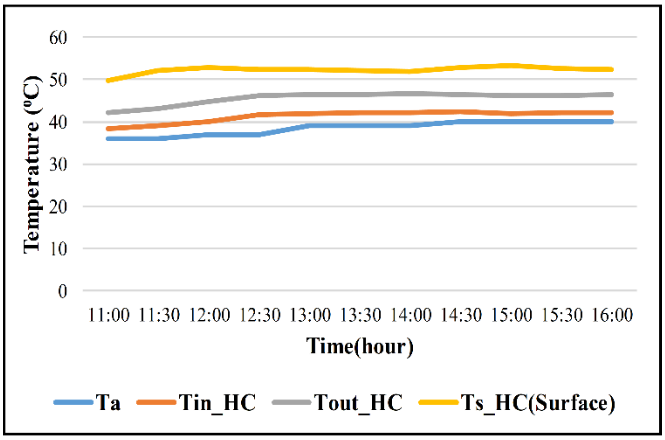

Figure 14. Changes in Inlet-Outlet Water Temperature and Panel Surface Temperature of the HC Panel

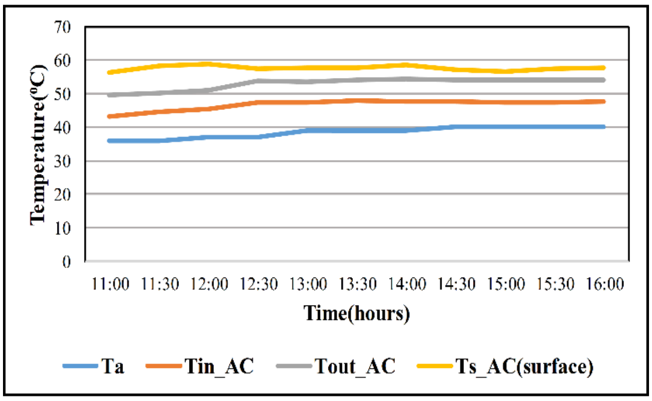

Figure 15. Changes in Inlet-Outlet Water Temperature and Panel Surface Temperature of the AC Panel

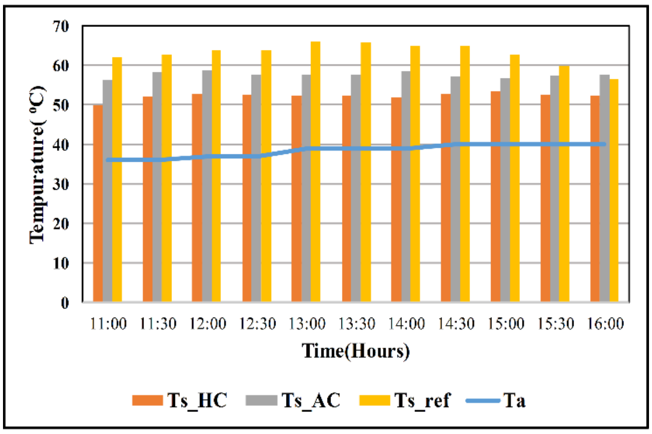

Figure 16: Changes in Surface Temperatures of HC, AC, and Reference Panels and Ambient Temperature

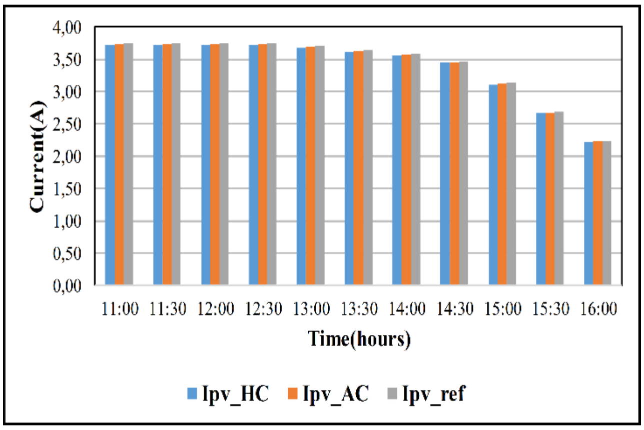

Figure 17. Measured Maximum Currents for HC, AC, and Reference Panels

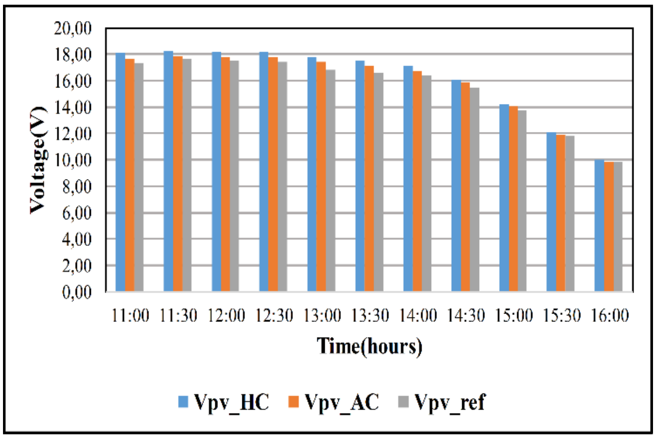

Figure 18. Measured Maximum Voltages for HC, AC, and Reference Panels

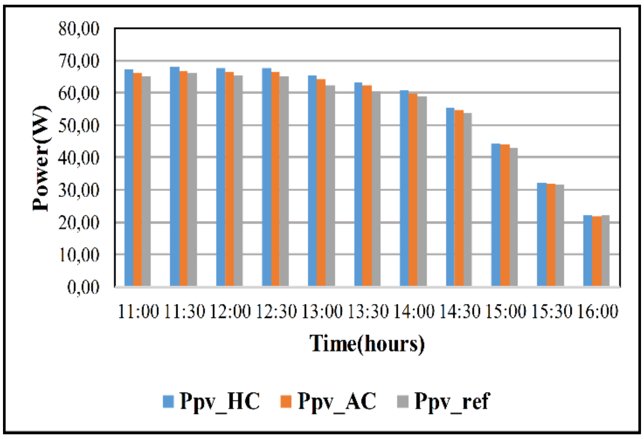

Figure 19. Measured Maximum Powers for HC, AC, and Reference Panels

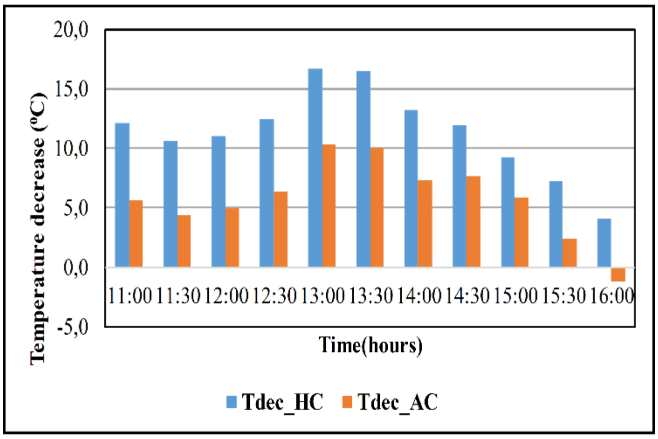

Figure 20: Decrease in Temperature for HC and AC Panels Compared to the Reference Panel

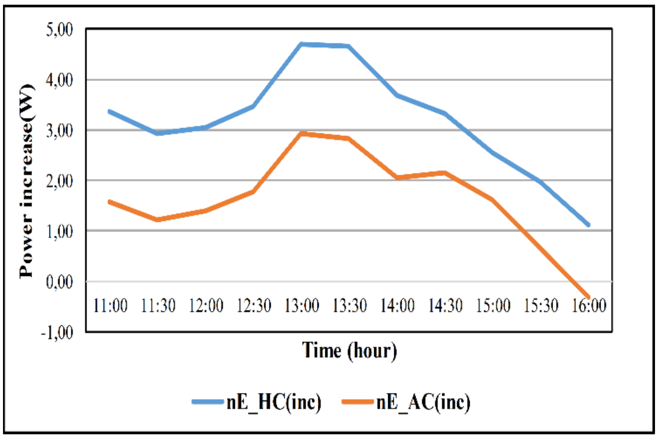

Figure 21. Increase in Electrical Power for HC and AC Panels Compared to the Reference Panel

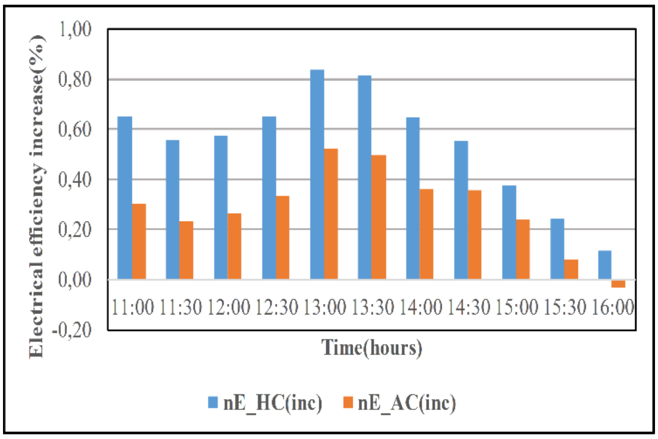

Figure 22. Increase in Electrical Efficiency in HC and AC Panel Temperatures Compared to the Reference Panel

In this experimental study, instant measurements were taken for two days from 11:00 AM to 4:00 PM. Since the results for both days were very close to each other, data from a single day were used. During the experiment, temperature sensors were used to measure the inlet and outlet temperatures of the water passing through the copper pipes behind the panels, as well as the temperature of the transformer oil. Surface temperature sensors were used to measure the panel surface temperatures. Current and voltage sensors were used to measure the maximum current and voltage values of each panel. Sensor data were recorded on a computer using the SCN 100 scanner and alarm device.

Fig.12 and 13 provide the electrical parameters measured for the reference panel, including maximum current, voltage, and power, as well as irradiance, ambient temperature, wind speed, and surface temperature values.

Fig. 14 and 15 present the results of the copper pipe inlet and outlet measurements and surface temperatures for the HC panel and AC panel subjected to cooling. When examining the results, it can be observed that the HC panel, with its cooling system, had lower inlet and outlet water temperatures compared to the AC panel. Additionally, the surface temperature of the HC panel was lower than that of the AC panel. While water was actively circulated through the aluminum AC panel using a pump in conjunction with car radiator and fan cooling, passive cooling occurred simultaneously through the aluminum cooler on the HC panel. As a result, the HC panel was effectively cooled more than the AC panel.

Fig.16 displays the surface temperatures and ambient temperature for all three panels. As seen in the figure, the surface temperature of the reference panel, which was not subjected to any treatment, was higher than the two cooled panels. This temperature, which varies depending on irradiance and ambient temperature, reaches significantly high values during the noon hours when irradiance is high.

Fig. 17-19 compare the electrical parameters, including maximum current, voltage, and power, measured for all three panels. When analyzing the graphs, it can be observed that the HC panel and AC panel had higher voltage and power values compared to the reference panel, while the current value was lower for both HC and AC panels. The change in voltage due to temperature variation is more pronounced among the three panels, whereas the change in current is less significant. This is theoretically expected since, under constant irradiance, an increase in temperature leads to a decrease in voltage and power while causing an increase in current. However, the change in current is limited.

Figure 20 provides information about the temperature decrease in the HC and AC panels compared to the reference panel. The temperature decrease in the HC panel was greater than that in the AC panel. These temperature decreases were most significant around noon, between 13:00 and 13:30, where the temperature drop in the HC panel was approximately 16.6°C, while it was around 10.3°C for the AC panel. Around 11:00, the temperature decrease in the HC panel was about 12°C, whereas it was approximately 5.2°C for the AC panel. At 16:00, the HC panel showed a temperature decrease of about 4.1°C, while the AC panel displayed a negative value, indicating that the temperature was lower than that of the reference panel. This can be attributed to the closed heating of the transformer oil located behind the panel and the effect of wind.

Figures 21-22 analyze the increase in electrical power and efficiency compared to the reference panel. When examining these figures, it can be seen that the power increase in the HC panel was higher at noon but decreased around 16:00. The highest recorded power increase was 4.7 % for the HC panel and 2.94 % for the AC panel at 13:00. The lowest recorded power increase was 1.11% for the HC panel and -0.32 % for the AC panel at 16:00, indicating a decrease in power for the AC panel. The electrical efficiency increase was also at its highest, with 0.84% for the HC panel and 0.52 % for the AC panel at 13:00. The lowest increase in electrical efficiency was 0.11 % for the HC panel and -0.03 % for the AC panel at 16:00. These results indicate that cooling is more effective during the noon hours when irradiance and ambient temperature are high, resulting in an increase in electrical power and efficiency.

Furthermore, the HC panel was equipped with a rectangular finned aluminum cooler and LED lighting. When comparing the results in Figure 12-22, it is evident that the aluminum cooler had a significantly positive effect

4. CONCLUSION

In this study, measurements of temperature, maximum current, maximum voltage, and maximum power generation were conducted at various points of the reference panel, HC, and AC panels. Additionally, meteorological data such as irradiation, ambient temperature, humidity, and wind intensity were measured. The measurements were carried out in Diyarbakır, over a one-day period in August, from 11:00 AM to 4:00 PM under the same conditions. Comparisons have been made based on these obtained data. The results have been written in bullet points:

- The HC system was observed to provide more cooling compared to the others and was measured to have higher power generation and higher electrical efficiency. In the hybrid method, the highest increase in power and electrical efficiency was measured as 4.7% and 0.84%, respectively, while in the AC system, it was found to be 2.94% and 0.52%, respectively.
- The effectiveness of using the aluminum cooler in cooling is evident from the difference in power increase and efficiency gain obtained in both methods.
- Although the thermal conductivity of transformer oil is not as high as water, it was used considering its insulation advantages, but no significant efficiency gain was recorded.
- All necessary parameters for the study were recorded using sensors, thereby minimizing measurement errors due to human factors in the results.

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