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THE EFFECTS OF CLIMATE CHANGE ON PHOTOVOLTAIC SOLAR PRODUCTION IN HOT REGIONS

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Abstract

The work of solar cells and their production of electrical energy have been affected by climate change, especially in hot regions which became significantly hotter and still receive relatively high levels of solar radiation throughout the year. Higher ambient temperature and solar radiation result in higher PV cell temperature and, therefore, the reduction in PV module power output and efficiency. This study investigates how a PV module performs throughout the year in a hot region by considering the variations in cell temperature resulting from changes in ambient temperature and solar radiation every day. The tilt angles and two-axis tracking have also been examined. Results indicate that the two-axis solar tracking system is critical to use in hot regions for obtaining higher output power. Therefore, part of this power can be used to cool solar panels using various methods to keep their efficiency high, such as operating air fans or operating pumps to cool them with coolant.

Keywords: PV cell temperature; PV cell performance; Climate change; Hot regions; Two-axis tracking.

1. INTRODUCTION

A significant challenge of our time is climate change. Extreme weather is becoming more frequent and destructive at a global level due to rising temperatures, with devastating effects on economies and societies across the world. Over the past five years, global average temperatures have been among the highest ever (Figure 1) [1]. As a result of human-produced greenhouse gases, scientists predict that the planet's temperatures will rise for decades to come [2].

Climate change and global warming have affected solar cells and their ability to produce electrical energy. The performance of the PV module is critically dependent on the cell temperature [3]. Throughout the solar day, the temperature of PV cells is mainly influenced by ambient temperature and solar radiation intensity [4]. The cell temperature strongly influences the efficiency of the PV module [5, 6]. As PV cells' temperature alters, power output is affected, and the PV module's efficiency is affected, as well [7].

Solar cells at constant temperatures have been investigated extensively experimentally and numerically [8-10], but very few studies [11, 12] explain transient temperature effects. Moreover, studies do not examine an actual site where the levels of temperature change throughout the year, especially in the hot regions, where the effect of temperature rise is critical in a dramatic decrease in solar cell power production.

Burnett et al. [13] investigated the impact of climate change on solar irradiance across different regions of the UK. The effect of a temperature rise as a result of climate change on solar energy production was not taken into account in this study as it is limited to a very cold region, where the effect is negligible. Solar energy production is more severely affected in hot regions due to increased temperature resulting from climate change. In their analysis, they found that solar irradiance increases by 7.9% in the southwest while decreasing by as much as 2.9% in the north of Scotland. On the performance of photovoltaic systems in Greece, Panagea et al. [14] examined the effects of projected changes in irradiance and temperature. Increasing temperature negatively affects photovoltaic performance. The relative contributions of temperature and irradiance show that temperatures will decrease significantly (3%), but this is countered by an increase in irradiance, which results in an overall slight increase in photovoltaic systems. According to Jerez et al. [15], Europe's photovoltaic power generation could suffer from climate change. As a result, their findings suggest that solar PV supply by the end of this century will change by (-14%) compared with current climate conditions, with the greatest changes occurring in northern countries. Solar PV power production is therefore predicted to be reduced by at most 10 - 12% due to climate change in Scandinavian areas where renewable energy sources may not become the primary ones. The PV supply was slightly increasing in southern regions, despite decreasing its daily stability. Pasicko et al. [16] studied climate change impacts on PV production in Croatia. In accordance with the cell temperature coefficients for the energy generated in a PV module, an increase in air temperature results in a reduction in PV efficiency. During the summer, when the temperature was at its highest, PVs negatively impacted electricity production. Between 3 and 5% of electricity was lost.

Many research studies use a cooling process to increase solar cells' lifetime and energy efficiency [10, 17-19]. As a result of the cooling, solar cells produced more power [4, 5, 10, 17-19]. However, the cooling system needs the energy to function.

The present study aims to describe the effect of the cell temperature variation due to weather conditions from the ambient temperature rises and the change in the intensity of solar radiation throughout the year on the power output changes and the efficiency of a commercial solar cell in a hot region as a case study. The study considers the effect of the PV module tilt angles and the two-axis tracking on the system performance to get more power to compensate for the overheating losses and provide the ability to operate solar cell cooling systems.

2. METHODOLOGY

The work of solar cells and their production of electrical energy have been affected by climate change, especially in hot regions. In a hot region, the Iraqi city of Najaf has been chosen as a case study. The climate of Najaf, shown in Figure 2 (32.0107° N, 44.3265° E, 53 m elevation), is considered one of the desert climates, which has been dramatically affected by climate change and has become hotter recently. As well as the relatively hot weather of this city, it also receives relatively high levels of solar radiation throughout the year [20].

The weather history for this city's monthly average ambient temperature shows it has become hotter recently, as clear from Figure 3 [21]. A solar module has been installed and oriented southward to receive maximum solar radiation. Table 1 summarizes the solar system specifications used in this study at standard test conditions (STC).

Figure 4 illustrates the energy balance for the PV module and can be defined as follows [22]:

$$\tau\alpha G_T = \eta_c G_T + U_L(T_c - T_a) \quad (1)$$

where τ is the solar transmittance of the PV module cover's [%], α is the solar absorptance of the PV module [%], G_T is the solar radiation on the PV module [kW/m2], η_c is the PV module conversion efficiency [%], U_L is the heat transfer coefficient between the PV module and its surroundings [kW/m^2°C], T_c is the temperature of the PV cell [°C], and T_a is the temperature of the surrounding environment [°C].

Table 1 System specifications.

Model type	RT6E 100p
Rated maximum power (Pmax)	100 W
Power tolerance range	0 ~ 5 W
Open circuit voltage (Voc)	21.9 V
Maximum power voltage (Vmp)	17.9 V
Short circuit current (Isc)	6.03 A
Maximum power current (Imp)	5.59 A
Module efficiency	15.43 %
Dimension	120 × 54 × 3 cm
Temperature coefficient of Isc	0.05 %/C
Temperature coefficient of Pmax	-0.39 %/C
Operating temperature	-40 ~ +85 C
System Losses: 2% Soiling, 3% Shading, 2% Mismatch, 2% Wiring, 0.5% Connections, 1.5% Light-Induced Degradation, 1% Nameplate Rating, and 2.08% Availability.	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2
Standard test condition (STC)	Insolation:1000W/m^2, AM: 1.5, Cell temp.: 25 C.

In equation (1), the solar energy balances the output of electricity and the heat transfer into the surrounding environment with the solar energy absorbed by the PV module. Solving this equation for cell temperature yields:

$$T_c = T_a + G_T\left(\frac{\tau\alpha}{U_L}\right)\left(1 - \frac{\eta_c}{\tau\alpha}\right) \quad (2)$$

According to the procedure of Duffie and Beckman [22], the laboratory of the "Hybrid Optimization of Multiple Energy Resources" (HOMER) uses a value of 0.9 for $\tau\alpha$ in equation (2). Furthermore, the PV module continuously works at its maximum power point efficiency, so the efficiency of the cell is always equal to the maximum power point efficiency as follows [5, 17, 22]:

$$T_c = T_a + G_T\left(\frac{\tau\alpha}{U_L}\right)\left(1 - \frac{\eta_{mp}}{\tau\alpha}\right) \quad (3)$$

where η_{mp} is the PV module efficiency at maximum power [%].

The PV module efficiency at maximum power depends mainly on the cell temperature and can be written [5, 17, 22]:

$$\eta_{mp} = \eta_{mp,STC}\left[1 + \mu_p\left[T_c - T_{c,STC}\right]\right] \quad (4)$$

where $T_{c,STC}$ is the temperature of the PV cell under conditions for standard testing [25°C], μ_p is the coefficient of the temperature of the maximum power [%/°C], and $\eta_{mp,STC}$ is the efficiency of the PV module at maximum power under conditions for standard testing [%].

$$\eta_{mp,STC} = \frac{V_{mp} \times I_{mp}}{G_T \times A_{PV}} = \frac{P_{max}}{G_T \times A_{PV}} \quad (5)$$

where V_{mp} is the maximum power voltage [V], I_{mp} is the current at maximum power [A], P_{max} is the rated maximum power output [W], and A_{PV} is the PV module area [m^2].

Standard geometrical equations are used to calculate angles of incidence (α_{fixed}) for fixed systems given surface tilt β, solar azimuth γ_{sun}, azimuth γ, and angle of the solar zenith θ_{sun}, as detailed in the following equation [23, 24].

$$\alpha_{fixed} = \cos^{-1}[\sin(\theta_{sun})\cos(\gamma - \gamma_{sun})\sin(\beta) + \cos(\theta_{sun})\cos(\beta)] \quad (6)$$

Solar panels mounted on the tracking systems ensure the azimuth and the surface tilt are set to equal sun azimuth angle and sun zenith angle, respectively, and naturally the incidence angle is set to zero [23-26].

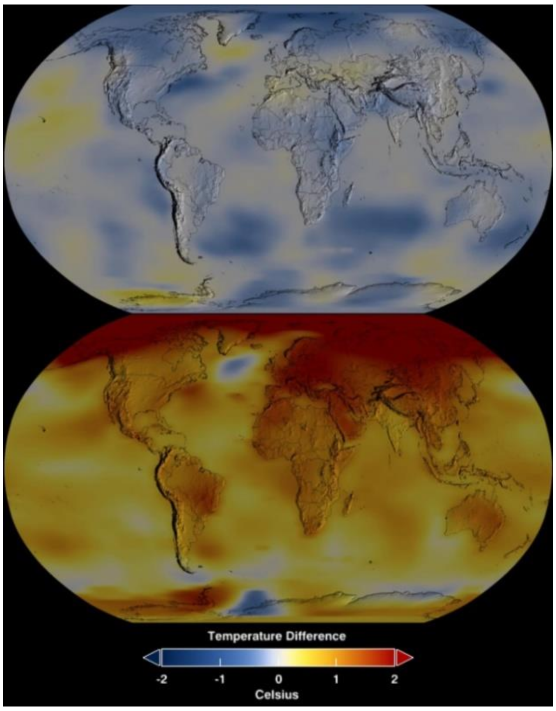

Fig. 1 The colour-coded maps show changing global surface temperatures for two years, 1968 (upper) and 2021 (lower). Normal temperatures are represented as the average over the past thirty years baseline period, specifically from 1951 to 1980. The red colour in the map shows the temperatures higher than normal, while the blue refers to temperatures lower than normal. Source: NASA's Earth science missions [1].

3. RESULTS AND DISCUSSION

The daily solar radiation for different tilt angles and two-axis tracking at Najaf city from the "National Renewable Energy Laboratory" are shown in Figure 5.

Based on the ambient temperature and solar radiation changes during the year, Figure (6) shows the average cell temperature for each month.

Figure 7 shows the monthly average maximum PV power production, which is negatively impacted by increased the temperature of the PV cell, as shown in Figure 6.

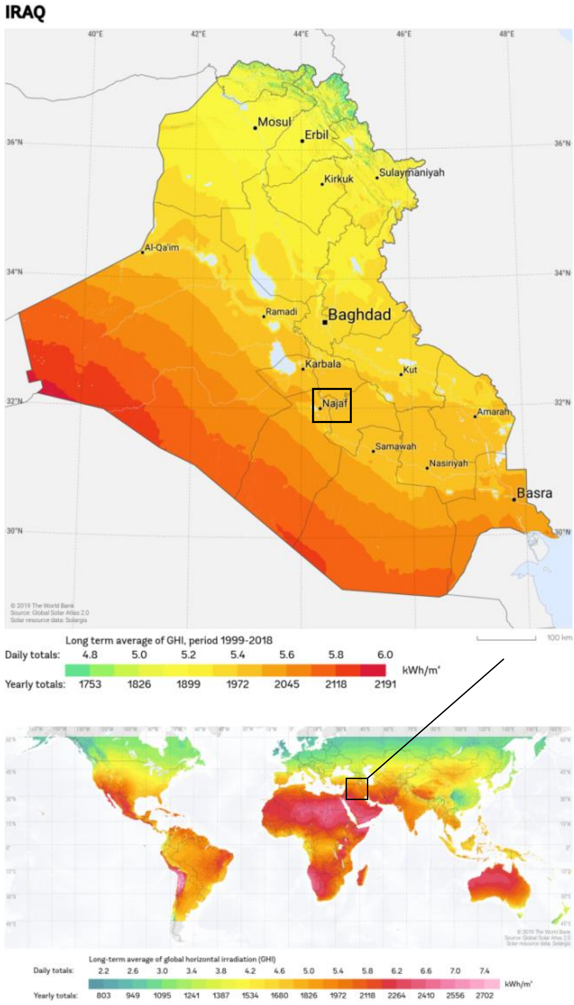

Fig. 2 The location of the studied site shows the global horizontal irradiation. Source: Global Solar Atlas [20].

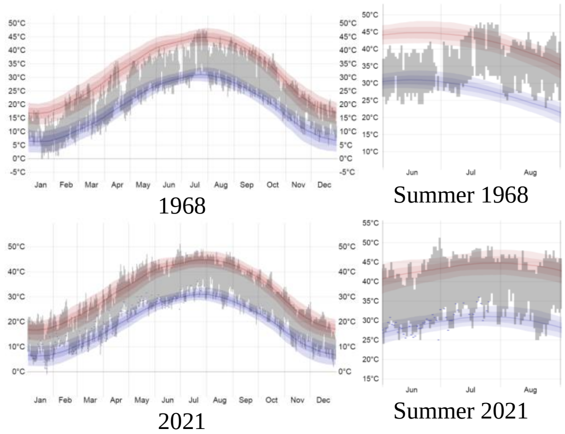

Fig. 3 Weather History for the monthly average ambient temperature for two years at Najaf city, Iraq. The daily recorded temperatures (grey bars) and the highs and lows reported in the twenty-four-hour period (red and blue ticks) place these over the average high and low daily temperatures on record (faint red and blue lines). Source: weather station at Al Najaf International Airport [21].

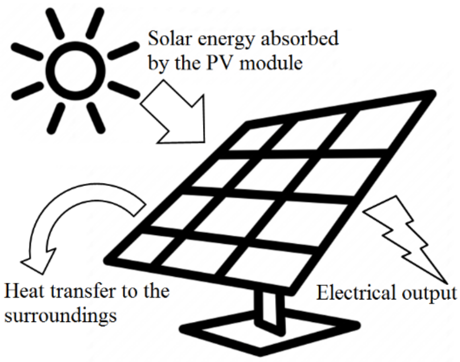

Fig. 4 The energy balance for the PV module.

According to Figure 8, increased cell temperatures significantly reduce the module's monthly PV efficiency. In July, the PV module efficiency decreased by about 3.5 per cent.

The PV efficiency changes with cell temperature can be seen in Figure 9.

Figure 10 shows the monthly AC power production by the photovoltaic system for different tilt angles and two-axis tracking considering cell temperature-related losses. These monthly totals are calculated by adding up the hourly values for each month.

The annual AC power production for different tilt angles and two-axis tracking considering cell temperature-related losses is shown in Figure 11. The value of electric power is the product of the total power generated each month. According to these results illustrated in the figure, two-axis tracking for the PV module increases power production by 35.7% annually.

Another analysis was conducted in this study to compare the power production generated by solar energy on a hot sunny day for a period of time between 5.00 am till 6.00 pm using the two-axis tracking versus the fixed systems for one day. Figure 12 shows the ambient temperature measured on an open field two meters above ground and the estimated temperature of a PV cell for a hot summer day on 30 June' 2021. The chart in Figure 13 illustrates the solar radiation hourly for different tilt angles and two-axis tracking on this day. A graph of the hourly evolution of AC power production by the photovoltaic system for different tilt angles and two-axis tracking considering cell temperature-related losses on this day is represented in Figure 14. Solar panels are produced between the hours of 5:00 am and 6:00 pm. The sunrise and sunset times on the site correspond to these hours. Based on the figure, it can be seen that the power produced was impacted dramatically by the high ambient temperature, which resulted in about of 40% reduction of power due to an excessive rise in the cell temperature.

The investigation of the cell temperature variation due to weather conditions has allowed a better and deeper understanding of the dynamic behaviour of a solar cell when working in a hot region. The investigation's results in the current study demonstrate the importance of using the two-axis tracking system in hot regions to obtain a higher output power, where some of that power can be used in the cooling process of solar panels by various methods to prevent the efficiency of the cell from breaking down, such as operating air fans or pumps to cool them with appropriate coolant. The results showed that the solar cell cooling issue in the hot regions is becoming a critical necessity to improve solar cell efficiency, ensure the continuation of its work and increase power production and its lifetime.

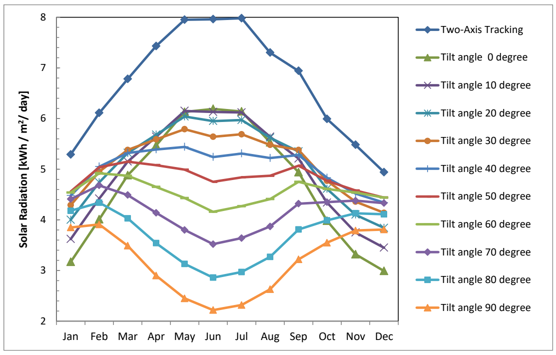

Fig. 5. Daily solar radiation for different tilt angles and two-axis tracking at Najaf city, Iraq.

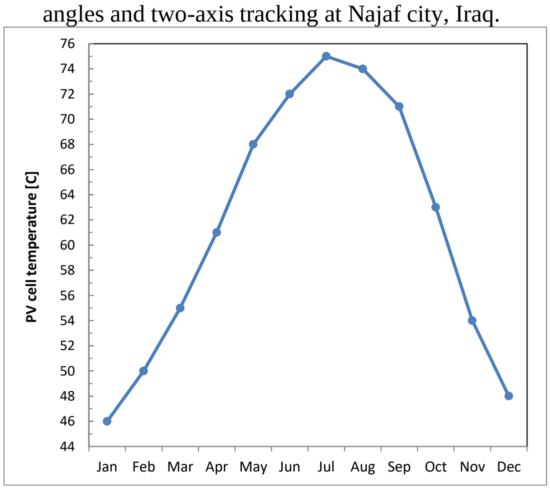

Fig. 6. Monthly average PV cell temperature.

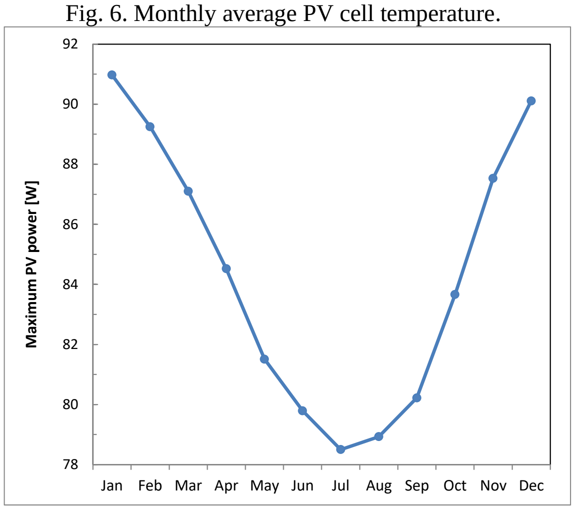

Fig. 7. Monthly average maximum PV power

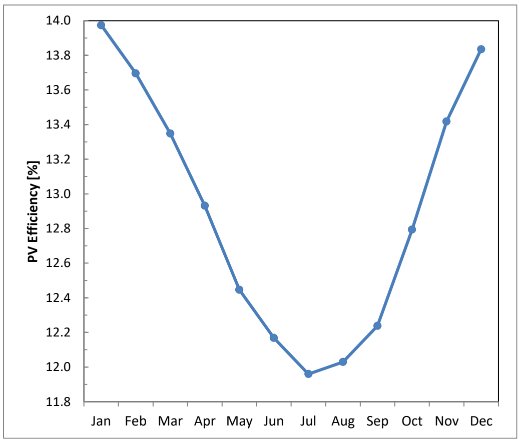

Fig. 8. Monthly average PV efficiency.

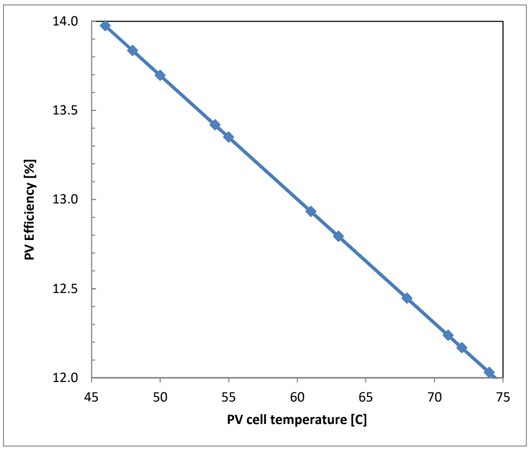

Fig. 9. The changes in the PV efficiency with PV cell temperature.

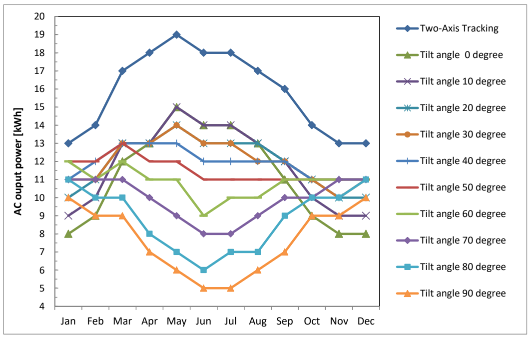

Fig. 10 Monthly AC power production for different tilt angles and two-axis tracking considering cell temperature-related losses at Najaf city, Iraq

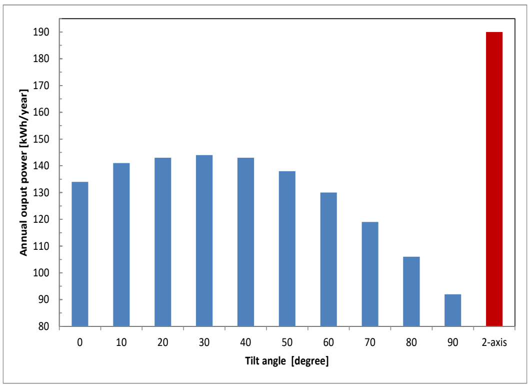

Fig. 11 Annual AC power production for different tilt angles and two-axis tracking considering cell temperature-related losses at Najaf city, Iraq.

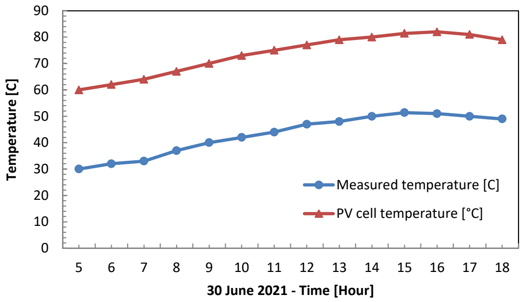

Fig. 12. The measured temperature at approximately two meters above the surface of an open field and the estimated PV cell temperature for a summer day of 30 June’2021.

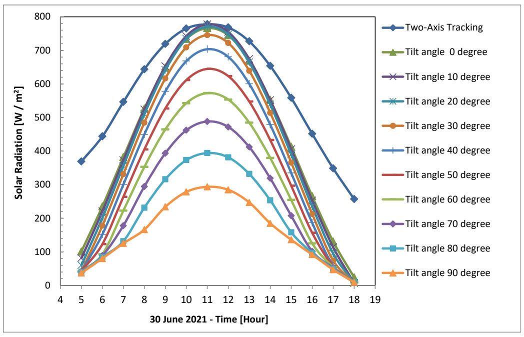

Figure 13 Hourly solar radiation for different tilt angles and two-axis tracking at Najaf city, Iraq

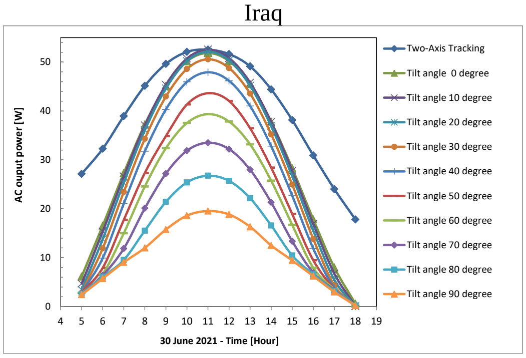

Fig. 14 Hourly AC power production for different tilt angles and two-axis tracking considering cell temperature-related losses at Najaf city, Iraq.

4. CONCLUSION

The work in this case study aims to determine the performance of an installed PV module in a hot region throughout the year by considering the daily fluctuations in cell temperature resulting from variations in surrounding temperature and incoming solar radiation. With the cell temperature increased, maximum power and efficiency decreased, despite the short circuit current rising very slightly, perhaps reflecting the primary growth in the rate level of the charge carrier generation. The study considers the effect of the PV module tilt angles and the two-axis tracking on the system performance. Results indicate that the two-axis tracking system for solar energy is essential for obtaining higher power output, especially in hot regions, which have been affected by climate change and have become hotter recently, to compensate for the lost power. Thus, a portion of this power can be used to cool solar panels through various means to keep their efficiency high, such as running air fans or running pumps to cool them with coolant. According to the results of this study, solar cells need to be cooled in hot regions to improve their efficiency, ensure their continual function, and increase their power production and lifetime.

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