PERFORMANCE ANALYSIS OF PHOTOVOLTAIC MODULE EQUIPPED WITH PARABOLIC FIN EMBEDDED COTTON WICK EVAPORATIVE COOLING

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The photovoltaic (PV) cells are made of silicon semiconductor and they are temperature sensitive. PV cell lose their desired properties when temperature rises. A rise in temperature of PV cell causes drop in voltage generation and affect its overall performance. In this paper, evaporative cooling was studied as a passive cooling method that absorbs heat generated by the photovoltaic module and lowers the temperature using a parabolic fin embedded cotton wick (PFECW) attached behind the photovoltaic module. PFECW cools PV modules by reducing the dry air's temperature and raising the humidity. In support of experimental analysis, a mathematical model with polynomial regression is performed to get polynomial equation for non-linear relations of different independent and dependent parameters. The experimental results indicate that temperature of the PV module decreased by 29%, which relates to adequate cooling of solar cells by the wet state of the PFECW exposed to wind. The system efficiency output electrical energy is increased by 12.25% and 20.4 w respectively.

Keywords: Photovoltaic cell, Evaporative cooling, Tilt angle, PFECW

1. Introduction

Worlds 85 % of energy comes from fossil fuels which accounts for 56.7% of greenhouse gas emissions. For achieving sustainable development without hampering environmental system, major change over in energy resource should be developed. Increased human activity in the industrial, agricultural and even household sectors poses challenges because of their reliance on conventional fuels as their primary energy source. Several academics and governments have turned to renewable energy source as a substitute for their energy needs as a result of oil price fluctuations, energy supply limitations, and air pollution [1]. Solar energy is a natural resource that generates both thermal and electrical energy. Solar power is produced by photovoltaic panels, which transform sunlight into electricity. Photovoltaic (PV) cell converts 14-22% sunlight into solar power [2,3]. When in use, solar cells are exposed to high-intensity solar radiation. Overheating of solar

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cells occurs due to rise in ambient temperature and that leads to deterioration of PV cells performance. The strength of the sun's radiation, the surrounding temperature, silicon solar cell's composition all affects a solar module's efficiency [4].

Performance of solar modules degrades as a result of the photovoltaic cells' high temperature. The most significant elements influencing the working temperature of PV modules in hot nations, particularly in the summer, are climatic conditions, which will cause intrinsic issues like damage to PV modules or a reduction in capacity [5,6,7].

It is vital to boost the effectiveness of PV modules, which can be done by lowering their temperature. The conversion efficiency of PV modules has been improved, and PV panels' performance has been maintained at high temperatures using a variety of cooling approaches. With the use of cooling solutions, modern solar cells may achieve an efficiency of 40–45%. [8,9]. The effectiveness of solar modules was examined by Farmahini et al. in relation to the impact of evaporative cooling employing pin fins and wet wool pads. The solar module's heat exchange is increased by the needle-shaped fins' regular arrangement, which transfers heat from photovoltaic panel to the air. To ensure contact with the rear of the fins, a wet wool pad is fastened to the back, water falls naturally onto the pad to keep it wet. As a result of the high humidity levels at its rear, the PV cells temperature dropped from 59 to 42°C, boosting the efficiency and output power of the unit by 32.7% and 31.7%, respectively [10]. Haidara et al, covered PV module's back with a damp towel for evaporative cooling. Rubber tube clamped to PV cells rear and supplies water to towel. Water flow rate is manually controlled. They found that the cooling method reduces the photovoltaic module's temperature by more than 20°C and increases its output power 14% when matched to solar cells without cooling [11]. Haidar et al. placed a piece of cloth in angled channel attached to the PV module's back. Water runs over the fabric while air is forced by a fan within channel in the same path as the water moves. They reported that as the water in the channels evaporates when air blows over them, the water absorbs heat of PV modules, enhancing the PV modules performance. Abdolzadeh et al analyzed passive cooling by placing aluminum and copper fins at back of solar cell [12]. The study found that adding fins to the copper-based cooling system improves cooling performance and lowers photovoltaic cells temperature around 10.2°C, indicating that technology is successful. Alami et. Al. examined the effect of synthetic clay evaporative cooling for PV modules [13]. They mount synthetic clay on the copper plate and a shallow layer of water is allowed to evaporate. They found that PV's power grew by 19.1% and its temperature was decreased. Simpson et al studied desiccant cooling technology. Desiccant is being embedded on the PV modules [14]. The desiccant absorbs moisture from the humid air as the PV modules cool at night. As temperature rises over the day, water begins to passively evaporate, extracting the surplus heat and produces cooling effect. They concluded that by evaporative cooling PV modules may cool down by up to 30°C. As per previous research both passive and active cooling techniques are used for PV modules, and both are effective at removing heat from Photovoltaic cells. Recent years, particularly the last two, have seen a significant increase in the usage of passive heat dissipation, which has helped to improve the performance of Photovoltaic cell [15]. Also, evaporative cooling is more reliable and inexpensive cooling technique in hot climates. The continual heat and mass movement between water and air causes' air temperature to fall and humidity to rise, which makes the air colder [16,17,18,19].

In this investigation the impact of passive cooling is created by adding a parabolic fin embedded cotton wick (PFECW) on the back of photovoltaic module. There have been a few researches on such strategies. We have used different methodology and working circumstances than existing research. Parabolic fins are designed by considering optimum condition for natural convection. The logic behind the addition of parabolic fin is that it improves the rate of heat transfer from solar cell and provides maximum surface area for evaporative cooling. Thin layer of cotton wick is embedded on parabolic fin and whole assembly is mounted on the solar module's backside. Water is fed to cloth wicks by gravity which aids cotton absorption and minimizes water use. Wet cotton wicks are open to the atmosphere, which lowers the temperature of the dry air and raises the humidity. This creates evaporative cooling. The approach makes a significant contribution by generating a required cooling condition that uses less quantity of water and performs well in hot temperatures compared to previous research. The effectiveness, thermal characteristics, and power output of a photovoltaic panel under warm weather conditions was evaluated.

2. Experimental setup

In this study, three photovoltaic panels were used; the first had PFECW installed in cooling system, second module is attached with parabolic heat sink only and third will act as just a comparator without cooling to allow for operational comparisons. For this experiment, cloth fibers that are widely used for readily available lanterns were employed. The cloth fibers are distinguished by heat transfer coefficient and reduced thermal conductivity, which facilitates the distribution and transmission of water to all cloth fibers located on the back of PV cells. Its affordability and ease of usage allowed for its use. Thermal silicon was used to hold fin on PV cell in place such that there was no gap between them. Eight ends of cloth fibers are submerged at top side of the PV cell in the four cans filled with water; that allows water to PV panel. Water flows with gravity, enabling transmission to cloth fibers without the use of additional power.

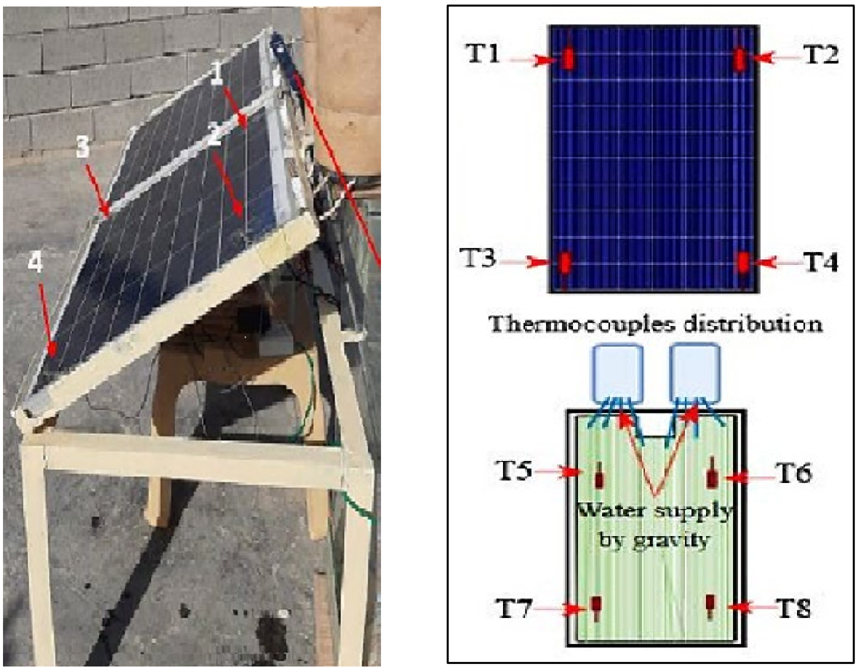

Fig.1 Experimental setup of Solar PV module

The temperature of photovoltaic module surface is monitored using four thermocouples (T1, T2, T3, and T4) placed in various regions of the surface. The remaining four thermocouples (T5,T6,T7,T8) are located behind PV module as shown in fig1. Two hours before the start of the test, the cotton wick was placed in the water and the load was connected to the photovoltaic module and the data logger.

3. Instrumentation

A data logger kind of Arduino was used to measure temperatures, voltage, and current using thermocouples scattered throughout the PV modules. K-Type thermocouples with a precision of 0.25 and a length of 3 m were used to measure temperatures having range from 10 °C to 1350 °C. To examine thermal behavior of PV module, thermocouples were placed all over the surface and underneath. Voltage sensors having resolution of 0.015 V, range 30V and current sensors of type ACS712 with an accuracy of 0.02 A, range of 30 A were used as input to in the data logger.

Throughout the experiment, two 20V bulbs were wired as a load between data logger and the PV cells. During the experimentation the data logger measures the readings of current, voltage and temperature and saves this information in memory card. The sun radiation was recorded using a pyrometer (Model SM206) having an accuracy of 0.12 W/m^2, and the measurement was carried out manually every 15 minutes. On a flat roof, three polycrystalline 55 W solar power panels with 0.70 m 0.60 m dimensions were used. During the course of the investigation, the third PV module acted as a benchmark for reference. The first module was outfitted with cooling attachment. The voltage and current values were utilized to calculate the energy produced by the solar panel using equation 1. The areas of the module (A) and mean solar radiation readings (S) are taken into account in order to evaluate the module efficiency by equation 2[6].

$$P_{PV} = V_{PV} X\ I_{PV} \quad (1)$$

$$n = \frac{P_{PV}}{A\ x\ S} \quad (2)$$

From 01 March 2023 to 05 April 2023, the trials were carried out in accordance with the climatic parameters at Wadwadi, Satara, Maharashtra, India. The majority of the days in March are sunny, with high temperatures, low humidity, and moderate winds. Throughout the studies, there was no discernible difference in temperature, and experimental days were sunny.

4. Polynomial Regression Model

A polynomial model is a type of regression method. To represent the link between the variable of interest y and the variable that forecasts x, we employ an N-th degree polynomial. The aim is fitting a non-linear model for the correlation among independent and dependent variables.

For this research polynomial regression model is utilized to develop the relations between dependent and independent parameters. Present work focused on the impact of cooling effect on PV modules and their performance. Here the effect of ambient temperature, time, cooling methodology are discussed considering ambient temperature, time as a dependent parameter whereas power and cooling methodology as an independent parameter.

We can utilize the generic polynomial regression technique for the prediction of y as an N-th N-order polynomial as

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \cdots + \beta_N x^N + \varepsilon \quad (3)$$

As the equation is linear with respect to of the parameters (e.g., β_0, β_1)

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \beta_4 x^4 + \varepsilon \quad (4)$$

From the experimental data and polynomial regression model 4th degree equation is developed. In above Eq. 4, y is nothing, but the temperature of PV modules and x is the time with consideration of respective ambient temperature.

The above equation gives an idea about identification of relation between standers parameters to be compared. Correlations and equations developed will be useful for the understanding of relations between the dependent and independent parameters.

Following relations were developed using polynomial regression analysis for PV module surface temperature on its top and back surfaces with ambient temperature.

Case	Polynomial Equation Developed	R Square Values
1. PV module Top Surface Temp w. r. t. Time	$y = 0.0054x^4 - 0.2258x^3 + 2.6165x^2 - 3.016x - 3.4747$	0.992
2. PV module back Surface Temp w.r.t. Time	$y = -0.0004x^4 + 0.0326x^3 - 1.3534x^2 + 20.816x - 54.184$	0.9858

The polynomial equations developed give the value of response variable temperature at given time which is the explanatory variable. The R square values (i.e. Coefficient of determination) are 0.992 and 0.9858 which signifies that model developed is best fitting to the experimental data. In further discussion the effect of cooling on temperature of PV modules shows following equations which were developed to interpret the results of temperature during different cooling strategies.

Case	Polynomial Equation Developed	R Square Values
1. With parabolic fin embedded cotton wick cooling & Ambient Temperature	$y = 0.0056x^4 - 0.2565x^3 + 3.8203x^2 - 19.647x + 58.051$	0.9846
2. Without cooling & Ambient Temperature	y = 0.0054x4 - 0.2258x3 + 2.6165x2 - 3.016x - 3.4747	0.992
3. With Parabolic Fin cooling & Ambient Temperature	$y = 0.0043x^4 - 0.2016x^3 + 3.0073x^2 - 15.104x + 54.469$	0.9825

The above equations relates to following cooling methods like 1. With parabolic fin embedded cotton wick cooling, 2. Without cooling and 3. With Parabolic Fin cooling. In this case the value of coefficient of determination, R is in the range of 0.98 to 0.99 which means that there is a strong relation and perfect model is developed between cooling methods employed and the ambient temperature at corresponding time factor.

Effect of cooling on development of power by PV Modules now highlighted with reference to adaptation of cooling. Experimental study carried out shows significant results to develop the equations.

Case	Polynomial Equation Developed	R Square Values
1. Power developed without cooling w.r.t. Time	y = 0.0173x4 - 0.863x3 + 15.191x2 - 110.54x + 284.64	0.9897
2. Power developed with cooling w.r.t. Time	y = 0.0273x4 - 1.4019x3 + 25.218x2 - 185.09x + 476.77	0.9818

Now with reference to above relations again to the specific level a relation is developed to understand the effect of different cooling methods on power development, which gives following results. The model developed signifies that with parabolic fin embedded cotton wick cooling generates the maximum power.

Case	Polynomial Equation Developed	R Square Values
1. With parabolic fin embedded cotton wick cooling & Power	y = 0.0173x4 - 0.863x3 + 15.191x2 - 110.54x + 284.64	0.9897
2. Without cooling & Power	y = 0.0273x4 - 1.4019x3 + 25.218x2 - 185.09x + 476.77	0.9818
3. With Parabolic Fin cooling & Power	y = 0.0206x4 - 1.0502x3 + 18.74x2 - 136.44x + 348.55	0.9699

Table 1

Test	Effect of Different Cooling methods on Power development		
	Without cooling	With parabolic fin embedded cotton wick cooling	With Parabolic fin cooling
R Square	0.399051347	0.399051347	0.399051347
Adjusted R Square	0.173695602	0.173695602	0.173695602
Standard Error	0.957669044	0.995496307	1.547636131

Table 2

Test	Effect of cooling on development of Power by PV Modules	
	Power without Cooling	Power with Cooling
R Square	0.337127274	0.337127274
Adjusted R Square	0.189822223	0.189822223
Standard Error	0.808015921	0.357267224

Table 3

Test	Comparison of PV surface temperature w.r.t. Ambient Temperature		
	PV module Top Surface Temp	PV module back Surface Temp	Ambient Temperature
R Square	0.362628939	0.362628939	0.362628939
Adjusted R Square	0.123614791	0.123614791	0.123614791
Standard Error	0.628082648	0.812815742	1.037407755

These tables give a detail about examination of the statistical significance of the regression models.

5. Results and Discussion

5.1 Comparison of PV surface temperature w.r.t. Ambient Temperature

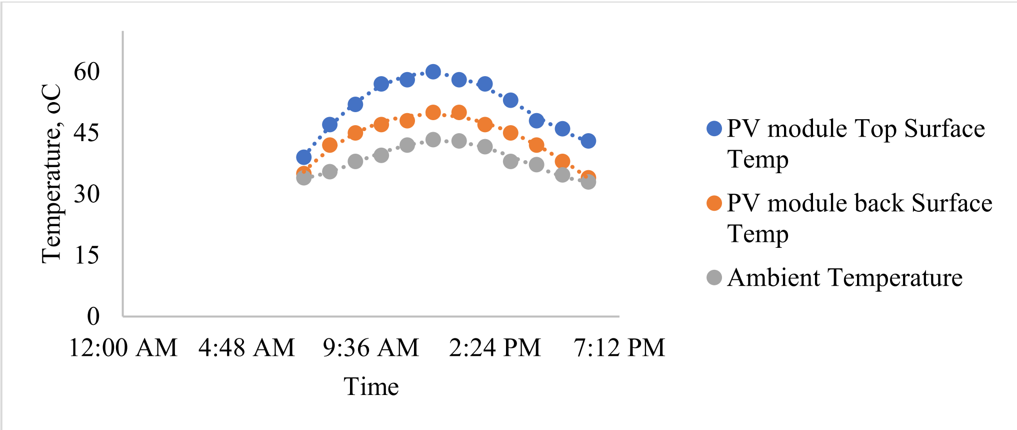

Fig. 2 : Comparison of PV surface temperature w.r.t. Ambient Temperature

Temperature changes of solar panels with time are given in fig. 2. Graph indicates that temperature of solar panel increases from 8.00 am to 12.15 am. and afterwards the temperature decreases. Maximum temperature recorded at Top and back faces of solar panel are of 59.90 °C and 49.70 °C respectively at 12.15 am. The maximum atmospheric temperature was 43.30 °C. PV modules top surface temperature is 16.60 °C more than atmospheric temperature. Heating over this temperature will impair PV cell performance and power production.

5.2 The impact of cooling on the temperature of a solar panel module

The impact of cooling on the temperature of a solar panel module is shown in fig.3. The graph shows that there is remarkable drop in temperature reading of PV module with cooling attachment. The maximum temperature recorded at the top with PFECW, with fin, without cooling are 45.20 °C, 48.40 °C, and 60.30 °C respectively. Recorded maximum atmospheric temperature was 43.30 °C. PV modules top surface temperature is 25 °C more than atmospheric temperature. Wet CWIW of is having exposure to enough air to cool and drop the photovoltaic module temperature by 15.1°C. The movement of air across a wet cotton wick causes the water to evaporate and the air to cool the photovoltaic module. The result of using evaporative cooling for enhancing solar panel performance is practical and result oriented.

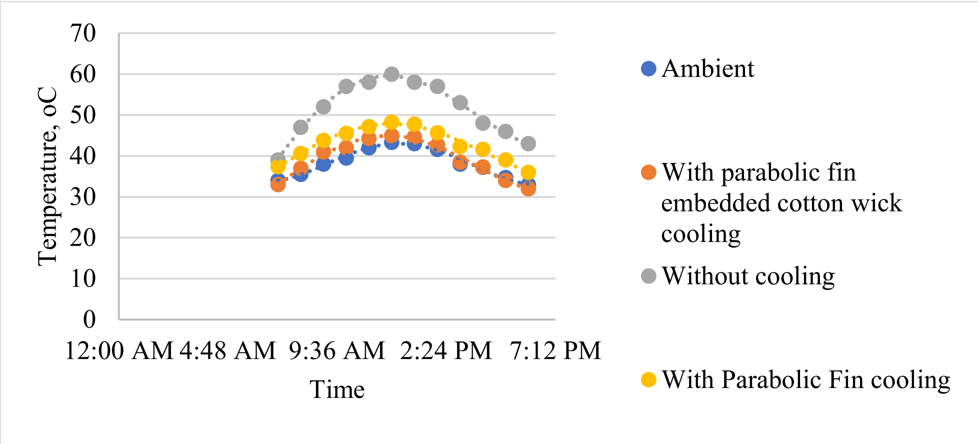

Fig. 3 Effect of Different Cooling methods employed for PV Modules

5.3 Effect of cooling on development of Power by PV Modules

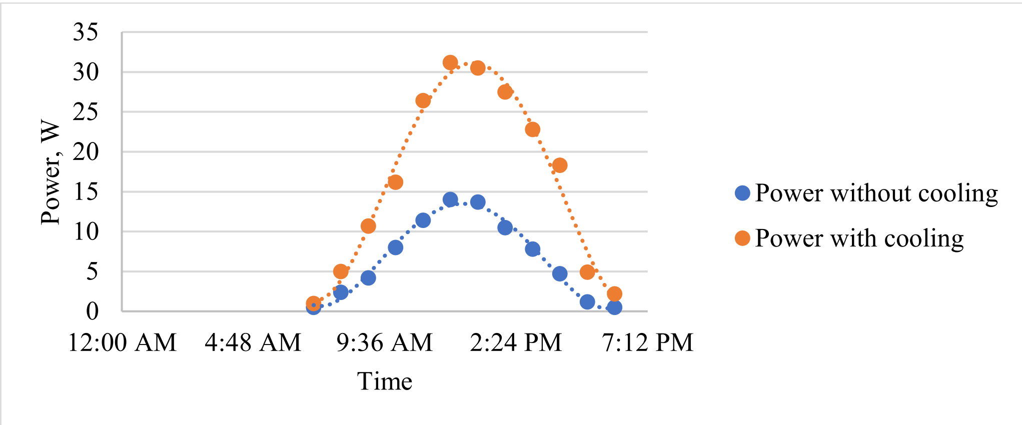

Fig. 4 : Effect of cooling on development of Power by PV Modules

The impact of cooling on solar panels performance is shown in fig. 4. The graph indicates that there is substantial increase in performance parameters of solar panels with cooling attachment. The temperature of an uncooled solar panel has affected output current and voltage. The uncooled PV module's maximum voltage and current at 12:15 pm are 15.2 V and 1.2A. Due to convective mass transfer, the air movement on the wick is crucial for enhancing the evaporation process and decreasing temperature of photovoltaic module. The top-down immersion of the cotton wick in water is responsible for the drop in temperature and rise in PV Module efficacy.

5.4 The impact of cooling on solar panel's (power) performance

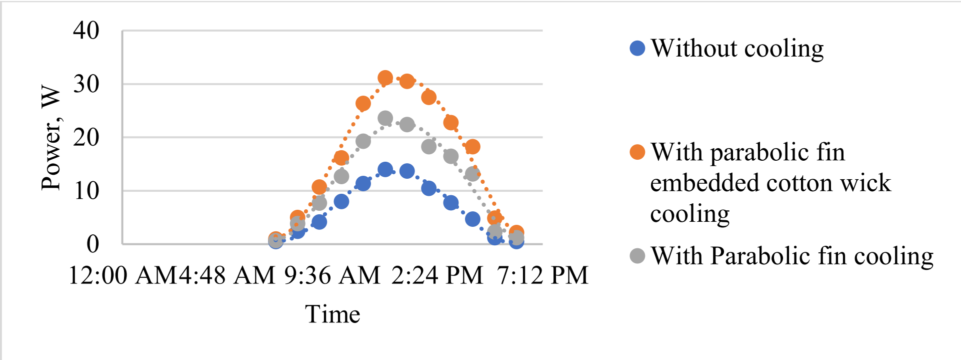

Fig. 5 : Effect of Different Cooling methods on Power development

Impact of cooling on solar panel's performance is shown in fig.5. The graph shows a remarkable increase in power production of PV module with cooling attachment. Photovoltaic module conversion efficiency is influenced by temperature and solar radiation intensity. Maximum power recorded for PV module with PFECW, with fin and without cooling were 31.2W, 23.6W, 14.2W respectively at 12.15pm. PV modules with CWIW have increased the power output to 31.2W due to rise in current and voltage values. The cotton wick soaked in aids in the dispersal of water behind the PV module, giving continual cooling during the test. The evaporative cooling method utilized for increase of performance of solar panel outperforms previous research.

6. Conclusions

High temperature of photovoltaic cell reduces its performance. The cooling approach utilized in this study outperformed similar strategies employed in prior studies in terms of performance. A predictive polynomial regression model also gives significant examination models to interpret the experimental results. The evaporative cooling function of the PFECW aids in removal of heat from photovoltaic module and improves the working performance.

- PFECWs technology has strong cooling capacity, can regulate the temperature of photovoltaic modules, is inexpensive in cost, easy to install, and uses less water.

- PFECW put behind solar panel acts as a cooling device, lowering the PV module temperature by 29% as compared to an uncooled PV module.
- Wet water cotton bristle provides enough cooling for the module, increasing efficiency to 12.25% and power production by 20.4W.
- Using CWIW increases output by around 14% since PV module loss is minimized when compared to uncooled PV module.
- When compared to prior research, the cooling procedure utilized in this study enhances performance of photovoltaic module, making it more suitable for the application.
- When temperatures of the solar cells increase to 59.4°C, there was a decline in electricity production and performance of photovoltaic modules.
- With a high R2 of 0.989 and a low SE, the suggested polynomial regression displayed remarkable predictive reliability.
- The proposed method of integrating polynomial regression and experimentation would predict power and cooling temperature for PV modules.

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