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THE EFFECT OF RELATIVE HUMIDITY ON PHOTOVOLTAICS ENHANCED WITH AUTOMATIC COOLING MECHANISM

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Abstract

This study investigated the sensitivity of photovoltaic (PV) modules towards relative humidity close to the Calabar river in Cross River State, Nigeria. An automatic cooling mechanism for thermal regulation and a smart photovoltaic Maximum Power Point Tracker (MPPT) tester for tracking the maximum power points of the modules were deployed in the study. In situ measurements were carried out in real-time outdoor conditions. Results indicated that adequate cooling of the PV modules positively affects the performance as well as efficiency. Improvement in the output electrical parameters was observed to be 12.5%, 10% and 23.7% for voltage, current and power respectively. Furthermore, the PV module with thermal regulation demonstrated an improved efficiency of 23.5%. It was also revealed that PV module performance deteriorated with low level of humidity if the module temperature exceeds its maximum operating cell temperature.

Keywords: Threshold temperature, Cooling mechanism, Relative humidity, Maximum power point, Efficiency.

1. Introduction

People who do not fully understand the science of solar photovoltaics are under the illusion that the hotter the module the more electricity it will generate, and this misunderstanding is been transferred to the way it is used and maintained. This misunderstanding coupled with the inappropriate care and maintenance towards it has led to its poor performance and efficiency which ultimately led to the poor acceptance of solar photovoltaic for electricity generation in Nigeria.

Photovoltaic cell is a beautiful technology that directly produces direct current (DC) electricity when exposed to light. when light is incident on a photovoltaic cell, DC electricity is generated. Unlike batteries and fuel cells, photovoltaics do not need to be recharged (Luque and Hegedus, 2011).

Solar energy has emerged as the leading essential source of renewable energy and the photovoltaic technology is the major technology for the conversion of solar to electrical energy. The discovery of the PV effect by Alexandre E. Becquerel in 1839 paved the way for the development of solar cells, since then enormous efforts has been poured into it to improve its efficiency (Gaur and Tiwari, 2013). As years goes by solar energy has gained more attention due to the role its playing in providing noiseless, pollution free and sustainable energy

(Jacobson and Delucchi, 2011). Irrespective of its sustainability, solar energy depicts the most favorable renewable energy resources (Bonkaney *et al*., 2017). However, researches that are linked to the nature of semiconductors used in solar cells have limited systems that incorporate photovoltaic technologies to the efficiency of 15-20%. To improve PV system efficiency, some adjustments and improvements, such as applying sun tracking system and maximum power point tracking controllers have been incorporated into PV system designs (Maghami *et al*., 2016). Other incorporations include automatic cooling mechanism, dust wiping mechanism lenses and mirrors. Usually, photovoltaic cells are expected to deliver its maximum output with low panel temperature in an atmosphere with considerable wind velocity. However, a number of factors influence its output, and they can be classified as unchangeable variables and volatile variables (Njok *et al*., 2020a). The unchangeable variables by default need to be adapted to while the volatile variables calls for modifications and flexibility in design so that installation requirements can be well taken care of. These variables affect the system design and the configuration of a photovoltaic panel, its operation and installation, and also play a significant role in its power generation (Njok *et al*., 2020a).

The efficiency of solar photovoltaics is largely influenced by the temperature it is subjected to, which depends on the ambient temperature, the level of sunlight (solar power and solar flux) as well as the humidity level (Aish, 2015). Solar photovoltaics are specially manufactured and designed to be operated in a perfect environment called the standard test conditions, where the humidity level is constant and the module temperature is also held constant at 25^0C with an air mass of 1.5 around it while receiving $1000W/m^2$ of irradiance (Ogbulezie *et al*., 2020). But during real outdoor operation these weather parameters vary continually, hence photovoltaic modules do not operate under the perfect environment they were designed and manufactured for (Ogbulezie *et al*., 2020). Even in the perfect environment, the module efficiency drops by about 0.40%-0.50% for each degree rise in temperature (Natarajan *et al*., 2011).

Due to the rising cost in fossil fuel (especially in Nigeria) coupled with various environmental issues arising from the burning of fossil fuel, it is of great importance that we recognize the potential of generating electricity through nonconventional sources. Renewable energy sources such as biomass, tidal, wind, geothermal, solar thermal and solar energy are viable options to check energy shortage and decrease environmental pollutions (Kamgba *et al*., 2017). Unlike the alternative sources of energy revealed above, fossil fuels are the foremost sources of energy in Nigeria, they can be rapidly depleted or temporary made unavailable due to scarcity and/or price as was observed in the most recent covid-19 outbreak (Corona Virus Disease 2019), a pandemic that triggered the Organization of Petroleum Exporting Countries (OPEC) to come to an agreement of reducing oil production to a record value of 10 million barrels per day in March 2020. This presents alternative energy sources as a viable option due to their limitless nature (Agbo *et al*., 2021).

The efficiency of photovoltaic modules will unavoidably plummet when forced to operate under temperature that exceeds its maximum allowable cell temperature. On exposure to light, their temperature rises with the absorption of infrared and other wavelengths that negatively affects their efficiency (Njok *et al*., 2020a). However, their dark nature permits them to easily heat up quite considerably (Boxwell, 2012). In a hot climate such as the one experienced in Nigeria (Ewona and Udo, 2010; Ewona and Udo, 2017), the temperature of a photovoltaic module can easily rise above 60^0C (Njok and Ewona, 2022).

EL-shaer *et al*., (2014) disclosed that the current parameter is the parameter mostly influenced by temperature. Njok and Ogbulezie (2018) revealed that the current and efficiency of photovoltaic modules increases with temperature up to the maximum operating cell temperature, beyond this temperature the efficiency begin to fall. Moharram *et al*., (2013) employed water cooling techniques to enhance the efficiency of photovoltaics and found that the power output of PV modules is significantly enhanced when the cooling is programmed to start at the maximum allowable temperature (MAT) of the PV cells. Njok *et al*. (2020b) researched on how sunrise and sunset times causes monthly variations in photovoltaic efficiencies and reported that photovoltaics would be more efficient in months with low average relative humidity coupled with low panel temperature in an atmosphere with considerable wind velocity. A study by Govardhanan *et al*., (2020) in which a PV module was cooled with uniform flow of water on its surface revealed that the application of cooling mechanism improved the output power as well as efficiency of the PV module by 15% and 14% respectively. Also, Arifin *et al*., (2020) performed a numerical and experimental study by employing aluminum heat sinks for effective cooling of PV modules. Their results were very encouraging as it revealed the open circuit voltage been raised by 10%.

Numerous researches are available on the effect of relative humidity on the performance of photovoltaics, but a huge percentage of the information out there does not apply to photovoltaics in Calabar. Generally, there is a huge lack of pertinent information on the effect of relative humidity on photovoltaics enhanced with automatic cooling mechanism in Nigeria (especially Calabar) that can be commendably employed for the purpose of designing and sizing of photovoltaic modules.

In this part of the world where the cost of assembling a photovoltaic system is relatively high, it is desired for the system to operate perfectly with little or no losses irrespective of the ambient temperature and humidity. But the temperature and average daytime level of relative humidity in Africa and Nigeria in particular do not encourage positive performance from photovoltaics. Meanwhile PV systems are most efficient in an ambience where the humidity does not enhance the module temperature to exceed its maximum operating cell temperature. Then the solution is to design and modify the PV system to be capable of operating at temperatures not above its maximum operating cell temperature, which leads to the introduction of the automatic cooling mechanism.

This research is aimed towards the experimental investigation on the effect of relative humidity on photovoltaics enhanced with automatic cooling mechanism.

2. Materials and method

2.1. Materials Used in This Research

Two identical polycrystalline photovoltaic module of the model AF-130W manufactured by Africell solar with rated maximum power of 130W was used in the research: electrical output parameters of the module are revealed in table 1. A submersible DC solar water pump, hose and water sprinkler were employed in the cooling section. While a smart automatic digital temperature sensor (model W1209) coupled to a relay were also utilized for the research. A digital infrared thermometer, solar battery (Gel battery: 12V, 100A) and a digital charge controller was also employed. While a digital high precision photovoltaic smart panel maximum power point tracker (MPPT) tester of the model WS400A was used to track and determine the maximum power generated by the photovoltaic module.

Table 1: PV module technical characteristics

Electrical Specification	Value
Maximum Power	130W
Current at Maximum Power	7.18A
Voltage at Maximum Power	18.10V
Short Circuit Current	7.91A
Open-circuit Voltage	21.72V
Number of cells	36
Module dimension	1480mm*670mm*35mm

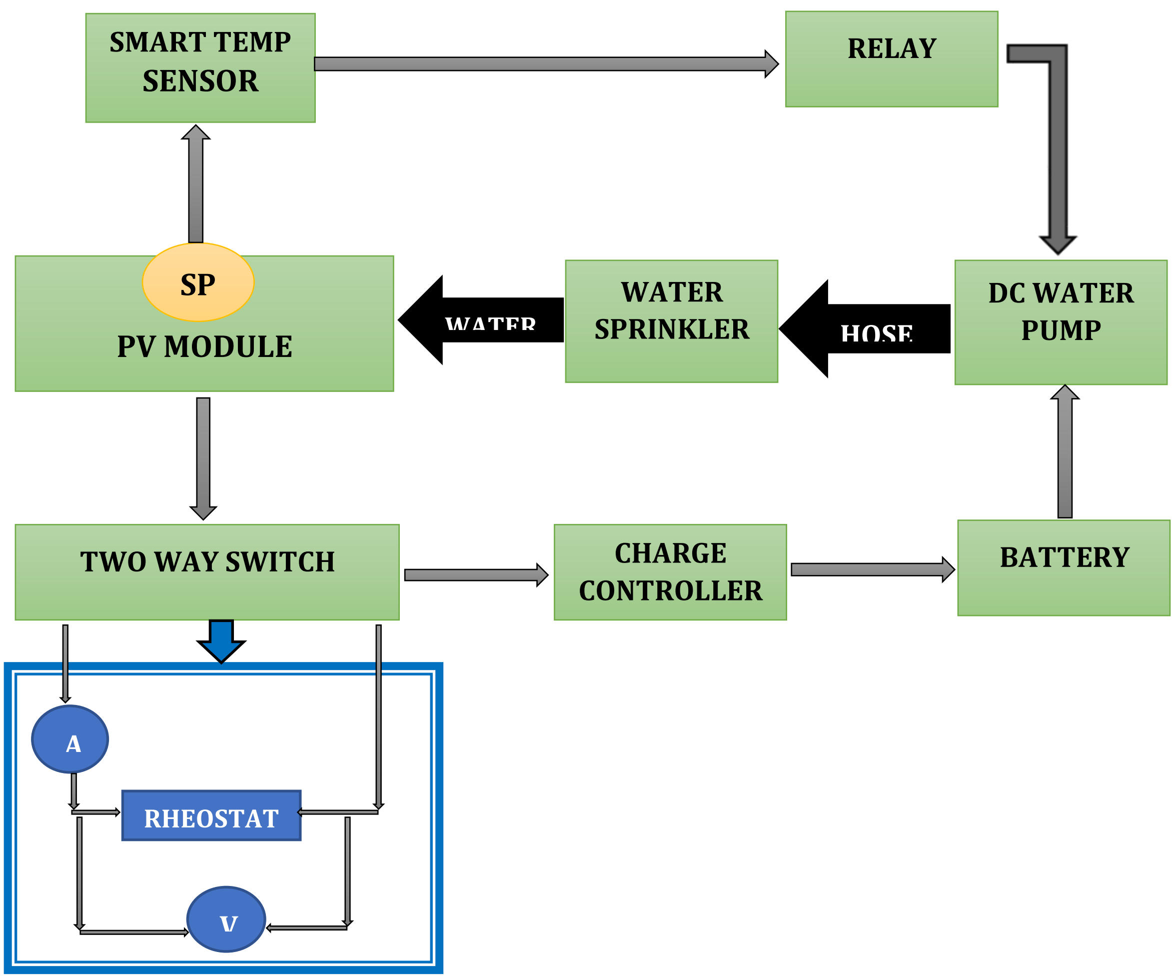

Fig 1: PV module experimental setup

2.1. **Experimental setup**

The experiment was carried out in an outdoor environment in Calabar at a location close to the Calabar River (latitude $4^0 57' 38.6161''$ N and Longitude $8^0 18' 58.482''$). The two PV modules were installed at an angle of 5^0 facing the north on a platform of 1m above sea level. One module was used as the control while the other was mounted and coupled with the cooling mechanism. Connecting cables were linked directly from the output of the PV module to the input of the photovoltaic smart panel MPPT tester from which the maximum power points were tracked and determined as described in Fig 1. Also, from the output of the PV module, connecting cables were linked to the charge controller which is linked to the battery to ensure smooth charging. The smart automatic digital temperature sensor was installed at the surface of the panel and its output was linked to a relay from which the submersible DC solar water pump was powered.

2.2. Measurement procedure

Data was acquired from the PV modules at an interval of 30 minutes from 6.00 am to 6.00 pm for a period of 4months. At the point of data acquisition, measurements were taken from both modules at the same instance of time.

2.3. Data processing and measurements

The research was carried out in real outdoor conditions. The panel temperatures were measured and recorded with the aid of the digital infrared thermometer. The instantaneous voltage V_{mp} and Current I_{mp} at maximum power under a particular real-time humidity level were measured and recorded. The open-circuit voltage V_{oc}, V_{mp}, I_{mp}, and, P_{max} values were taken with the aid of the smart panel MPPT tester. The open-circuit voltage (V_{oc}) and the voltage at maximum power $V_{mp}$of the PV module is greatly influenced by several parameters including design, maintenance of the module, humidity as well as temperature (T), and may be determined by (1) as shown by (Njok *et al*., 2020c), while the normalized power output efficiency was computed by (2) as shown by (Njok *et al*., 2020c).

$$V_{oc} = \frac{KT}{Q} ln \frac{I_{sc}}{I_o} \quad (1)$$

$$\eta_P = \frac{P_{mea}}{P_{max}} \times 100 \quad (2)$$

Where$P_{mea} = V_{mp} \times I_{mp}$

From the individual output electrical parameters (X), the performance gains X_{gain} of the PV module with thermal regulation can be calculated using (3)

$$X_{gain} = \frac{X_{with\ cooling} - X_{without\ cooling}}{X_{without\ cooling}} \times 100\% \quad (3)$$

3. Results and discussion

This section displays results acquired by in situ measurement and the analysis is about the impact of the cooling mechanism on the PV modules electrical parameters with different levels of relative humidity around it. The cooling mechanism is programmed to ensure that the panel temperature does not exceed 35^0C which is the preset threshold temperature (TT). It should be noted that the voltage, current and power used in the analysis of the results are the maximum voltage, current and power respectively that the modules can generate under a particular level of humidity.

Fig 2 displays the relative humidity level and the temperature behavior of the panels with and without the cooling mechanism throughout the day. From the figure it could be seen that between 6:00 to 12:30 there is a smooth decrease in relative humidity which is followed by a gradual rise in temperature of both panels from 6:00 to 10:00. Above 10:00 the temperature of the panels exceeds the threshold temperature (TT) and triggers the cooling mechanism to switch on to commence regulating the temperature of the panel not to exceed the TT, while the temperature of the panel without the cooling mechanism continues to rise. Between 10:00 to 16:00 the temperature of the panel with the cooling mechanism is regulated not to exceed the TT while the unregulated panel show rise and fall in temperature well above the TT as relative humidity varies fairly. After 16:00 the humidity level begins to rise which is accompanied by a decrease in temperature of both panels. Furthermore, between 12:30 and 16:00 the level of relative humidity remains almost stable, but the stability in the level of relative humidity is not reflected on the temperature of the unregulated panel due to accumulated absorption of infrared.

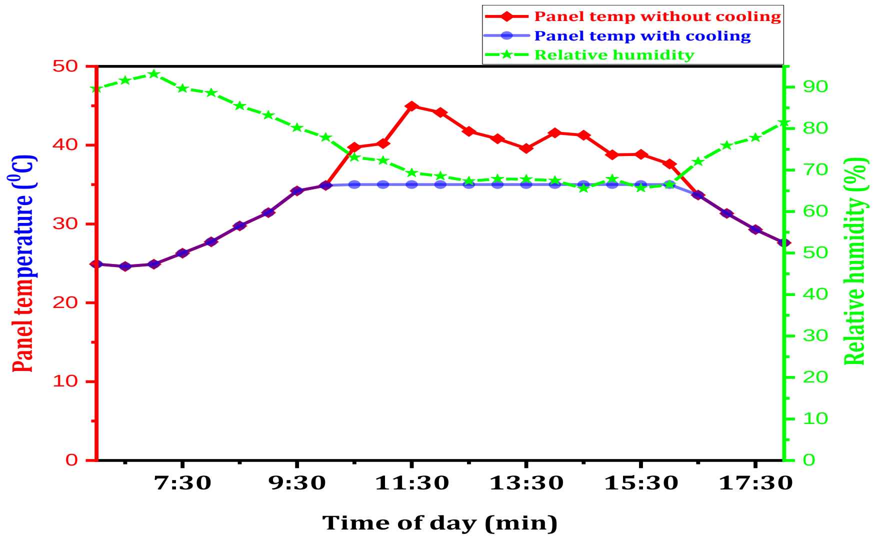

Fig 2: Panel temperatures and relative humidity at different time of day

Fig 3 reveals the temperature of both panels as relative humidity decreases. The figure reveals a steady increase in panel temperature for both panels as relative humidity decreases. At about 77.5% of relative humidity, the temperature of the panels exceeds the TT and the cooling mechanism is triggered to regulate the temperature of panel with the cooling mechanism, while the panel without temperature regulation continues to experience increase in temperature as relative humidity further decreases.

Fig 4 depicts the voltage performance of both panels as relative humidity decreases. It shows that high relative humidity does not enhance the voltage performance of photovoltaics, which is in agreement with studies by (Njok and Ogbulezie, 2018). However, the figure reveals that low relative humidity enhances the PV module to exceed its MAT which triggers the cooling mechanism on. Furthermore, it could be clearly seen that the PV module under thermal regulation shows a better voltage performance with an increase in voltage of 12.5% which agrees with earlier studies by Arifin *et al*., (2020) who reported that with the application of cooling mechanism the open circuit voltage was raised by 10%. The current generated by both modules with respect to relative humidity is portrayed in Fig 5 which depicts the PV module under thermal regulation generating higher current. The current generated by the PV module under thermal regulation was 10% higher than that without regulation, which conforms to studies by Ogbulezie *et al*., (2020) whoreveal that PV module temperature above its maximum operating cell temperature adversely impact on its performance ratio.

The power generated and the efficiency of both modules with and without thermal regulation with respect to relative humidity is displayed in Fig 6 and Fig 7 respectively. Both figures starkly depict the module under thermal regulation generating higher power as well as attaining higher efficiency. The higher power (23.7%) and efficiency (23.5%) produced by the module with thermal regulation follows from the fact that it generated higher voltage and current when compared with that without thermal regulation. Fig 6 and Fig 7 is in agreement with study performed by Govardhanan *et al*., (2020) which revealed that the application of cooling mechanism improved the output power as well as efficiency of the PV module by 15% and 14% respectively.

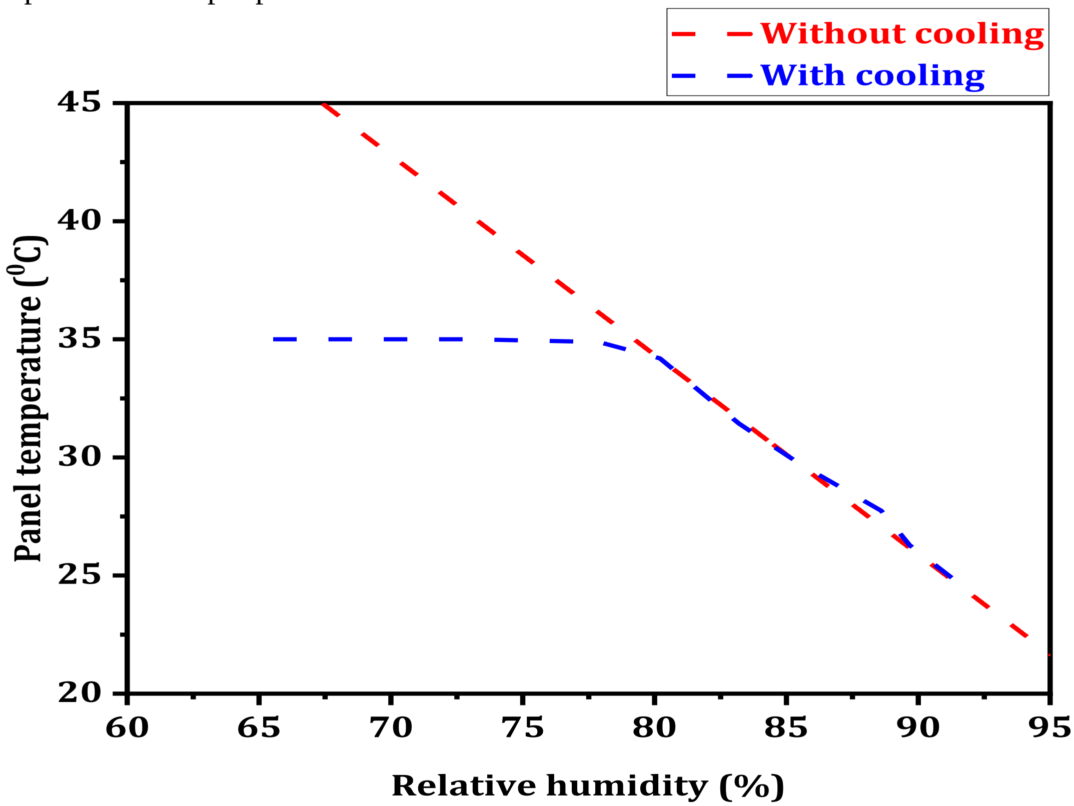

Fig 3: Influence of cooling mechanism on panel temperature with respect to relative humidity

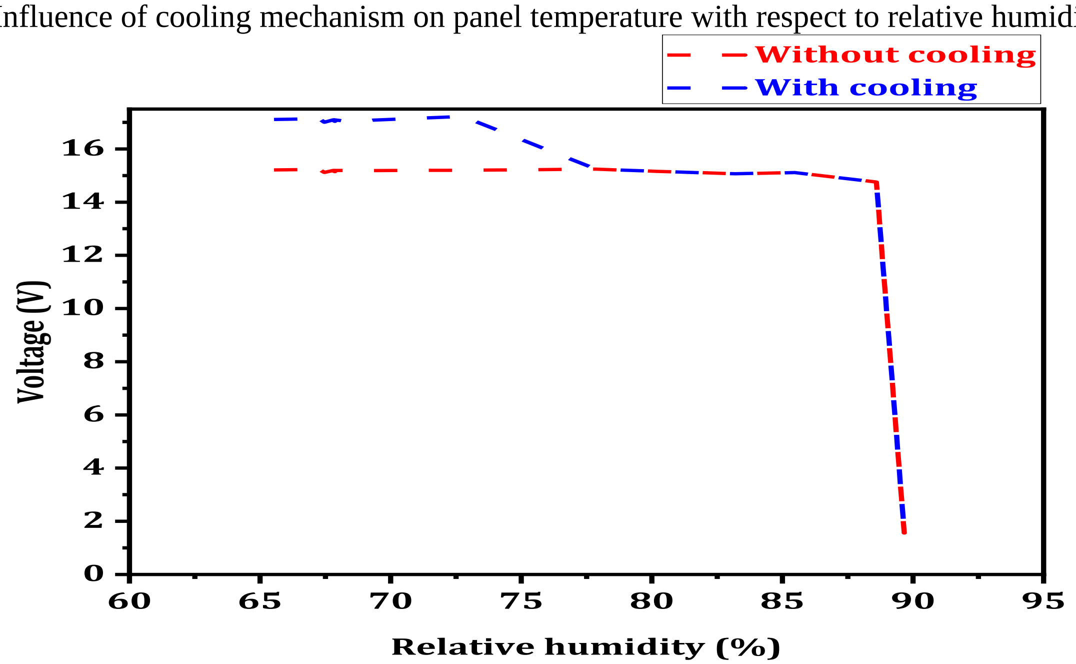

Fig 4: Influence of cooling mechanism on panel voltage with respect to relative humidity

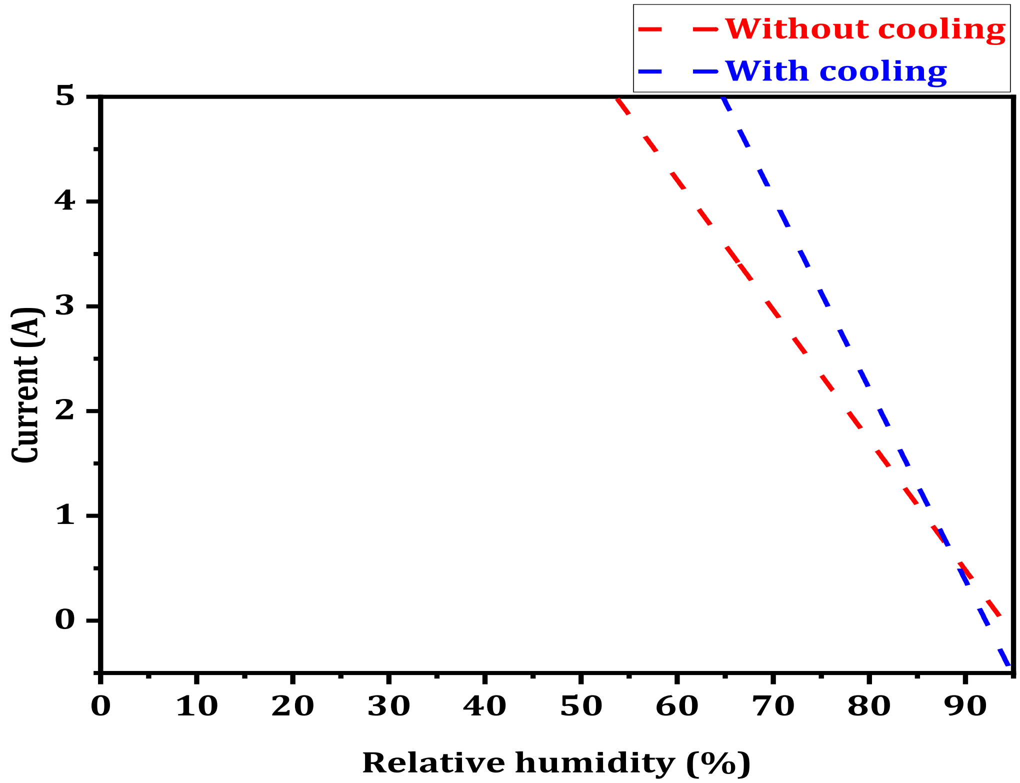

Fig 5: Influence of cooling mechanism on panel current with respect to relative humidity

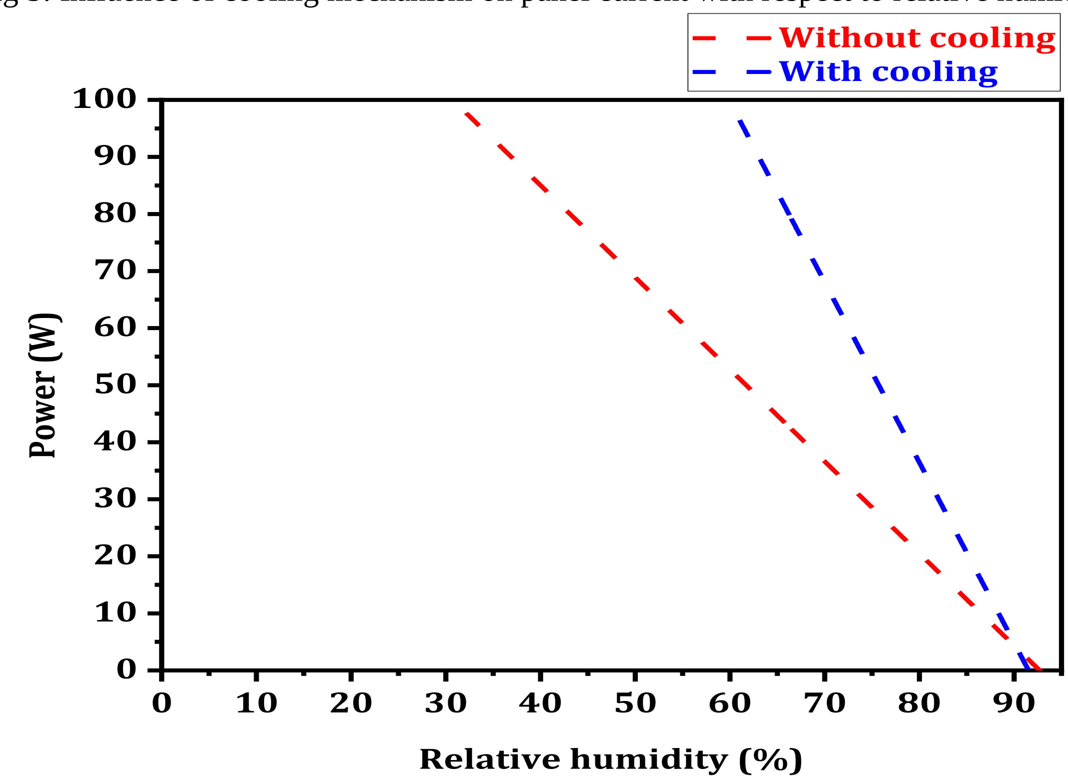

Fig 6: Influence of cooling mechanism on power output with respect to relative humidity

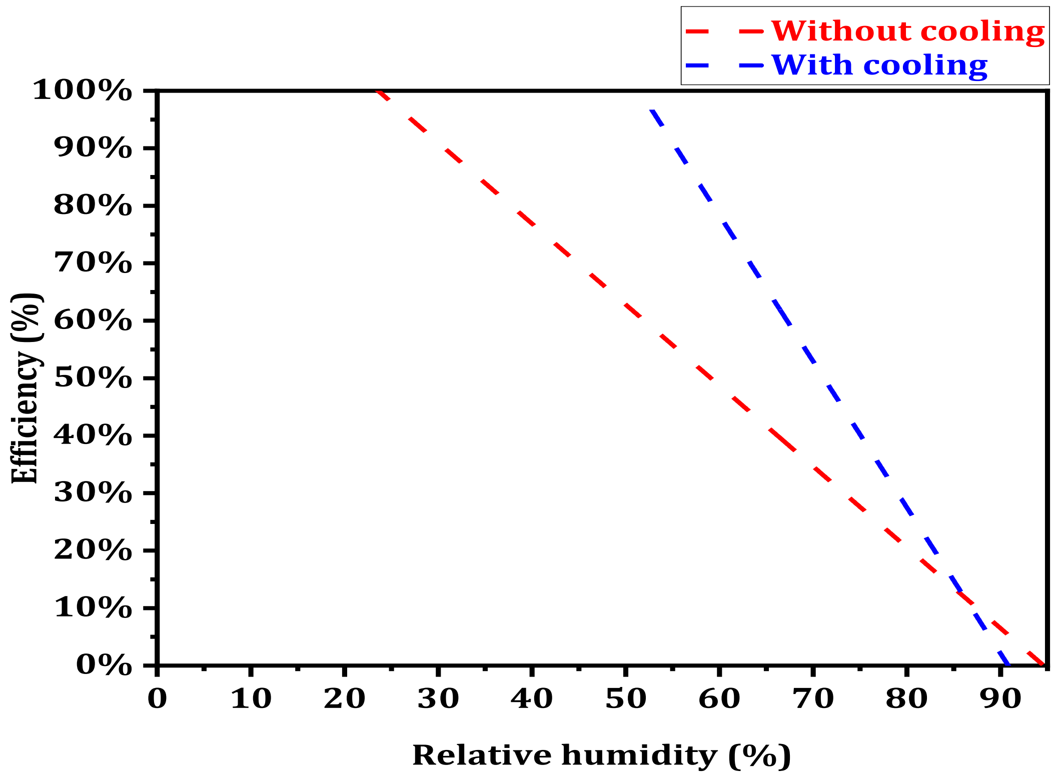

Fig7: Influence of cooling mechanism on panel efficiency with respect to relative humidity

4. Conclusion

The comparative performance and efficiency of two identical polycrystalline silicon photovoltaic modules with and without thermal regulation with respect to relative humidity was investigated experimentally. The outdoor experimental measurements of the module's performance were obtained; impact of cooling mechanism was determined by obtaining the output operating parameters of both modules. One PV module was installed with an automatic cooling mechanism while the other without thermal regulation served as the control. It was observed that as the level of relative humidity decreases the temperature of the modules increases. Once the temperature of the module exceeds its preset threshold temperature, the cooling mechanism is automatically switched on to commence thermal regulation. The study revealed that low relative humidity level which corresponds to high module temperature deteriorated the electrical performance and efficiency. Due to the application of the cooling mechanism, an increase in electrical parameters of 12.5%, 10%, 23.7% and 23.5% for voltage, current, power and efficiency respectively was observed. The study proves that cooling mechanism should be considered by engineers when designing, sizing and installing PV systems.

Abbreviations

PV: Photovoltaic
V_{oc}: Open circuit voltage
V_{mp}: Voltage at maximum power
I_{mp}: Current at maximum power
P_{max}: Maximum power of PV module at STC
MPPT: Maximum power point tracker
STC: Standard test condition
SP: Sensor probe
TT: Threshold temperature
MAT: Maximum allowable temperature

Conflicts of Interest

The authors declare that no conflict of interest exist between them that might influence the work described in this manuscript.

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