Enhancing the performance of photovoltaic module by water cooling.

[1]Ekpo, C.E., [1]Kogbe, K.O. and [2]Udo, S.O.
[1]Department of Physics, University of Uyo, Uyo, Nigeria
[2]Department of Physics, University of Calabar, Calabar, Nigeria

Abstract -The efficiency of photovoltaic panel decreases with increase in temperature there by reducing the quantity of electricity generation. To enhance the performance of PV system, water –based cooling system is investigated by an experimental set-up. Two identical PV modules are used for the experiment for two days at different tilt angles for each day, one with an active cooling system and the other without a cooling system. The experiments were done on 4th November, 2017 and 5th November, 2017 at tilt angles of 15^o and 5^o respectively. On the 4th of November, 2017, both modules were tilted to 15^o and on 5th of November, 2017 the modules were adjusted to 5^o according to the latitude of Uyo town. For both days, output voltage and current, irradiance and temperature values were measured. The experimental set-up reports that without active cooling, the temperature of the modules were high as a result of which the module achieved a maximum operating efficiency of 8% and with cooling maximum efficiency of 11% was achieved for 4th of November, 2017 when the modules were oriented at 15^o. 5th of November, 2017 reports a maximum efficiency of 14% without cooling and a maximum efficiency of 20% with active cooling when the modules were adjusted to 5^o according to the latitude of Uyo. Generally, the results show that active cooling and tilting modules to the angle of the site's latitude reduces the temperature of the cells and increases electrical efficiency of the PV panel.

Keywords -Temperature, Efficiency, Photovoltaic and cooling.

---

1. Introduction

Energy has become one of the greatest challenges of this century. Before now, fossil fuels such as petroleum, coal and natural gas were the main energy resources available for human energy needs. The emergence of renewable energy has brought succor to the non-sustainability and environmental pollution of the fossil energy sources.

With the increasing human population and the unending quest for sustainable energy, a question arises; what will be the next reliable source of energy in Nigeria after the disappearance of fossil fuel?

Solar energy offers the largest resource of renewable energy. It manifests itself directly as solar irradiance and indirectly as wind energy and hydropower. Solar energy has a great potential in Nigeria, considering it location in the tropical region and an annual daily sunshine of 6 hours.

According to Chen (2011), if only 10% of the total solar radiation is utilizable, 0.1% of it can power the entire world. Photovoltaic module is one technology that can be used to harvest the clean energy from the sun through the principle of photoelectric effect, thereby mitigating the production of harmful release into our environment. The photovoltaic technology comes with its limitation of overheating. The cells are affected by high temperature in a negative way due to the negative temperature coefficient of crystalline silicon.

According to Lee et al; (2008), it is estimated to be in the range of -0.4% to -0.5% per Kelvin. This implies that for everyone Kelvin of temperature rise, there is a corresponding drop of 0.4% to 0.5% in the efficiency.

The high temperature is due to excessive solar radiation and high ambient temperature. This causes the efficiency of the solar cells to reduce. A decrease in the temperature of the PV cells can lead to a rise in the efficiency of the PV cells. It is therefore pertinent to intensify efforts to reduce the cost of photovoltaic cell production and enhance the efficiency as well. This will enable the photovoltaic technology to compete with other conventional energy resources.

Solar radiation is one of the most important parameter for PV technologies. Without solar radiation, no electricity can be generated from it. It is important to record the performance of PV modules under real climate condition because the outdoor PV electrical characteristics (voltage and current) are different from those corresponding standard conditions (which rarely occur outdoor). The PV modules are rated at standard condition of 1000W/m2 of irradiance, 25 °C of ambient temperature, air mass of 1.5, and 1 m/s wind speed different from outdoor environmental conditions (Perraki et al., 2013). Despite the fact that irradiation is the main indicator of PV potential, it is also necessary to consider secondary parameters such as PV technology, environmental parameters (wind, temperature, humidity). They allow us to quantify with precision the amount of electricity produced by a PV system (Bashir et al., 2013).

The design of a photovoltaic system must balance the rate of solar energy deposition on a given area with the power required by the load. The measure of the total solar irradiance commonly used to access the input for photovoltaic panels is the daily peak sun hours and the number of daily peak sun hours is equal to the value in kwh of the total amount of direct and diffuse solar radiation incident on a square meter in a day (http://www.learnabout energy.org/renewable energy/renewable energy 4.html).

In recent years, there has been an increasing amount of literature on PV systems. Numerous attempts have been made to improve the performance of such systems. Several studies focused on the effect of dust, the type of photovoltaic modules used, the tilt angle and meteorological parameters such as humidity, cloud cover, temperature and wind speed on the efficiency of PV systems.

Solar cell temperature is one of the most important factors responsible for lowering the performance of PV modules (Jakhrani et al., 2011). Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons move. This is due to an increasing resistance of the circuit resulting from the rise in temperature. Therefore, resistance decreases with decreasing temperatures (Jakhrani et al., 2011).

The temperature modifies the power output and the system efficiency. The solar cell temperature depends on the module encapsulating material, the thermal dissipation, the absorption properties, the functioning point of the modules as well as the irradiance intensity, ambient temperature, wind speed and the accurate installation (Perraki et al, 2013). Therefore, it is important to perform a quantitative analysis of the temperature influence on PV modules properties such as voltage, current, efficiency under real operating conditions. Thus, increased temperatures affect all PV technologies. However, certain types of modules are more resilient to temperature increasing than others. Based on experimental investigation in Pakistan, it was reported that monocrystalline silicon modules are more efficient than other modules. However, they have shown a higher decreasing at higher module temperatures (Bashir et al, 2013). Diaf, et al, (2008), have investigated the impacts of irradiance and temperature on PV system. They found that solar irradiance has the greatest impact on the power output of PV systems since it determines the module surface temperature.

Krauter (2004) carried out a study on increased electrical yield through water flow over the front of photovoltaic panels. He discovered that reflection on the PV panel can be reduced by causing a film of water to run over the surface of the solar panel. The reduced temperature resulted in an increase efficiency of 10.3%.

In a study, an attempt was made by Zhu at el (2010) to optimize the collection of solar energy within the period of its availability in order to increase its utilization through appropriate determination of optimum solar collector tilt angles. The results of this work confirmed that solar radiation on tilted surfaces increases with latitude. Latitudes between 1^0 and 14^0 were simulated.

According to Tomislav, et al (2010), the power incident on a PV module depends both on the power contained in the sunlight, and the angle between the module and the sun rays. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight. Nevertheless, the best technology of PV enabling the sunlight perpendicular to the PV panels, i.e., the solar tracking systems, is much more expensive than fixed PV systems. Tilting the surface causes the diffuse light to decrease. Thus, in cloudy sky condition, it is better to put the panel horizontally in order to have a best capture of the direct solar radiation, because PV panel works with global radiation. So the best option is to put your PV panel to the optimal tilted angle in order to yield more outputs. A good orientation and tilt angle of PV module can maximize its energy potential. For the best performance of your systems in the year, in most locations, fixed PV modules should be oriented to true south (in the Northern Hemisphere). In the case that there is no possibility to move the surface of the PV modules at all, the optimal tilt angle for maximum amount of direct irradiance is to set it to the site's latitude. According to (Mondoc and Pop, 2010), the best tilt angle for any PV array is the one that produces the highest annual energy output for that particular location. The primary reference point is the latitude of the site.

Teo et al., 2012 carried out an active cooling system for photovoltaic modules. To cool the PV cells a parallel array of ducts with inlet and outlet manifold designed for uniform air flow distribution was attached to the back of PV module. The experiment was carried out with and without active cooling. Without active cooling, the temperature of the module was high and solar cell achieved an efficiency of 8-9%. For the module operated under active cooling condition, the temperature of the module dropped significantly and solar cell achieved efficiency of 12-14%.

Moharram et al., 2013 carried out experiment for enhancing the performance of photovoltaic panels by water spraying. When the temperature of PV panel reached maximum allowable temperature of 45^{o}C the temperature sensor runs the motor resulting in water spraying on PV module and cools the PV cell to normal operating temperature of 35^{o}C. From the result it was found that PV panels yield the highest output energy by cooling the PV panels to the normal operating temperature at cooling rate of the solar module 20^{o}C/min. In the same vein, heat has an effect on panel degradation. Consequently, long term exposure to heat will damage the panel more rapidly, some materials may not be even able to withstand short peak of very high temperature (Kurtz et al 2009). It is possible to cool PV panel either passively through natural air flows (Tanagnostopoulo et al, 2010), or actively, through forced air (ventilation systems and liquids coolants).

Relative humidity affects the efficiency of the solar cell. It is the amount of water vapor present in the air. When the light consisting of energy/Photon strikes the water layer which in fact is denser, refraction occurs, which results in the decrease of intensity of the light which appears to be the root cause of decreasing of efficiency (Dill L. M, 1977). Also there are minimum components of reflection which also appears on the site and in that, there appears light striking is subjected to more losses. Efficiency of a module is termed as the amount of the light that can be converted by the module into usable form of electricity. Because efficiency depends upon the value of maximum power point of the solar cell, due to the effect of humidity, the maximum power point is deviated and that indirectly results in decreasing of the solar cell efficiency (Mustapha and Khan, 2009). The effect of humidity on the solar panels which create obstacles for drastic variation in the power generated, indirectly make the device work less efficient than it could have without it.

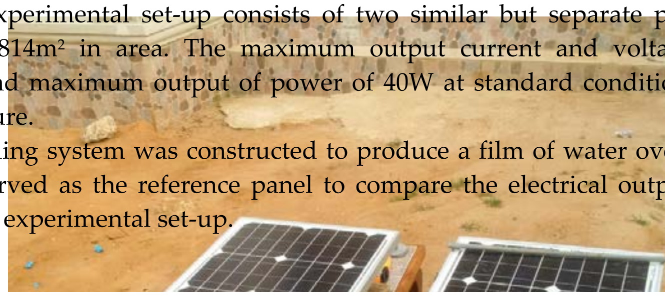
Skoplaki et al(2009) identified wind velocity as one parameter that influence the efficiency of solar cells. By increased wind velocity, more heat can be removed from the PV cell surface. In the same vein, higher air velocity lowers the relative humidity of the atmospheric air in the surroundings which in turn leads to better efficiency (Mekhilef et al., 2012)

2. Methods

The experimental set-up was designed to investigate how of temperature and tilting of solar panels with respect to the horizontal influence the power output and ultimately, the efficiency of the PV modules in Uyo Akwa Ibom State.

The experimental set-up consists of two similar but separate photovoltaic modules of 40 watt, measuring $0.2814m^2$ in area. The maximum output current and voltage are 2.25Amps and 17.8VDC respectively and maximum output of power of 40W at standard conditions of $1000w/m^2$ irradiance and 25^0C temperature.

A cooling system was constructed to produce a film of water over one of the PV panel, while the other panel served as the reference panel to compare the electrical outputs. Figure 1 shows a schematic diagram of the experimental set-up.



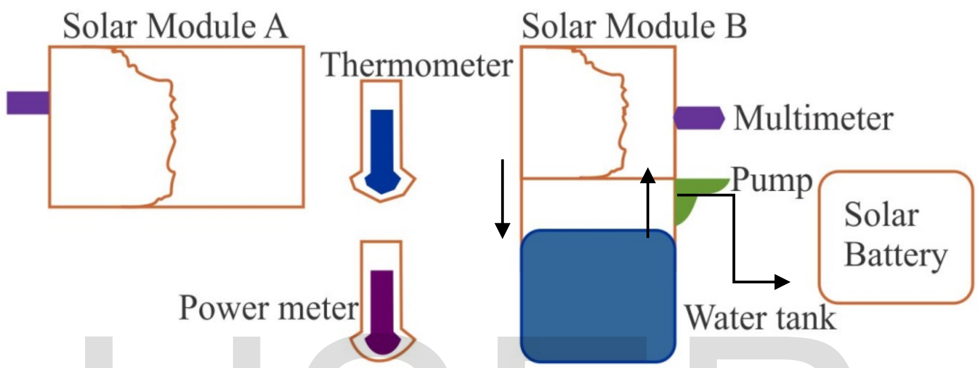


Figure 1: Schematic diagram showing the general experimental setup for module with cooling (B) and that without cooling (A).

Film Cooling

The cooling of the photovoltaic panel was achieved by constructing a 30 liters water tank where a water pump of maximum head of 3.1 meters and a flow rate of 1liter per minute was connected to pump water to feed a perforated pipe installed at the top end of the photovoltaic panel. The water collected at the lower end of the module passes through the 30 liters tank located under the solar panel and the cycle continues. Figure 2 gives a general view of the experimental system used.

ISSN 2229-5518

Figure 2 :*General view of the experimental system used.*

3. Experimental Procedure

The experimental was conducted and the data were recorded every thirty minute from 9:00am to 4pm on Saturday; November 4th and Sunday November 5^{th}, 2017 under the meteorological conditions of Uyo (latitude 5^0 3^1 N and longitude 70 56^1E) in Akwa Ibom State, Nigeria.

The time interval was selected due to the fact that the intensity of the sun is appreciable within this interval.

SM206 high quality professional Mini Pocket High Precision Solar power meter installed in between the modules normal to the modules inclination was used to capture the daily global solar irradiation. The module maximum output power was determined from current and voltage measurement by using two multimeters connected to the two solar panels, one connected to the solar panel without a cooling system and the other connected to that with a cooling system to measure simultaneously. The product of the output voltage and output current gives the power produced from the module.

GM320 Laser Non-Contact Infrared Digital Gun Thermometer -50~380^{o}C was used to capture the temperature on both panels

Calculation of the efficiency of the system

The efficiency of the system is that portion of the irradiance that can be converted by the photovoitaic module into electricity.

The efficiency is calculated based on the following equation:

$$ŋ = \frac{V \times I}{A \times E} \quad x \quad 100…………… \qquad \text{Equation } \mathbf{1}$$

Where

ŋ = efficiency in %

V = output voltage …………in volt

I = output current…………in ampere

E = solar flux or solar intensity ………. W/m^2

A = surface area of the photovoltaic module …..m^2 ($0.2814 m^2$)

P = I x V ………………………………….. Equation **2**

4. Result and Discussion

Photovoltaic module with active cooling and without cooling was set-up in order to determine the most efficient system. Both panels we exposed to similar meteorological conditions, and the inclined to the same lilt angles of 15^0 and 5^0 respectively for day 1 and 2. Current, voltage, solar irradiance and surface temperature readings were taken on both systems simultaneously to aid the comparison

Figure 3 represents the effect of the active cooling on the PV panels power output inclined at $15^{0.}$ While fig 4 shows the effect of the active cooling on the panel's power output inclined at 5^0.

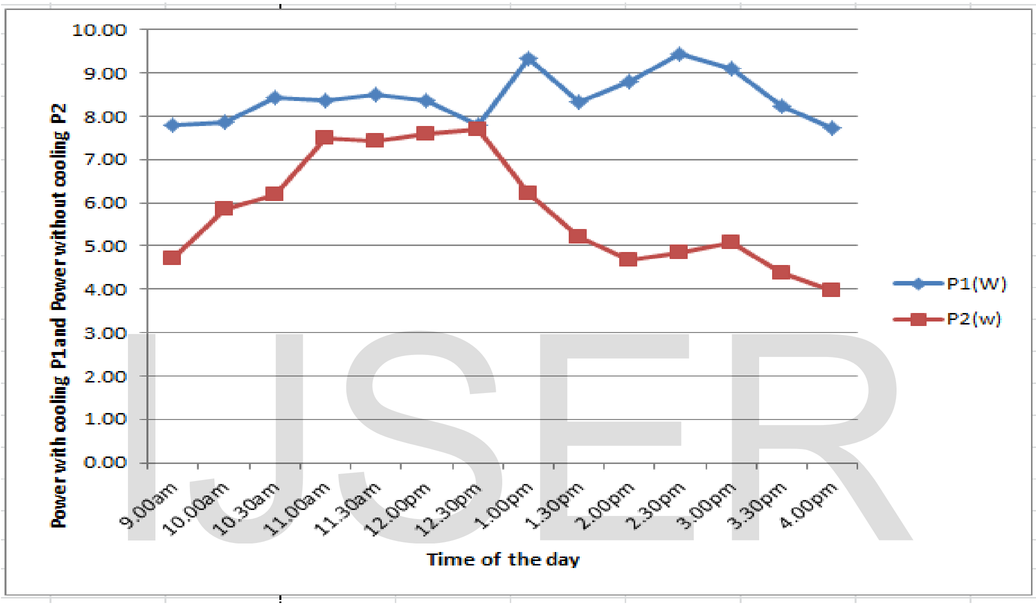


Figure *3: Comparison of Module power with Cooling (P1) and without Cooling (P2) inclined at* 15^o

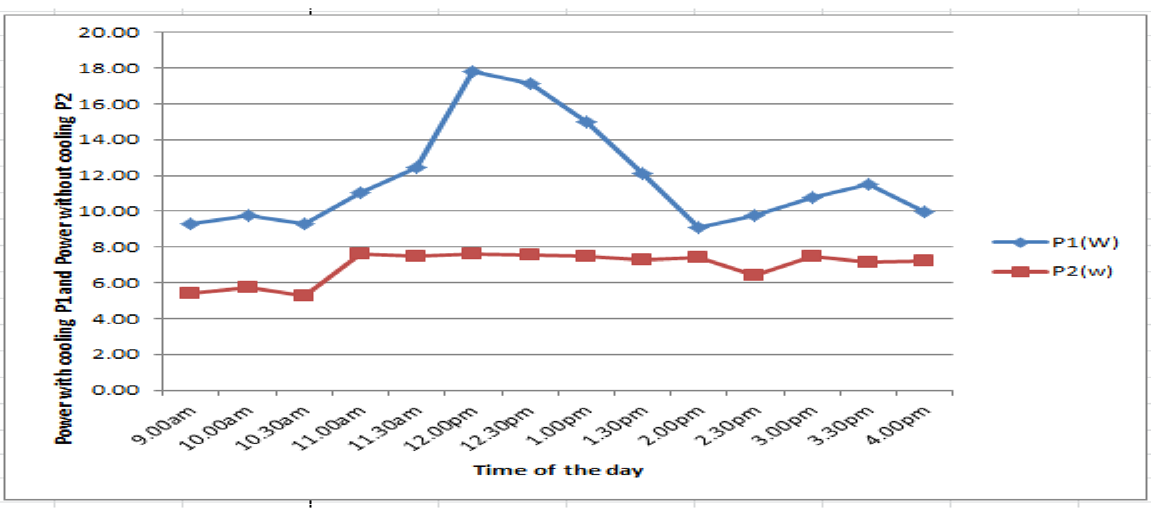


Figure *4: Comparison of Module power with Cooling (P1) and without Cooling (P2) inclined at 5°*

The average power output for the panels cooling, inclined at 15⁰ is 8.44W and 11.78W for panel inclined at 5⁰.

The average power output for PV without- cooling inclined at 15⁰ and 5⁰ are 5.82W and 6.94W respectively.

It can therefore be seen that the PV module with active cooling inclined at 15⁰ is more efficient than the system without cooling by 3%.

However the combined effect of cooling the photovoltaic module and inclining the module to 5⁰ with respect to the horizontal, according to the latitude of Uyo yield an average efficiency of 14.3%.

The efficiency was peak between 3:30pm and 4pm due to the erratic nature of the weather.

Figure 5 shows the comparison of module efficiency with cooling at 5⁰ and cooling at 15⁰.

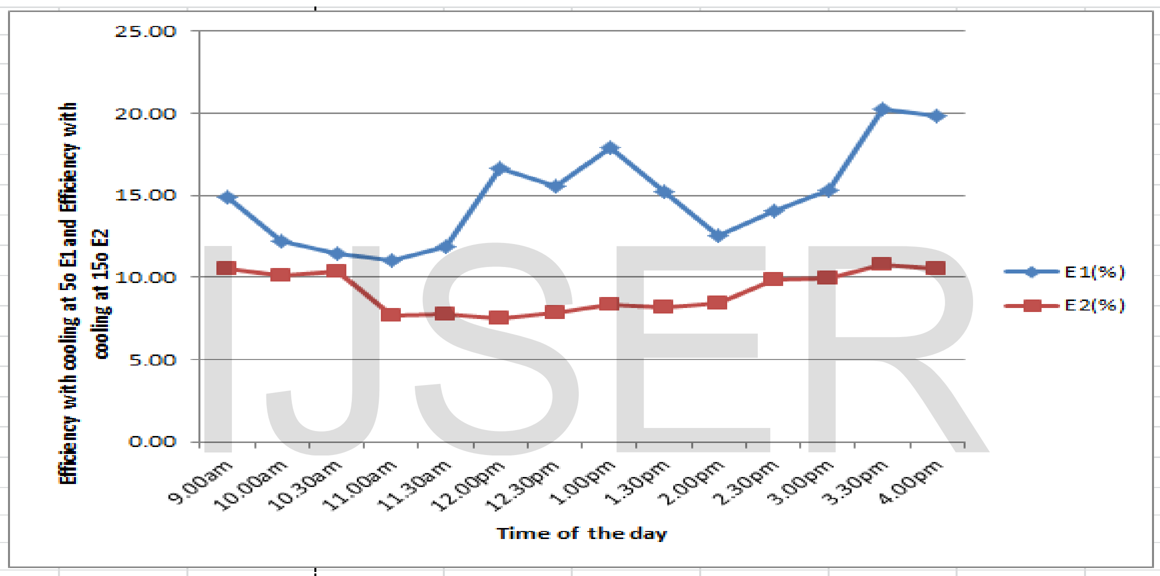


Figure *5: Comparison of Module Efficiency with Cooling at 5° (E1) and with Cooling (E2) inclined at 15°*

Figure 6 shows the effect of the water cooling on the photovoltaic solar panel when the modules were inclined to 15⁰. The maximum temperature of the PV panel with cooling and without cooling 34⁰C and 52.5⁰C respectively the average temperature difference is 14.83⁰C.

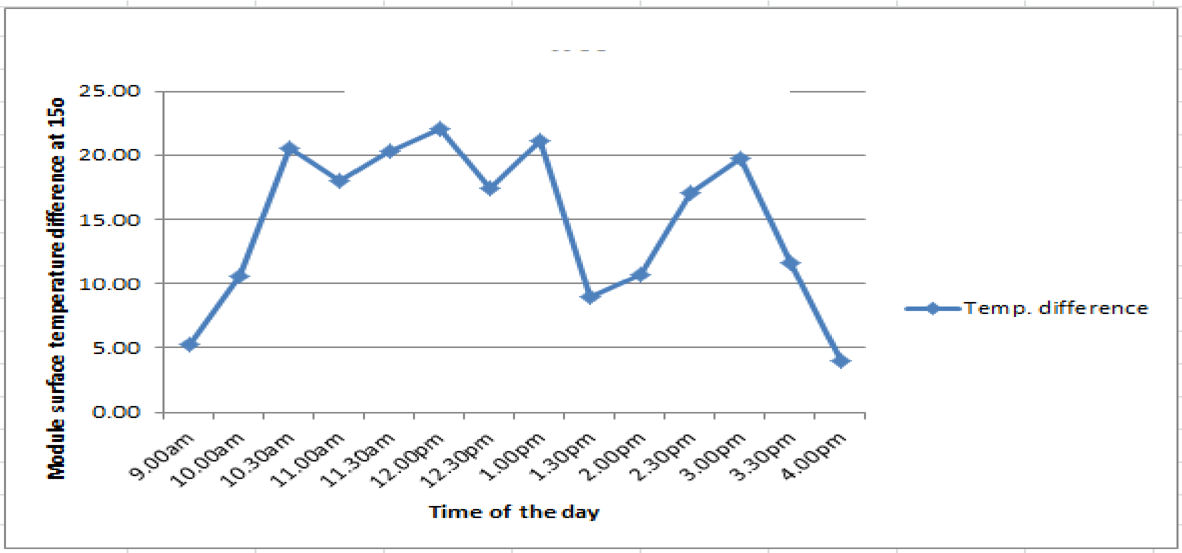


Figure *6: Difference in the Module Surface Temperatures with and without Cooling inclined at 15°*

Figure 7 also shows the effect of cooling on the solar module when the panels were inclined to 5^0. The maximum temperature for the panel without cooling and with active cooling are 56.8^0C and 33^0C respectively with an average temperature difference of 11.74^0C. From these experimental results, it can be seen that the cooling of the solar panel yielded a positive effect on the PV modules output. Although the cooling did not reduce the cell temperature to and below the conventional module temperature of 25^0C but it did not allow the cell temperature to rise above the operating temperature of 75^0C which would have destroyed the solar cells.

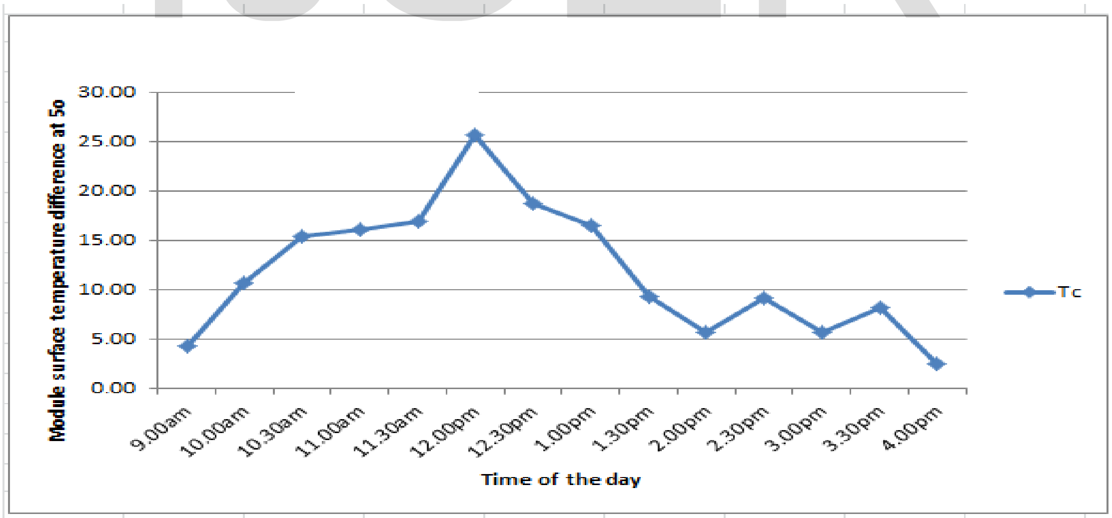


Figure *7: Difference in the Module Surface Temperatures with and without Cooling inclined at 5°*

It can therefore be established that the photovoltaic module efficiency is inversely proportional to the cell temperature. Consequently, reducing the cell temperature will definitely increase the photovoltaic module efficiency.

5. Conclusion

This article has presented enhancing the performance of the photovoltaic module using water cooling technique. In addition to this, the orientation of the PV panel was also investigated. There was a comparison with the tilt angle of 5^0 the site location being Uyo town (Latitude $5^0\,3^1$, longitude) and 15^0 tilt angle during the period of 4th November, 2017 and 5th November, 2017.

The maximum efficiency was obtained when the PV Modules were tilted to an angle of 5^0, the results show that there is an enhancement in the performance of the panel. Therefore, applying the two techniques together by cooling and tilting gave the best results for increasing the output power generated by PV module.

The cooling resulted in the module surface temperature decrease and increase in the output voltage and consequently the electrical efficiency and output power increased.

REFERENCES

[1] M. A. Bashir, H. M. Ali and A. M. Siddiqui, "An experimental investigation of performance of photovoltaic modules in Pakistan", *Thermal Science 2013,* doi: 10.2298/TSCI130613134B. Retrieved on 4th October, 2017.

[2] C. J. Chen, "Physics of Solar Energy", Department of Applied Physics and Applied Mathematics, Columbia University. John Wiley & Sons Inc. New York. 374p, 2011.

[3] S. Diaf, G. Notton, M. Belhamel , M. Haddadi, L. A,"Design and technoeconomical optimization for hybrid PV/wind system under various meteorological conditions" Applied *Energy*, 85, 968–987, 2008.

[4] Dill, M. Lawrence,"Refraction and the spitting behavior of the archerfish (Toxotes chateaus)." *Behavioral Ecology and Sociobiology* 2.2: 169-184, 1977.

[5] S. Krauter, "Increased electrical yield through water flow over the front of photovoltaic panels" Solar energy materials and solar cells 82 (1-2), 131-137, https://doi.org/10.1016/j.solmat.2004. Retrieved on 9th December,2018.

[6] S. Kurtz, D. Miller, M. Kempe, N. Bosco, J.K. Whitefield, N. Dhere and T. Zgonena, T, "Evaluation of High-Temperature Exposure of Photovoltaic Modules" 34th IEEE Photovoltaic Specialists Conference, Philadelphia, Pennsylvania, 1– 9, 2009. https://onlinelibrary.wiley.com/doi/full/10.1002/pip.1103. Retrieved on 14th May, 2017.

[7] B. Lee, B.J. Liu, B. Sun, Y.C. Shen and C.G. Dai, "Thermally Conductive and Electrically Insulating EVA Composite Encapsulants for Solar Photovoltaic (PV) Cell". Express Polymer, Vol.2, No.5, 357-363, 2008.

[8] M. Mani.and R. Pillai, "Impact of dust on photovoltaic (PV) performance: research status, challenges and recommendations", Renewable and Sustainable Energy Reviews, 14, 3124-3131, 2010. https://pdfs.semanticscholar.org. Retrieved on 23rd July, 2017.

[9] S. Mekhilef, R. Saidur and M. Kamalisarvestani, (2012). " Effect of dust, humidity and air velocity on efficiency of photovoltaic cells", Renewable and Sustainable Energy Reviews, 16, 2920–2925,2012. http://doi.org/10.1016/j.rser.2012.02.012. Retrieved on 18th May, 2017.

[10] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil and H. EI-Sherif, "Enhancing the performance of photovoltaic panels by water cooling," Ain Shams Engineering Journal; 4: 869-877, 2013.

[11] B. Mondoc and F. Pop, " Factors Influencing the Performance of a Photovoltaic Power Plant", 3rd International Conference on Modern Power Systems MPS, 2010, https://ie.utcluj.ro>MPS-2010-Mondoc. Retrieved on 14th September, 2017.

[12] G. Mostafa, and F. Khan (2009). "An efficient method of Solar Panel Energy Measurement System", Dhaka nancyschuelke.hubpages, Top-5-Users-of-Solar-Energy-In-the-World. 18997-population-coastal-areas-infographic.html, .live science, 2009, .https://ieeexplore.ieee.org>iels. Retrieved on 23rd September, 2017.

[13] V. Perraki and G. Tsolkas, "Temperature dependence on the photovoltaic properties of selected thin-film modules, 2. Effect of Temperature on the I-V Characteristics of PV Modules", 2(4), 140–146, 2013, http://doi.org/10.11648/j.ijrse.20130204.12.Retrieved on 2nd October, 2016.

[14] E. Skoplaki and J.A. Palyvos,"Temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations", *Solar Energy Journal*; 83(5):614-624, 2009.

[15] Y. Tanagnostopoulo and P. Themelis, " Natural Flow Air Cooled Photovoltaics", American Institute of Physic Conference Proceedings, http://dx.doi.org/10.1063/1.3322300, 1203, 1013–1018,2010, Retrieved on 13th August, 2017

[16] H.G. Teo, P.S. Lee and M.N.A Hawlader, "An active cooling system for photovoltaic modules" , *Applied Energy*; 90: 309-315, 2012.

[17] J. Zhu, C.M. Hsu, Z. Yu, S. Fan, and Y. Cui, "Nano dome solar cells with efficient light management and self cleaning" *Nano Lett,* 10 (1979-1984), 2010.