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ORIGINAL RESEARCH ARTICLE

TEMPERATURE PERFORMANCE ANALYSIS OF A PHOTOVOLTAIC MODULE

A. H. Onyenweuwa

Centre for Satellite Technology Development, Abuja, Nigeria

ARTICLE INFORMATION

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ABSTRACT

The electrical efficiency of photovoltaic (PV) cell is affected by significant increase of cell operating temperature. The efficiency and temperature performance variation on two mono-crystalline modules with and without an active cooling system have been studied. Experimental investigation performed on both modules at different period of the day, under the same ambient temperature reveals that the module efficiency is affected by substantial changes in cell temperature. The module efficiency increases and decreases as temperature decreases and increases respectively. The minimum and maximum module temperatures recorded are 21°C and 102°C while the minimum and maximum module efficiencies are 15.27% and 9.80% respectively. The efficiency performance of the cooled module was high compared with the uncooled module and this indicates that the reduction in cell temperature due to active cooling process improved the efficiency of the module

1.0 Introduction

The current erratic electricity generation situation in Nigeria presents an enormous challenge for the country to grow industrially and rank among the first twenty developed nations in the World. This therefore calls for a rethink in our energy resource mix. This issue is acerbated by the fact that the fossil fuel resources which are though abundant and exploited in the country since after independence are not only finite but also sourced through destructive processes. That is, the energy is obtained from sources that must be constantly destroyed, with a significant part of the results transformed into waste which is extremely aggressive both for our health and the equilibrium of the surrounding nature. Nigeria is blessed with abundant renewable energy resources but the country has focused solely on the development of non-renewable energy. Unfortunately, the fossil fuels have not provided the much-needed solution to the current energy crises as the total power generation capacity in Nigeria over the years has been less than 5000 megawatts (Akhator et al., 2019). The demand for electricity in Nigeria is growing rapidly and supply can hardly keep pace with demand. Economic and population growth are placing serious strain on the country's energy infrastructure. Electricity demand per person is expected to increase every year and this presents a new opportunity to invest in energy infrastructure. Thus, there is a need to accelerate efforts towards the development of a new and renewable energy sources to meet future energy demand. Renewable energy provides a continuous and unlimited supply of energy. However, technical difficulties, the intermittent nature of some of the renewable energy resources, as well as other constraints still pose limits to their wider deployment. Solar energy has been identified as the most promising of the renewable energy source as a result of its apparent potentials (Oyedepo, 2012). This energy is converted to electrical energy using Photovoltaic solar cell. However, previous research work on the performance analysis of the photovoltaic system revealed that the efficiency of the system is affected by the ambient temperature. The variation in daily average ambient temperature in Nigeria over the year prompted the need to study the effect of temperature on the photovoltaic module output in our environment.

According to (Kumar et al., 2014), the efficiency improvement of the PV system is still one of the top priorities for many academic researches. Also, (Virtuani et al., 2010) and (Abdulgafar et al., 2014) have shown that the efficiency and output of PV module voltage generation is inversely proportional to its temperature. (Achara and Adikankwu, 2017) investigation on cooled and uncooled module revealed that the voltage generation at low temperature is higher due to the orderliness in vibration of the silicon electrons. As the temperature increases, the vibration become more randomly and the net effect is lower voltage generation.

However, research has also shown that improve in cell efficiency can be achieved by changing the ambient temperature variation around the photovoltaic module (Siddiqui and Bajpai, 2012). Also, (Adikankwu and Ileberi, 2016) stated that cooling the module with an air-conditioning cooling system would improve the voltage output. An experimental result on solar module cooling using silicon oil also showed that the maximum power delivered by the module and hence efficiency increased (Nikhil and Premalatha, 2012). This is an indicator that the performance of the photovoltaic cell depends on its basic characteristic as well as the meteorological factor of the environment. This paper examines the ambient and module temperature pattern on the efficiency performance of cooled and uncooled monocrystalline module system at different period of the day

PV Module

The performance of a solar module depends largely on its efficiency, and adequate knowledge of the ambient temperature and the cell temperature are vital in evaluating the module operational efficiency. Research (Abdulgafar et al., 2014; Achara and Adikankwu, 2017; Siddiqui and Bajpai, 2012; Adikankwu and Ileberi, 2016) have shown that temperature affects photovoltaic parameters such as open circuit voltage, short circuit current, maximum output power and fill factor. But the maximum influence of temperature is recorded in the open circuit voltage. This shows that open circuit voltage of a pv module is sensitive to cell temperature. The relationship between temperature and open circuit voltage is shown in Equation (1)

$$V_{(OC)} = \frac{E_g}{q} - \frac{nKT}{q}\left[\mathrm{In}\frac{I_{0\,max}}{I_{SC}}\right] \quad (1)$$

Where:

E_g equals the bang gap energy, $I_{0\,max}$ is the maximum reverses saturated current, K is Boltzmann's constant, T is the temperature, n is the ideality factor, q is electron charge and I_{SC} is short circuit current.

Corresponding author's e-mail address: henryadiks@gmail.com

For silicon cell, (dV_{OC} /dT) is approximately equal to -2 mV/°C., this means that, the efficiency of the cell drops by about 0.4 % for increase of every one degree Celsius. A silicon solar cell of 20% efficiency at 20°C will reduce to 16% at 30°C (Katkar et al., 2009).

According to (Yixian et al., 2012), the pv module efficiency varies linearly with temperature as follows:

$$\eta_{pv} = \eta_{ref}[1 - \beta\,(T_{cell} - T_{ref})] \tag{2}$$

Where:

The value for β is dependent on the material. For crystalline silicon, the value is taken to be 0.0045/°C. η_{ref} is the PV efficiency of the solar cell at the reference temperature T_{ref} = 25°C, η_{ref} = 15%.

2.0 Methodology

In this work, comparative studies of the cell temperature of an air-condition cooled and uncooled monocrystalline photovoltaic module have been carried out. The experiments were conducted outdoor under the same atmospheric condition to investigate the effect of ambient temperature, active cooling of module system and module temperature variation on the electrical performance of the module. The data sets which included ambient temperature, module temperatures and voltage, generated by the cooled and uncooled module for a period of 8 hours (0900 – 1700) were measured using the thermometer, thermostat and voltmeter respectively. These data were used to evaluate the module efficiency using Equation 2. The experimental setup is given in Figure 1 and 2.

Figure 1: Cooled module

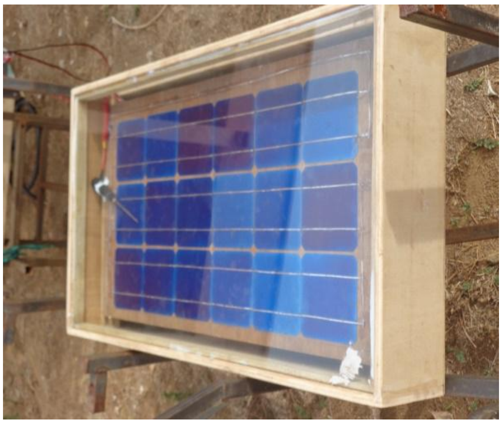

Figure 2: Uncooled module

3.0 Result and Discussion

The temperature and voltage data for the cooled and the uncooled system are presented in the Figures (3 – 8). In each of the Figures, the curves for ambient temperature, module temperature, voltage and efficiency are plotted against the time period of 0900 to 1700 for both cooled and uncooled module. The ambient temperature for a given time is the same for both cooled and uncooled module for any given day. Also, a rise in ambient temperature caused the module temperature and voltage to increase and decrease respectively. However, a slight decrease in ambient temperature at any given period of the experiment causes a corresponding decrease in module temperature, and increase in the open circuit module voltage output.

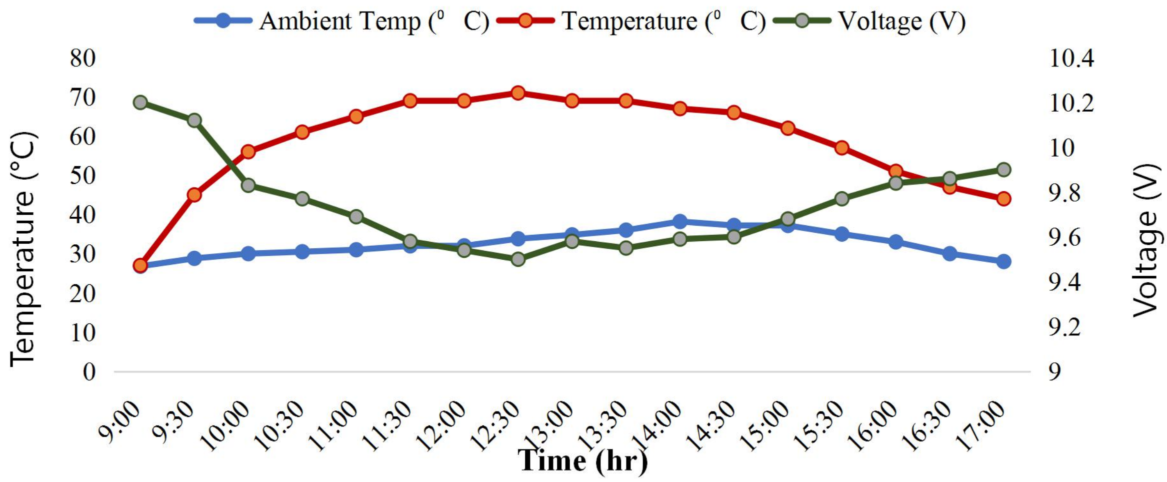

Figure 3: Cooled module temperature and voltage time profile for day one

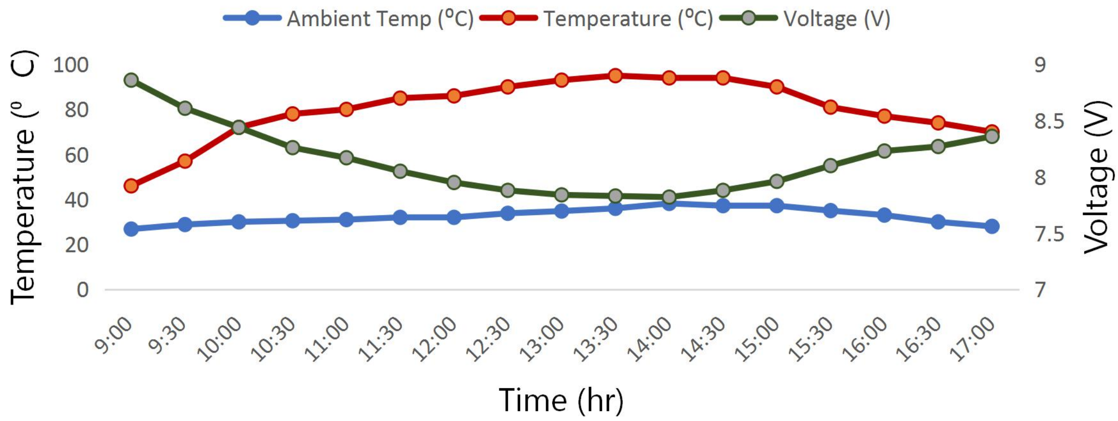

Figure 4: Uncooled module temperature and voltage time profile for day one

These results; which presented the relationship between the temperature and voltage against different hours of the day, show that the morning (0900 – 1200) hours were characterized by increase ambient temperature and module temperature and then decrease solar module voltage generated. The noon period (1200 – 1400) hours was characterized by peak temperature generation and low voltage generation for both modules: the module's temperature gets to maximum while the voltage reaches minimum. Also, the evening (1400 – 1700) hours was characterized by decrease in the ambient and module temperature and increase in voltage generated by both modules. The increase and decrease in module temperature as a result of ambient temperature changes is a function of the solar insolation, which is less in the morning and evening periods and more at noon periods

Corresponding author's e-mail address: henryadiks@gmail.com

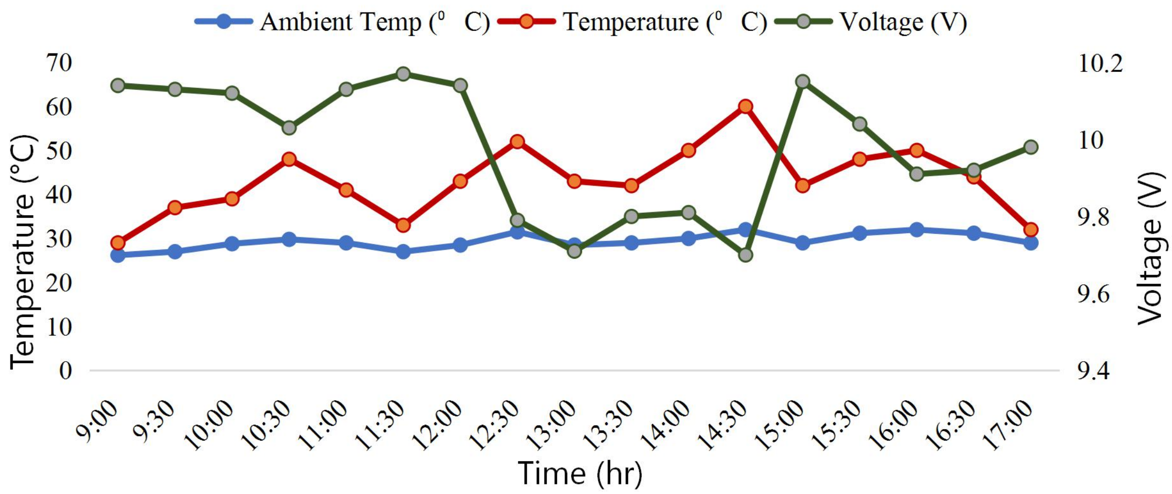

Figure 5: Cooled module temperature and voltage time profile for day two

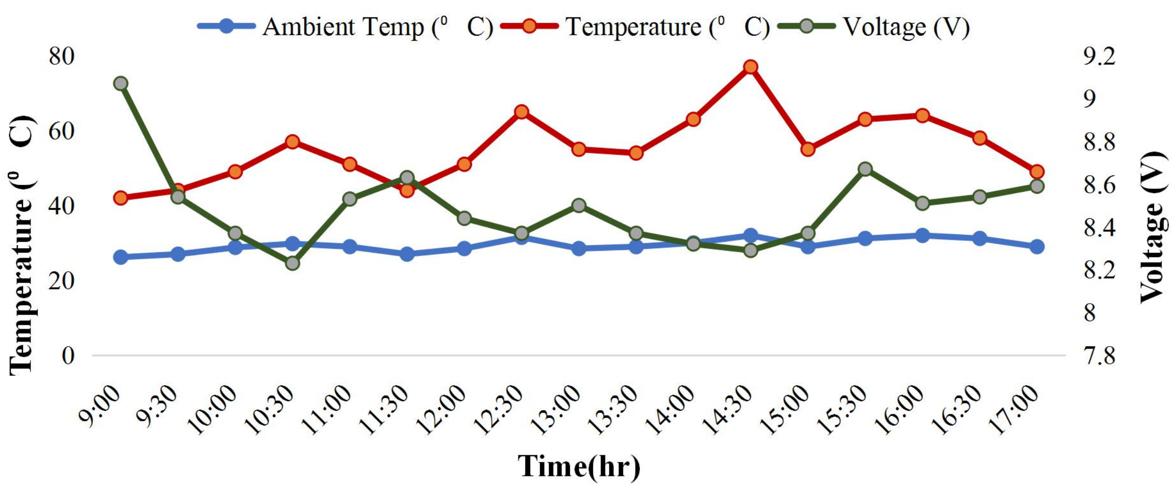

Figure 6: Uncooled module temperature and voltage time profile for day two

The rise in module temperature is more obvious in the uncooled module and correspondingly, the voltage generated by this module is low compare to the cooled module. This shows that temperature affects the module performance and reducing the module temperature by cooling improves the module output. The spikes vividly shown in Figure 5, 6, 7 and 8 can be related and explained by the sun being temporarily overcast by cloud.

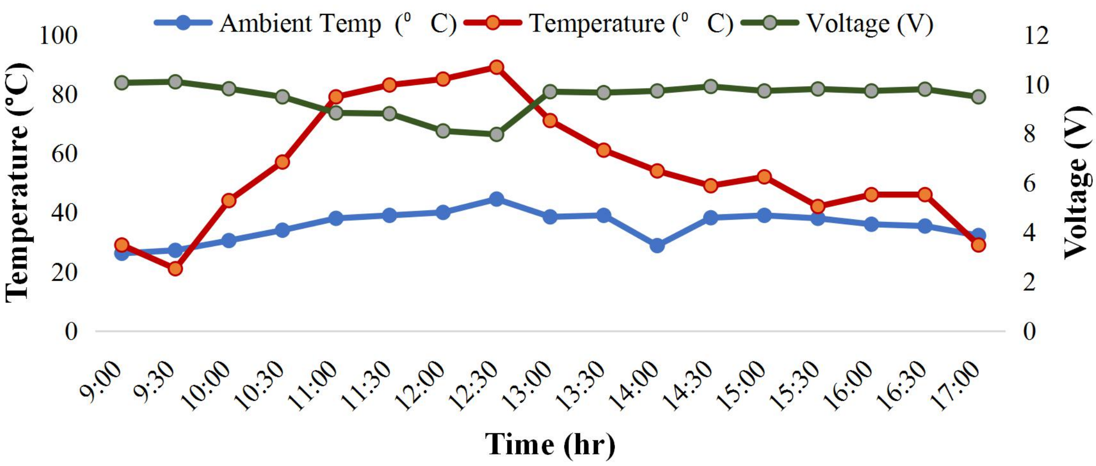

Figure 7: Cooled module temperature and voltage time profile for day three

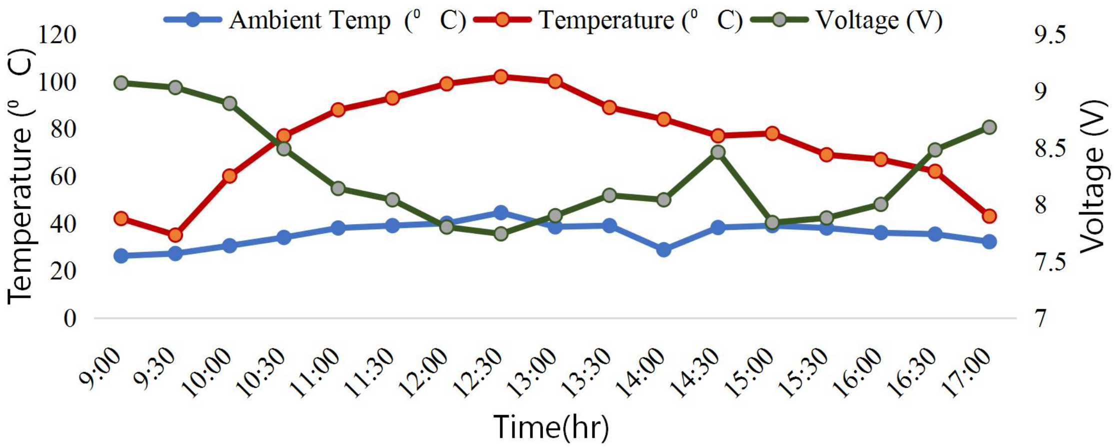

Figure 8: Uncooled module temperature and voltage time profile for day three

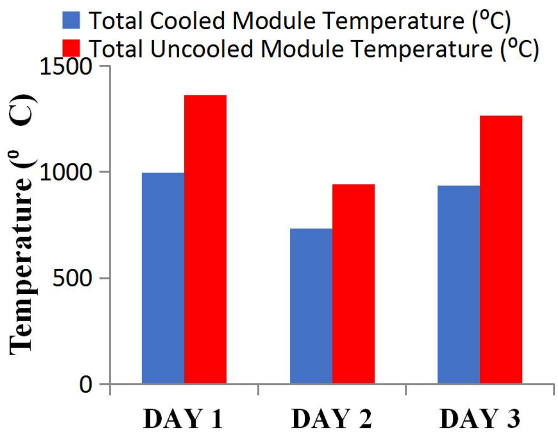

Figure 9: Module daily temperature

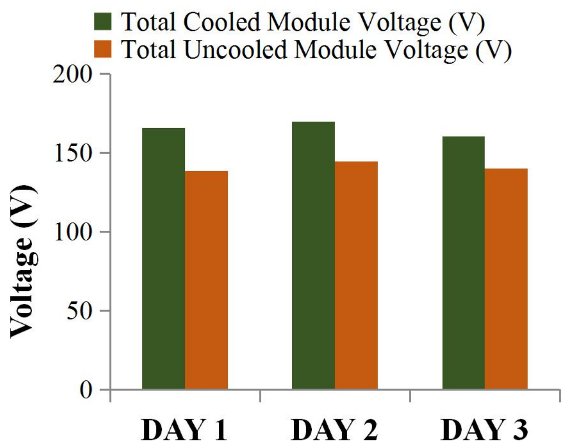

Figure 10: Module daily voltage

Figure 9 and figure 10 present respectively, the total daily temperature and voltage of cooled and uncooled modules for the three days period of experiment. Based on the data analysis, the cooled module voltage performed better compare to the uncooled module voltage. This is due to the cooling of the module, which reduces the temperature and heat build-up on the module and then improve the module performance.

The calculated module efficiencies with respect to temperature against time for Day 1, Day 2 and Day 3 are shown in Figure 11, 12 and 13. Based on the analysis of the data, the periods of 1200 hours to 1450 hours are characterized by lowest module efficiency generation and this is due to increase in ambient and module temperature as a result of increase in solar activities within the period. The module efficiency decreases for the period of 0900 hours to 1200 hours and increases for the period of 1450 hours to 1700 hours. This increase and decrease of the module efficiency is a function of decrease and increase in the module temperature respectively. This show that the efficiency of the pv module depends largely on the temperature.

However, in all the periods of the experiment, the efficiency performance of the cooled module was high compared with the uncooled module and this indicates that the reduction in cell temperature due to active cooling process improved the efficiency of the module. The results obtained in this study are consistent with other studies (Abdulgafar et al., 2014; Achara and Adikankwu, 2017; Dubey et al., 2013; and Fesharaki et al., 2011).

Corresponding author's e-mail address: henryadiks@gmail.com

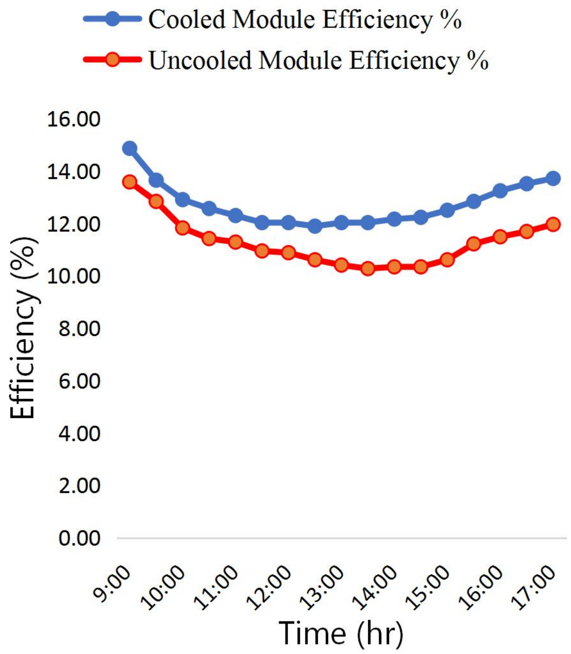

Figure 11: Module efficiency for day 1

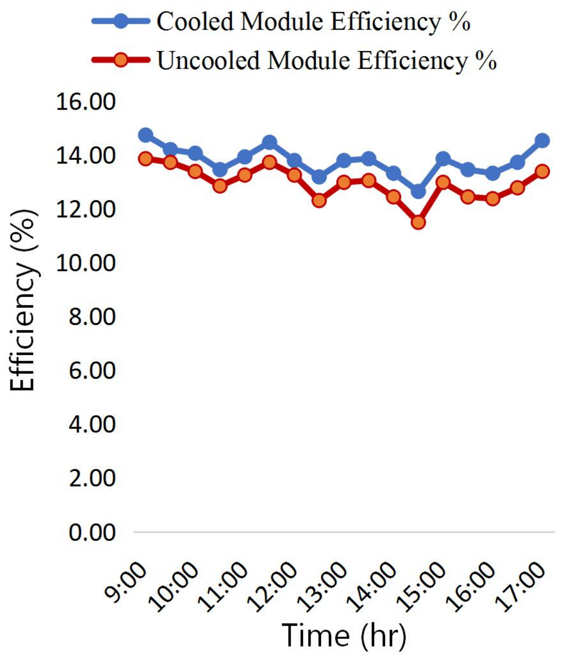

Figure 12: Module efficiency for day 2

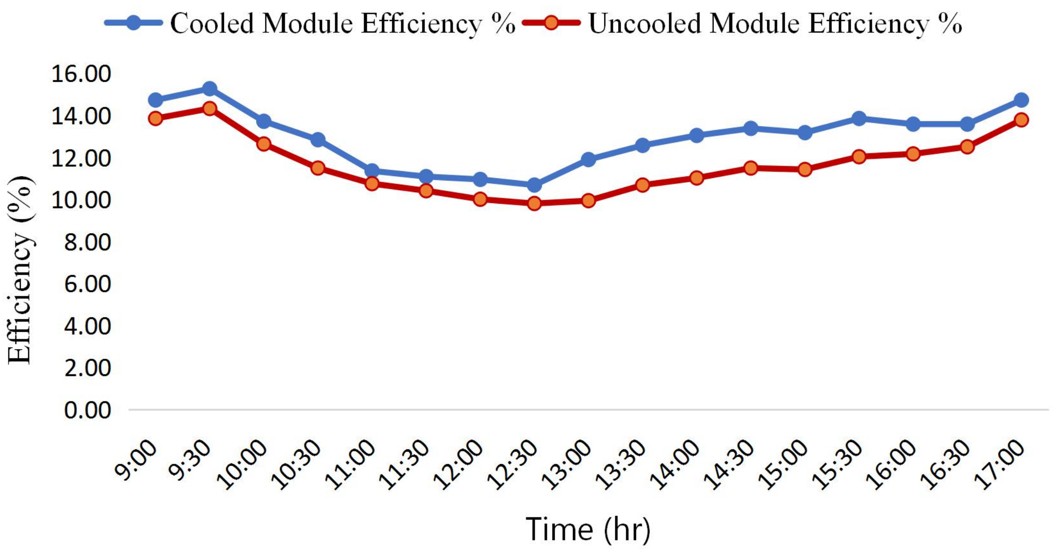

Figure 13: Module efficiency for day 3

4.0 Conclusion

The temperature performance of the photovoltaic module has been studied for various periods of the day. It has been found that the output of the module depends on the module temperature. Increase in module temperature causes a decrease in module voltage and efficiency output and vice versa. Also, the voltage and efficiency generated by the cooled module is higher compare to the uncooled module generation under the same environmental condition and this further show that the reduction in module temperature due to active cooling process improved the efficiency of the module.

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Corresponding author's e-mail address: henryadiks@gmail.com