NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Performance Evaluation of Photovoltaic System Using Different Cooling Methods

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Article Info

Keywords:
PV technologies, Electrical efficiency, Water Cooling System, Forced Air Cooling System.

Received 23 November 2022
Revised 06 December 2022
Accepted 07 December 2022
Available online 27 December 2022

https://doi.org/10.5281/zenodo.7486367

Abstract

A typical photovoltaic (PV) panel cell has ideal conversion efficiency in the range of 14-25%. The remaining energy is converted into heat and this heat increases the operating conditions (temperature) of PV system which therefore affects the electrical output power of PV modules in the system. Since the output of the PV modules decreases as a result of temperature rise, this effect results in decreased efficiency. Furthermore, if heat is not removed, structural damage to the PV modules will occur, shortening their useful life. To this end, this study presents the distinctive performance evaluation of photovoltaic cells under three cooling conditions to investigate the effect of cooling on the efficiency and output power of the photovoltaic cells. To achieve the set goal, three distinctive cooling techniques were employed for analysis namely forced air cooling, water cooling and natural air-cooling methods. In conclusion, results from analysis show a significant improvement in efficiency and output power of the PV module with the cooling system, thus indicating an improvement in the potential of PV system output as a renewable energy source.

1. Introduction

The potential of PV technologies cannot be greatly overemphasized, as it is becoming increasingly more relevant compared to conventional sources as need for backup of energy intensifies in emerging nations [1]. In general, the efficiency of the PV modules are affected by ambient temperature during absorption of radiation [2].The performance of the PV modules decreases with increase in temperature of the PV cell. Consequently, the output energy of the PV module decreases with increase in temperature, without removal of heat [3]. Overtime there's been increased global warming leading to increased temperature change owing to erratic industrial activities.

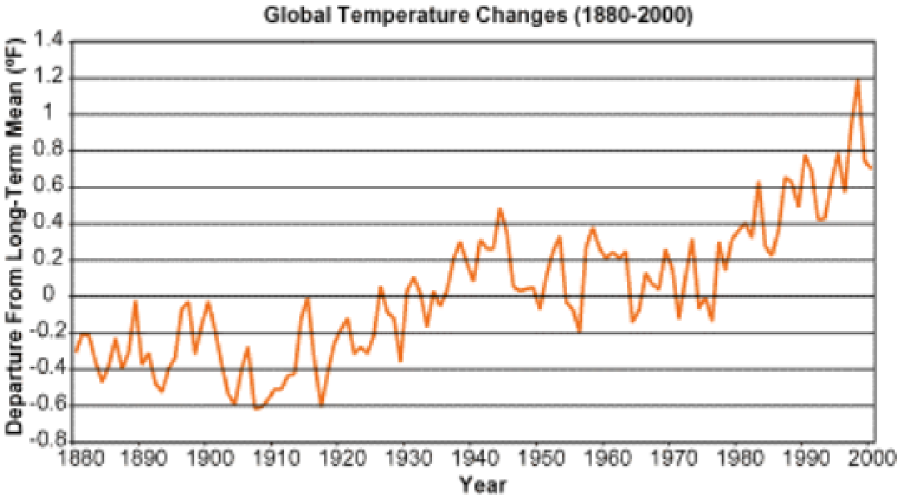

Fig 1. Global temperature changes [4]

Green gas emission has had a damning effect on the atmosphere and in turn adverse on the performance of PV system [4].This has also led to an upsurge in heat and increased operating conditions of PV cells. Further, there's a drop in efficiency and output power of the PV modules in this working state. In light of the above, researchers have been motivated to develop an adequate photovoltaic thermal system to address this problem [5].There are variety of merit associated with Photovoltaic/thermal (PV/T) system, as it can provide higher efficiency than individual photovoltaic and thermal collector system. To achieve such a system, efforts have been made to find an efficient cooling technology by analyzing the performance of solar cells using different technologies and various cooling liquids [6, 7]. The technique employed in this study is the cooling of solar panel back side using water and air as the coolant.

The main drive of this research is centered on comparison of the electrical conversion efficiency of the photovoltaic module with and without cooling at optimum flow rate. To this end, this paper proffers a systematic approach to boost the efficiency and output of the PV system by evaluating the PV cells with Forced air cooling, Water cooling and Natural air cooling methods as long-time high temperature operational conditions of photovoltaic panel can cause irreversible degradation of its output power [8]. Nonetheless, all data's rarely meet the actual solar conditions, as that hinge on the specific climatic conditions of each location.

The authors in [9] explored the possibility of employing water sprinklers, active fan, and passive heat sink as cooling technique to evaluate the efficiency of a PV system. A new control strategy is devised and its effect on the operating condition is examined.

A new performance related inverter index is employed to examine the impact of PV system on an inverter due to changes from optimal working condition by the authors in [10].Proper analysis were carried out on research site under different climatic at a specific time rate using fixed monitoring systems, however results were presented depicted significant improvement with an future research trend and challenges are also highlighted.

In [11] a working operation of DC fan controlled by PIC18F4550 microcontroller is proposed, which turn on the DC fan only when the ambient temperature reaches 35 °C. An experiment was conducted at outdoor condition, comparing PV panel with and without DC fan.

The effect of temperature on output power from different types of photovoltaic panel has been observed by the authors in [12]. Further, temperature coefficient of the PV panel, monocrystalline experienced highest losses in output power at average of -0.446%/°C. However, the impact of temperature changes on the overall PV potential is highlighted. In [13], the authors explored that possibility of amorphous photovoltaic panel being most efficient rather than monocrystalline silicon when operated under high operating temperature condition. Several experiments were performed, comparative results are presented along with recommendations for more research work in this area.

2. Materials and Method

A detailed survey was carried out at the case study environment. This location is impacted by some environmental factors and the efficiency of the PV modules in the designated area to achieve the desired results. Seventeen street BDPA opposite University of Benin, Benin city with latitude 6.3987^o.N and longitude 5.6095^{o}E is the area of research chosen as it fits the criteria of proper solar irradiation for analysis. Furthermore, solar irradiance data of 14 days from 9am to 12pm and from 12pm to 6pm were taken to ensure reduced error. This analysis was done between the months of October and November 2018.

The solar panels with water cooling and air-cooling system were placed side by side in a position to intercept the sun's incoming rays. The two multi-meters were connected to the output of the two photovoltaic cell respectively while the readings of open circuit voltage (V_{OC}) and on load voltage for without cooling and with cooling were measure simultaneously. After which, the average of the two weeks reading were calculated for as shown in Table 6 and 7. Also the power and efficiency were calculated for as well.

2.1 Procurement of Materials and Fabrication of Support

For this study the materials procured and employed for this research are as follows:

2.1.1 Photovoltaic Panel

The main component employed for this study was the PV solar panel. Mono crystalline was used owing to its characteristics of super high efficiency. The specification of the solar panel used in the experiment is shown in Table 1.

Table 1. Specification of Photovoltaic Module used in the Experiment

Flames 200W PV Module	
Maximum Output Power (P_{max})	200W
Maximum Power Current	5.17A
Maximum Power Voltage (V_{mp})	38.71V
Short Circuit Current (I_{sc})	5.53A
Open Circuit Voltage (V_{oc})	45.26
Weight	15.0
Dimensions	1500 x 100 x 35 mm

2.1.2 DC Brushless Fan

One way of cooling the photovoltaic cell is by using air. But in this case DC brushless fans were used to cool the panel. 5 DC brushless fans with specifications given in Table 2 were used for this process.

Table 2. Specification of Brushless Fan used in the Experiment

Bearings	Sleeve
Size	140 x 140 x 25mm
Voltage	12V
Speed	4500RPM

In the context of this study, other materials employed for performance analysis are water pipe (90mm by 9m), Aquarium pump with specifications shown in Table 3, water tank 50litres, two core flexible table of 1.5mm and a fabricated wooden structure. The aquarium pump is aided by a flow meter whose maximum flow rate of 8.30LPM was used to regulate the water flow into the cooling panels. The PV panels integrated with pipes for cooled air circulation with thickness of about 18mm as shown in Figure 2.

Table 3. Specification of Aquarium Pump used in the Experiment

Operating Voltage	DC 12V
Operating Current	65mA-380mA
Maximum flow	350 liter/hour
Diameter of Water pump (In)	8mm
Diameter of Water pump (Out)	7mm

Finally, two wooden structure of appropriate tilt angle of $\alpha = 15.2^0$ from fabrication are employed to support the PV modules and also to help ensure proper positioning of PV cells for maximum amount of energy production, while two multi meter were connected separately to the output wire of the panel of water cooling system and air cooling system.

2.2 Photovoltaic Modules Output Yield Evaluation (DATA collation)

In other to evaluate the effect of cooling on the performance of PV modules, three methods of cooling were adopted for the purpose of this research. These methods include:

1. Forced air cooling method
2. Water cooling method
3. Natural air cooling method

2.3. Method of Cooling
Water Cooled Photovoltaic Panel

Figure 2. Depicts a pictorial view of the water cooling system for analysis of the

PV module

Figure 2. Pictorial view of the water-cooling system for analysis of the

PV module

2.4. Forced Air Cooled Photovoltaic Panel

One way of cooling the photovoltaic unit is by using air. Of course in this particular case air is used to absorb the heat from the unit and consequently to cool it. The number passes was maintained for

Figure.3 depicts the air cooling system for analysis of the PV output power.

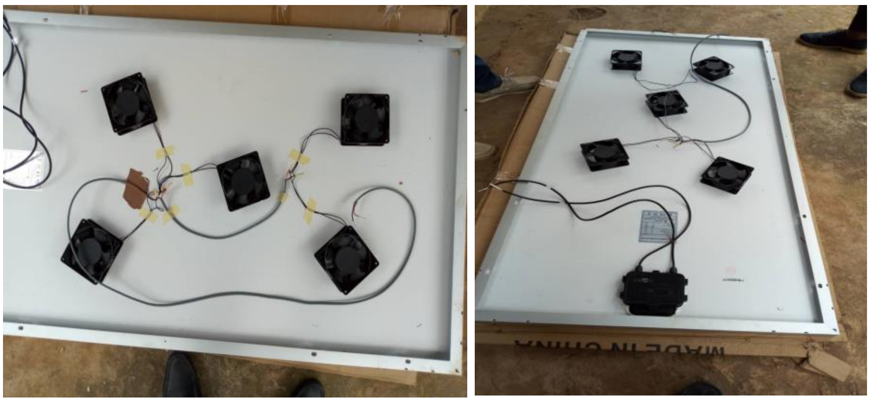

Figure.3 Air cooling system for analysis of the PV output power.

2.5 Table of Values for the adopted Cooling Systems

Solar irradiance data of 14 days from 9am to 12pm and from 12pm to 6pm were taken ensuring reduced error as presented from Tables 4 to 9. Further these readings was analyzed and the averaged reading for the voltages were calculated in tables 10 to 12 to ease the result analysis. After which the power and efficiency were calculated using the open voltage average values;

2.5.1. Forced Air and Water Cooling System

Table 4: Open Circuit Voltage for Forced Air and Water Cooling System

Time	**Open Circuit Voltage (V)**	
	Forced air Cooling	**Water Cooling**
9:00-10:00	37.1	32.2
11:00-12:00	43.0	39.0
12:00-13:00	49.8	48.8
13:00-14:00	53.0	52.6
14:00-15:00	57.6	55.1
15:00-16:00	56.3	55.7
16:00-17:00	46.7	44.6
17:00-18:00	34.3	31.2

Table 5. Open Circuit Voltage for Forced Air and Water Cooling System

Time	**Open Circuit Voltage (V)**	
	Forced air Cooling	**Water Cooling**
9:00-10:00	35.6	33.8
10:00-11:00	40.9	35.8
11:00-12:00	44.8	40.6
12:00-13:00	52.3	46.7
13:00-14:00	54.8	50.1
14:00-15:00	52.6	49.4
15:00-16:00	44.0	41.5
16:00-17:00	39.7	38.6
17:00-18:00	33.2	31.7

2.5.2. Forced Air and Natural Cooling

Table 6. Open Circuit Voltage for Forced Air and Natural Cooling System

Time	**Open Circuit Voltage (V)**	
	Forced air Cooling	**Natural Cooling**
9:00-10:00	33.4	29.2
10:00-11:00	37.2	30.3
11:00-12:00	36.3	32.4
12:00-13:00	43.5	35.2

13:00-14:00	49.4	36.0
14:00-15:00	53.3	41.0
15:00-16:00	57.6	42.9
16:00-17:00	34.3	20.7
17:00-18:00	33.2	20.1

Table 7. Open Circuit Voltage for Forced Air and Natural Cooling System

Time	**Open Circuit Voltage (V)**	
	Forced air Cooling	**Natural Cooling**
9:00-10:00	33.4	29.4
10:00-11:00	34.6	29.9
11:00-12:00	43.8	37.0
12:00-13:00	54.6	42.0
13:00-14:00	51.7	40.9
14:00-15:00	47.5	39.0
15:00-16:00	43.3	32.4
16:00-17:00	38.6	30.1
17:00-18:00	32.2	29.0

2.5.3. Water and Natural Air System

Table 8. Open Circuit Voltage for Water and Natural Air Cooling System

Time	**Open Circuit Voltage (V)**	
	Water Cooling	**Natural Cooling**
9:00-10:00	37.0	30.0
10:00-11:00	38.4	30.0
11:00-12:00	39.9	39.4
12:00-13:00	37.6	37.0
13:00-14:00	48.6	41.2
14:00-15:00	52.6	40.5
15:00-16:00	53.1	40.9
16:00-17:00	53.3	42.0
17:00-18:00	38.7	30.4

Table 9. Open Circuit Voltage for Water and Natural Air Cooling System

Time	**Open Circuit Voltage (V)**	
	Water Cooling	**Natural Cooling**
9:00-10:00	37.9	29.4
10:00-11:00	38.9	29.9
11:00-12:00	34.4	39.1
12:00-13:00	39.6	36.0

13:00-14:00	43.6	41.2
14:00-15:00	52.3	42.0
15:00-16:00	55.4	40.8
16:00-17:00	55.7	41.0
17:00-18:00	44.7	38.4

Table 10: Average Values for Air and Without Air Cooling

Time	Voltage (Voc) at No Load without Air Cooling	Voltage (Voc) at No Load with Air Cooling	Voltage on Load without Air Cooling	Voltage on Load with Air Cooling
9.00	38.4	44.1	31.1	36.3
10.00	40.2	46.7	30.2	35.2
11.00	40.4	45.7	30.1	35.1
12.00	42.5	49.8	32.5	37.6
13.00	44.4	53.0	31.5	36.5
14.00	43.4	57.6	33.7	38.7
15.00	44.2	57.2	32.0	37.8
16.00	42.5	55.1	31.8	36.0
17.00	42.7	50.3	32.0	37.1
18.00	41.5	49.4	30.9	35.7

Table 11: Average Values for Water Cooling and without Water

Time	Voltage (Voc) at No Load without water Cooling	Voltage (Voc) at No Load with water Cooling	Voltage on Load without Water Cooling	Voltage on Load with Water Cooling
9.00	39.0	43.1	30.9	34.9
10.00	38.9	42.5	30.7	35.0
11.00	38.1	43.2	30.8	34.8
12.00	43.0	45.5	31.9	35.7
13.00	46.2	50.0	31.8	35.0
14.00	46.7	56.6	32.9	37.1
15.00	44.1	55.0	31.9	35.2
16.00	41.5	52.2	32.0	35.0
17.00	42.9	48.2	32.1	36.8
18.00	40.1	48.1	30.8	35.1

Table 12: Average Values For Forced air and Water cooling

Time	Voltage (Voc) at No Load with forced air Cooling	Voltage (Voc) at No Load with water Cooling	Voltage on Load with forced air Cooling	Voltage on Load with Water Cooling
9.00	44.1	43.1	36.3	34.9
10.00	46.7	42.5	35.2	35.0
11.00	45.7	43.2	35.1	34.8
12.00	49.8	45.5	37.6	35.7
13.00	53.0	50.0	36.5	35.0
14.00	57.6	56.6	38.7	37.1
15.00	57.2	55.0	37.8	35.2
16.00	55.1	52.2	36.0	35.0
17.00	50.3	48.2	37.1	36.8
18.00	49.4	48.1	35.7	35.1

Furthermore, In determining the correct installation and performances of the PV module certain parameters are calculated namely the maximum power(P_{max}), Open circuit voltage(V_{oc}),short circuit current (I_{SC}),and more importantly the efficiency using the average open circuit voltages from the cooling methods **:**

Maximum power (P_{max}): This is the maximum power output of the PV module.

If P_{max} =IV It's unit is watt is the maximum power output

Efficiency of the PV cell is then given by;

$$\eta = \frac{P_{max}}{A \times I} \quad (1)$$

Where η is in %

Length of the solar panel =158cm

Width of the solar panel = 81cm

Average V_{oc} without cooling =

With Forced Air Cooling System

Length of the solar panel =158cm

Width of the solar panel = 81cm

Average V_{OC} without cooling = 42.02v

Average V_{OC} with cooling = 50.92v

Average V_L without cooling = 31.58v

Average V_L with cooling = 36.6v

Resistance = 13Ω

SI = 1000w/m^2

Length of the solar panel = 158cm

Width of the solar panel = 80cm

Where:

V_{OC} = Open circuit voltage

V_L= Load voltage

I = Current

R = Resistance

$\eta = Efficiency$

P = Power

SI = Solar irradiance

A = Cross sectional ar

$I = V_L / R$ (2)

= 36.6/13

= 2.815A

Area = length x width (3)

A = 158cm x 81cm

A=1.2798m^2

Power = I X V (4)

P = 2.815 X 50.92

P = 143.34W

Efficiency = power/area x solar irradiance (5)

= 143.34/ (1.2798 X 1000)

= 0.112 x 100

Efficiency = 11.2%

Without Cooling

$I = V_L/R$ (6)

= 31.58/13= 2.43A

Therefore Power (P) = I x V (7)

P = 2.43 X 41.65 =101.18W

Area (A) = length x width (8)

=1.58m x 0.81m

= 1.2798m^2

$$Efficiency\ (\%) = \frac{P}{A \times SI} \quad (9)$$

= 101.18/ (1.2798 X 1000)

= 101.18/1279.8

= 0.0791 X 100

= 7.91%

With water cooling system

Average V_{OC} without cooling = 41.65v

Average V_{OC} with cooling = 48.44v

Average V_L without cooling = 31.58v

Average V_L with cooling = 35.46v

$I = V_{L/R}\ V_{L/R}$ (10)

= 2.23A

Power = V x I I (11)

P = 48.44 X 2.23

P = 132.24W

$$Efficiency\ (\%) = \frac{P}{A \times SI} \quad (12)$$

= 132.24 /(1.2798 x 1000)

= 0.1033 x100

Efficiency = 10.33%

Without Cooling

Length of the solar panel =158cm

Width of the solar panel = 81cm

Average V_{OC} without cooling =41.65v

I without cooling = 2.43A

Therefore power (p) = p= I x V (13)

P = 2.43 X 41.65 =101.18W

Area (A) = length x width (14)

=1.58m x 0.81m

= 1.2798m^2

$$Efficiency\ (\%) = \frac{P}{A \times SI} \quad (15)$$

= 101.18/1.2798 X 1000

= 101.18/1279.8

= 0.0791 X 100

= 7.91%

3.0. Results

The graphical analysis of the PV cells for the various cooling methods is shown while the conversion efficiency of the cooling methods and their respective power output are depicted in Table 13.

3.1. Forced Air and Water Cooling System

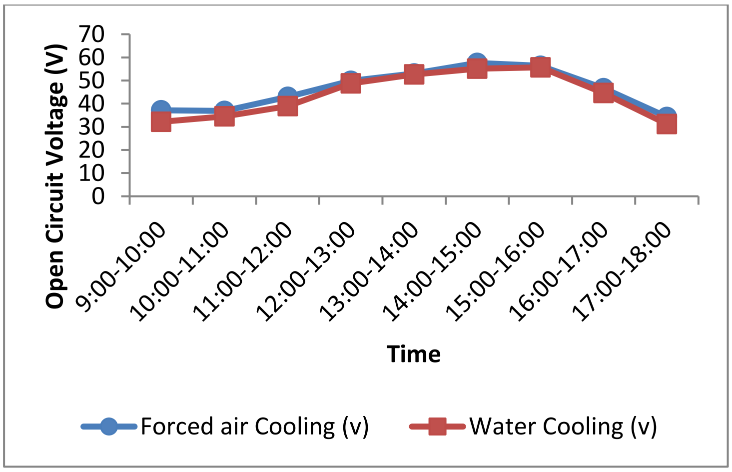

Fig. 4: Open Circuit Voltage versus Time for Forced Air and Water Cooling System

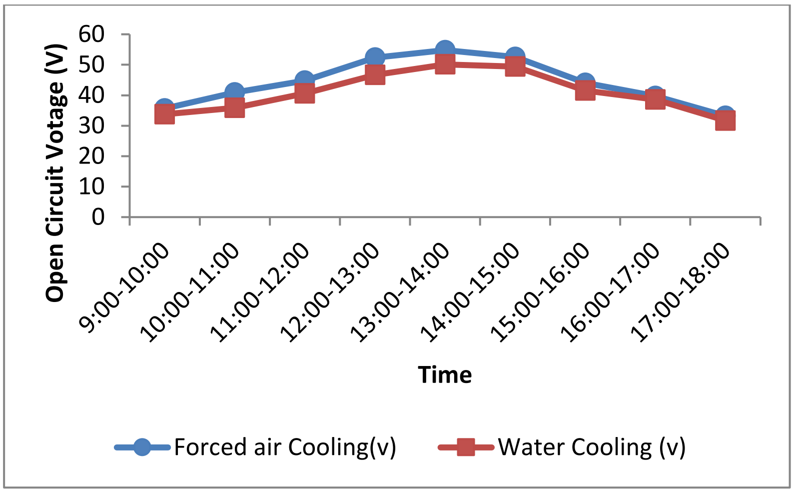

Fig. 5: Open Circuit Voltage versus Time for Forced Air and Water Cooling System

Figures 6 to 12 which is the graph of forced air and water cooling, show that during the early hours of 09:00 to 12:00 the open circuit voltage is low but between hours of 1200 to 1600 the intensity of the sun increases as well as the open circuit voltage, then between the hours of 1600 and 1800, the intensity of the sun decreases which leads to reduction in open circuit voltage.

3.2. Forced Air and Natural Cooling

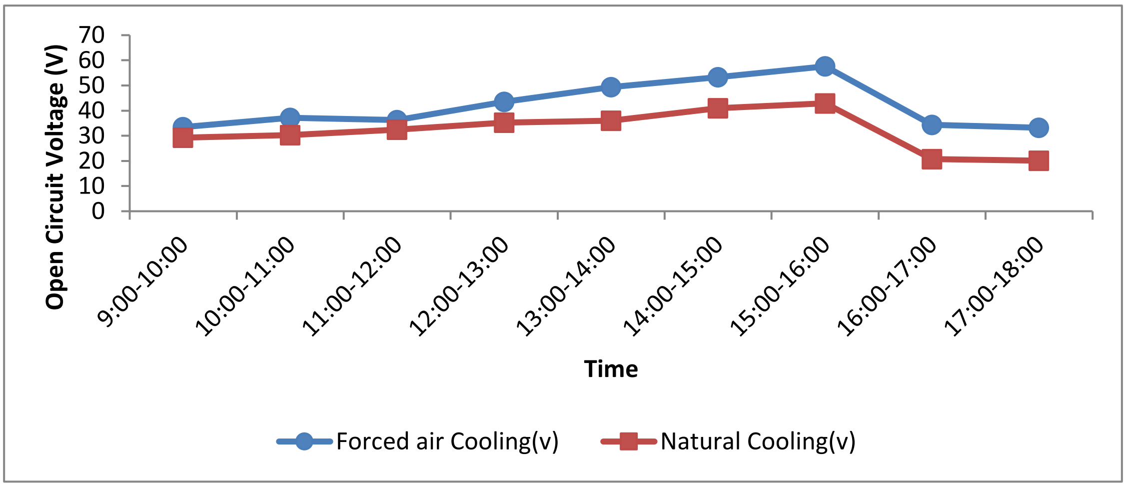

Fig. 6: Open Circuit Voltage versus Time for Forced Air and Natural Cooling System

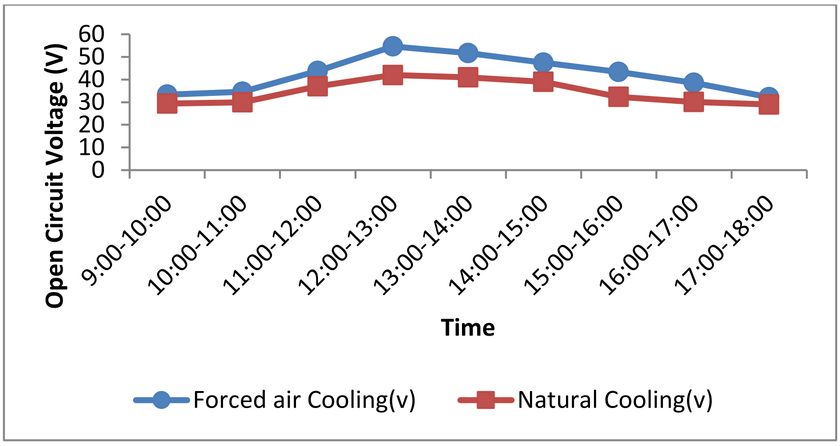

Fig. 7: Open Circuit Voltage versus Time for Forced Air and Natural Cooling System

Water and Natural Air System

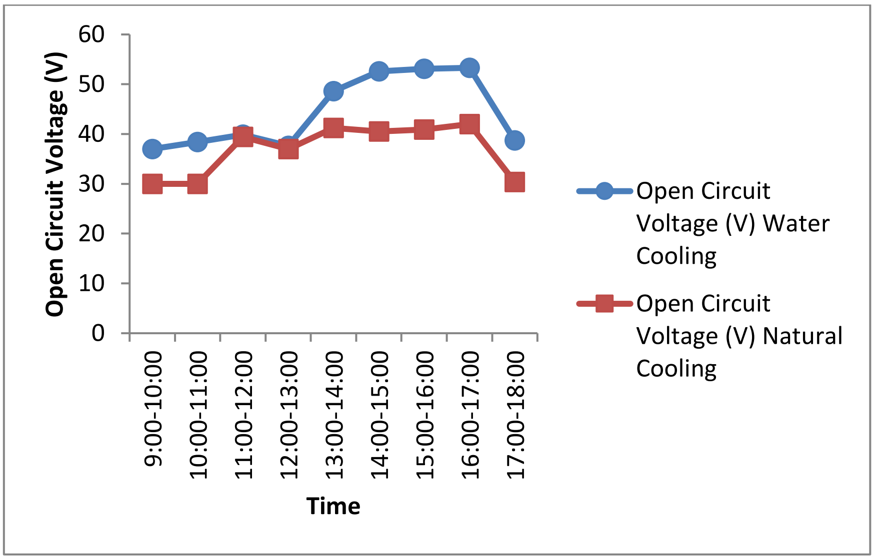

Fig. 8 Open Circuit Voltage versus Time for Water and Natural Cooling System

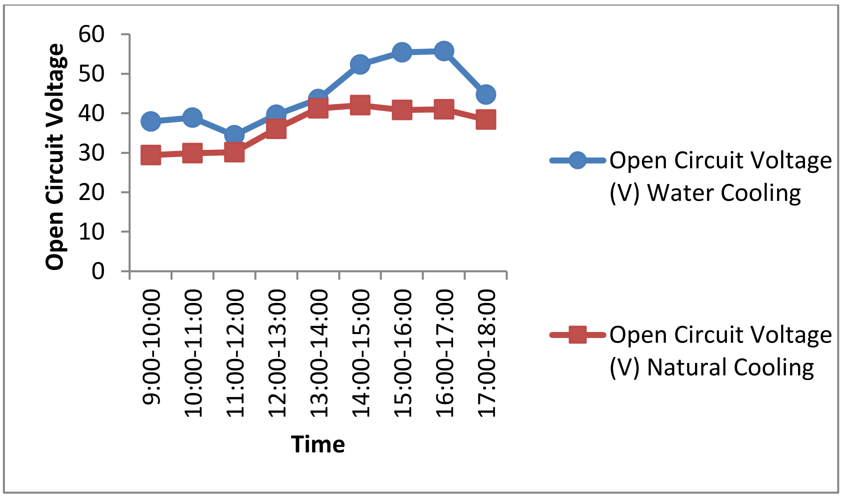

Fig. 9 Open Circuit Voltage versus Time for Water and Natural Cooling System

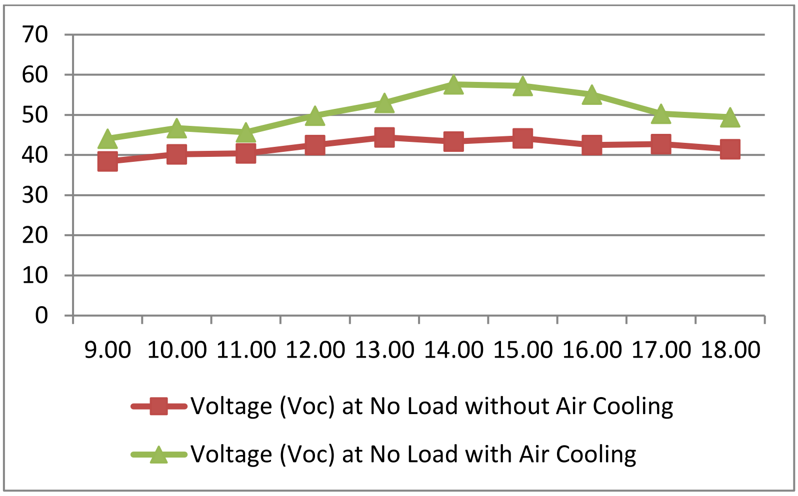

Fig. 10 Average Open Circuit Voltage versus Time for Forced air and Natural Cooling System

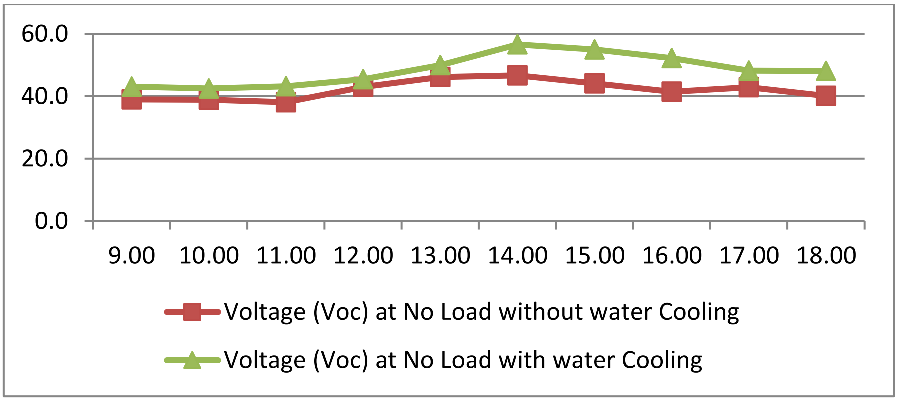

Fig. 11 Average Open Circuit Voltage versus Time for water cooling and without water Cooling System

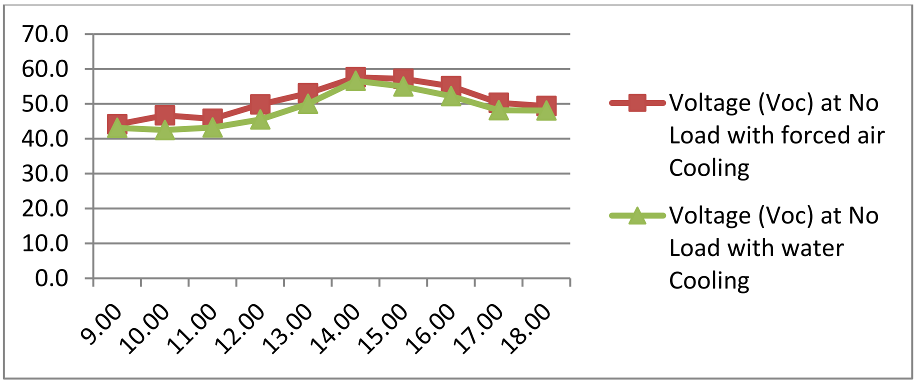

Fig. 12 Average Open Circuit Voltage versus Time for Forced air and Water Cooling System

The conversion efficiency and output power using the three cooling method are highlighted in Table 13;

Table 13. Cooling methods Conversion efficiency and its output

Cooling Method	**Conversion Efficiency**	**Power Output**
Natural air Cooling Method	7.9%	101.18W
Forced air cooling method	11.2%	143.34W
Water cooling method	10.33%	132.24W

Furthermore, comparing the two-cooling system (forced air- and water-cooling system), it was clearly observed that forced air has better effect than water cooling system. With reference to Table 14, it can be seen that forced air system cools the PV cells more than water system by decreasing the temperature of the PV cell more. This decrease in temperature led to increase in conversion efficiency of the PV cells and its power output.

4. Conclusion

This research has been able to provide a comprehensive survey of the PV system with and without cooling system. A deep review of closely related work was carried out and comparative examination of the photovoltaic cell without cooling system (Natural cooling) and with cooling system to ascertain the temperature level of its module.

Further, from observations the temperature of the PV module without Cooling system (Natural cooling), was so high, there was also limitation of natural air in the atmosphere which was due to the climatic weather condition. Therefore, little or no cooling took place in the PV cells. From the results obtained, the conversion efficiency of PV cell without cooling is very low compared to the ideal conversion efficiency of 15%, which also affects the power output of the PV module. As for PV cell with cooling(water or forced air cooling) system, there was an observable increase in conversion efficiency when compared to natural cooling this was due to the decrease in the temperature, this further led to increase in power output. Thus, the essence of introducing cooling system to PV cells is achieved: under cooling conditions, the temperature of solar panel can be reduced to effectively increase the photoelectric conversion efficiency of the solar system which in turn help to increase the life span of the solar panel, as excessive heat is reduced.

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