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Comparative Studies of the Efficiency of solar Panel using Power Output of Two 130 Watts Solar Panels on Rigid and Tracker Modules

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Abstract
The research aimed at carrying out comparative studies and analysis of the efficiency and power outputs of two 130Watts Solar Panels placed on rigid and tracker modules to find out the extent to which a tracker module will outperform a rigid horizontally mounted module. The experiment was carried out at Abakpa Nike, Enugu on 6.27°N, 7.32°E. The experiment lasted for a period of twenty days. One of the solar modules (P_2) was mounted on a dual axis tracking mount to track and position its panel perpendicular to sun. The second solar panel (P_1) was laid on a rigid mount which is a supportive structure that is used to hold the photovoltaic panels in a fixed position towards the sun. The Voltage output, current output and panel surface temperature of each panel was measured and recorded every thirty minutes starting from 6:00 hours - 18.00hours of each day. The result obtained with the energy produced by each panel for the twenty days was calculated and analyzed. The result showed that the difference between the average power output obtained from the two solar panels was 2.33W while that of the efficiency was 1.84%. The result showed that a tracking mounted solar panel collect more energy than the rigid horizontally mounted panel mostly when the sun was visible, intense and in the pre-meridian and the post meridian hours but when the sun was neither visible nor intense and the atmosphere is cloudy or misty, there is no significant difference between the efficiency and power output of tracking solar panel and that of the rigid horizontally mounted solar panel.
Keywords: *Solar Tracker, Efficiency, Solar Panel*

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I. Introduction

One of the most promising renewable energy sources characterized by huge potential of conversion into electrical power is the solar energy. The conversion of solar radiation into electrical energy by photovoltaic effect is a very promising technology; it is a clean, silent and reliable energy resource with very small maintenance costs and small ecological impact, (Priyanka and Akshay, 2016). The interest in the photovoltaic conversion system is visibly reflected by the exponential increase of sales in this market segment with a strong growth projection for the next decades. The total installed power of photovoltaic conversion equipment increased from 1GW in 2001 up to nearly 23GW in 2009, (Mints 2010). The continuous evolution of the technology has seen increased conversion efficiency of photovoltaic panels, but nonetheless, the most part of the commercial panels have efficiencies around 20 %. A constant research preoccupying the technical community involved in solar energy harnessing has been various methods that can lead to an increase in photovoltaic panels' conversion efficiency. Among the methods under study for optimizing the photovoltaic panels' conversion efficiency include; solar tracking technology, reflectors, use of new materials among others.

In few years to come, the need for energy will increase greatly while the reserve of conventional energy resources such as petroleum will get depleted in a rapid pace to meet developmental goals, then, to meet this growing demand of energy, harnessing non-conventional and renewable energy has become a necessity. Among all the available non-conventional sources of energy, solar energy is the most abundant and uniformly distributed on the planet. Though the technology of trapping the solar energy is in existence, the output needs to be improved in order to increase efficiency and make it cost-effective.

II. Literature Review

Mahendran *et al.*, (2014) in their work on an experimental comparison study between Single-Axis Tracking and Fixed photovoltaic Solar Panel Efficiency and Power Output: Case Study in East Coast Malaysia, conducted an experiment on a clear sky and partly cloudy day at 3.5 ^{o}N, 103.42 ^{o}E Pekan Campus, University Malaysia Pahang by using two Units of 50 Wp photovoltaic mono-crystalline solar panels. The horizontal global solar irradiation was measured using calibrated pyranometer with maximum irradiance measurement up to 2000 W/m² and sensitivity of 5 to 20 μV/W/m^2. The two panels were installed side by side with an adequate space and tilting towards due south at angle of 10̊. The voltage, ampere, power, and energy output from photovoltaic solar panel were measured using digital watt meter with maximum measurement up to 6554 W and 0.1 W resolution. Both photovoltaic solar were connected to digital watt meter separately and all the readings were taken simultaneously are recorded in an interval of 15 minutes from 9.00 hrs until 18.00 hrs. The solar panel efficiency was calculated using

$$\eta_p = \frac{P_o}{P_{max}} \quad (1)$$

where, η_p is photovoltaic solar panel efficiency,
P_o is power output from panel and
P_{max} is maximum power output of the panel.

The module efficiency of photovoltaic was evaluated using

$$\eta_m = \frac{P_o}{A_c G} \quad (2)$$

where, η_m is module efficiency
P_o is power output from panel
A_c is area of photovoltaic solar panel and
G is horizontal global solar radiation

The conclusions drawn from this study are as follow: First, Single-axis tracking panel is more efficient than fixed panel only in pre-meridian and postmeridian. Secondly; at noon-time or mid-day, both panels were producing comparable equal amount of power output. Finally, single-axis tracking produces higher power output than fixed panel throughout the day which means it is utilizing the most of available solar radiation effectively and this will reduce payback period for the initial investment cost of this technology.

Ajayi *et al*., (2013) in their work on Comparison of Power Output from Solar photovoltaic Panels with Reflectors and photovoltaic panels with Solar Tracker, a case study of Lagos state Nigeria. Solar photovoltaic panels with diffused reflectors and solar tracker were constructed in other to determine the system that will produce the higher power output. They were both placed in the sun close to each other to have the same sky condition as practicable enough. Readings were taking on both systems simultaneously for comparison. The longer axis of the panel is aligned horizontally in the east – west direction, facing south. The reason behind this kind of placement is to utilize the maximum area of the panel for diffused reflection. The reflectors were fixed to the four sides of the solar photovoltaic panel. For the solar tracker, the solar photovoltaic panel is attached to the tracker to track the sun as it rises from the east to set at the west. The open circuit voltage (Voc) and short circuit current (Isc) of the solar panel of the two systems were measured concurrently with two multi-meters. The performances of the two systems were measure on a sunny and cloudy day respectively. What was noticed during the experiment in the system with diffuse reflectors is that the east and west reflectors were blocking the sun thus casting shadow on the solar photovoltaic panel during rising and setting of the sun, thus causing lost of power during these periods. On a cloudy day, there is no much difference in the solar power output

Dhanabal *et al.*, (2013) in their work on Comparison of efficiencies of Solar Tracker systems with static panel Single-Axis Tracking System and Dual-Axis Tracking System with Fixed Mount compared the efficiency of fixed mounted panel with a single axis solar tracker mounted photovoltaic panel as well as the dual axis tracker photovoltaic system. Dual axis tracking system uses the solar panel to track the sun from east to west and north to south using two pivot points to rotate. The dual axis tracking system uses four light dependent resistors (LDR), two motors and a controller. The four LDR's are placed at four different directions. One set of sensors and one motor is used to tilt the tracker in sun's east - west direction and the other set of sensors and the other motor which is fixed at the bottom of the tracker is used to tilt the tracker in the sun's north-south direction. The controller detects the signal from the LDR's and commands the motor to rotate the panel in respective direction. According to the measured readings the efficiency of the dual axis tracker is found to be 81.68 % higher than that of fixed panel whereas the efficiency of the single axis tracker is only 32.17 % higher than that of fixed panel.

III. Materials And Method

The materials for the study include the following

1. Two 130Wp solar panels with the specification of the solar PV panels used in this experiment are as listed:

Max. Power (+5 %)	(Pmax)	=	130 Wp
Voltage Max. Power	(Vmp)	=	17.5 V
Current Max. Power	(Imp)	=	7.75 A
Short Circuit Current	(Isc)	=	7.3 A
Open Circuit voltage	(Voc)	=	17.5 V
Cell Technology		=	Polycrystalline
Module area of the Panel		=	1.0 m^2

All Technical data is at STC AM = 1.5, E = 1000 W/m^2, TC = 25 ^oC

2. A rigid mount
3. A tracking mount (Tracker)
4. Four (4) digital multi-meters
5. Two liquid in glass alcohol thermometers
6. Diodes
7. AIDA DT-830D Digital Multi-meter

The Rigid Mount

The rigid mount is constructed using an L-bar iron with dimension; 200 mm height, 870 mm width and 670 mm length. The joint is made permanent using arc welding process, and the diagram of the rigid mount is shown in Fig.1

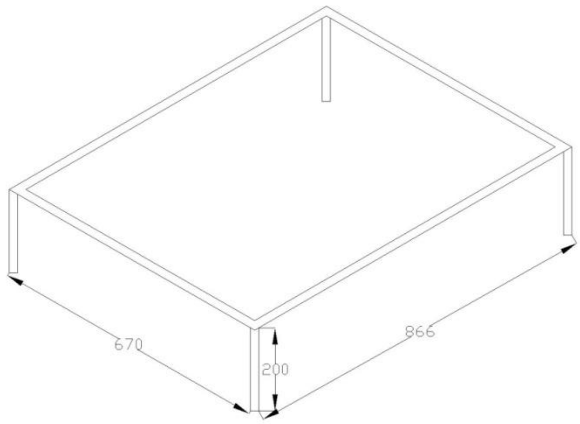


Fig. 1, Rigid Mount

The Tracking Mount

The tracking mount is a dual axis tracker designed and constructed to track and position its panel perpendicular towards the sun for optimum illumination. The construction diagram of the tracking mount is shown in Fig 3.3 and it is composed of the following parts;

- Base Support: This is made of a 14" radius wheel to stand the tracker and resist the tracker from being tossed over by wind. It also contains a metal fin opened at the centre where it is nailed to the ground permanently.
- Azimuth Bearing: the azimuth bearing connects the Stem to Base support and is capable of rotating the Stem through an angle of 360 ^{o} along the horizontal plane to position the tracker towards the Azimuth angle of the sun during the experiment.
- Zenith Bearings: The Zenith bearing connects the stem to the panel frame support and is capable of rotating the panel frame 80 ^{o} along the vertical axis both to the left and to the right respectively.
- Sensors: Two sensor systems are used to determine the angle of Zenith and Azimuth respectively. Each sensor comprises of four (4) light dependent resistors (LDR), a centre zero galvanometer and a switch connected in wheat stone bridge circuit structure such that the galvanometer pointer stands at the centre when all the LDR resistors are equally illuminated. Fig 3.2 shows the wheatstone bridge sensor and fig 3.4 shows the picture of the Tracking mounted panel while Fig 3.3 shows the diagram of the tracking mount contains the two sensors made with the light dependent resistors carefully positioned two top and two down the panel. The center-Zero

Galvanometer points to the center when the resistances of LDR-1, LDR-2, LDR-3 and LDR-4 are related by the expression

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (3)$$

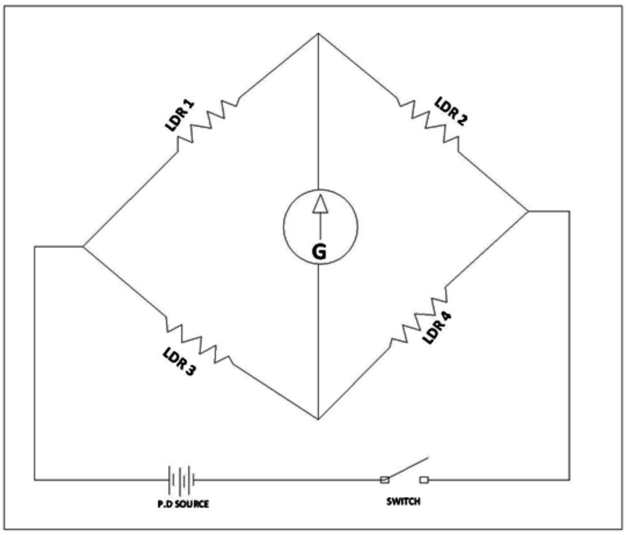


Fig. 2 Wheatstone Bridge Sensor

- The Stem: a two inch round galvanized metal pipe is used as the stem to convey the weight of the panel and the upper part of the tracker to the base support.
- The Wind Lock: The wind-lock is made of a bolt and knot attached to a cylindrical pipe to retain the angles of the tracker against wind action.

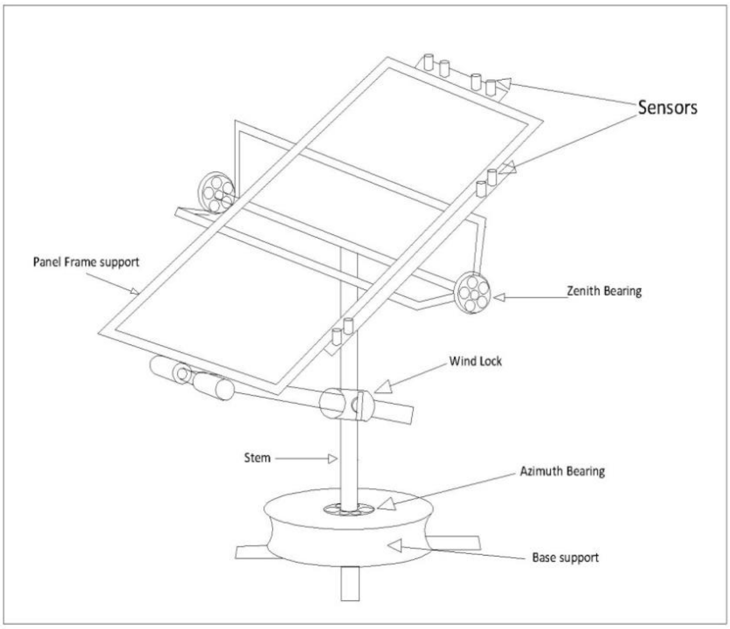


Fig. 3 Diagram of the Tracking Mount

Fig..4 Picture of the Tracking mounted Panel

Determination of the Sun Position

The sun position in the sky is determined based on the angles of zenith and azimuth viewed from a particular position on the surface of the earth. The zenith angle is the angle between the sun's direction and the axis perpendicular to the plane of observation and upward. The azimuth angle is the angle between the North Pole of the observation plane and the direction of the sun's projection on the earth measured in the clockwise direction. Fig. 5 shows the angles of Zenith, Azimuth and Elevation. The other angle that is complementary to the zenith angle is called the elevation angle. Geographically, the position of a region on the earth is marked by the parameters of latitude and longitude. The latitude refers to the position of an area between the northern and southern poles of the earth while the longitude marks it relevant with respect to east-west direction.

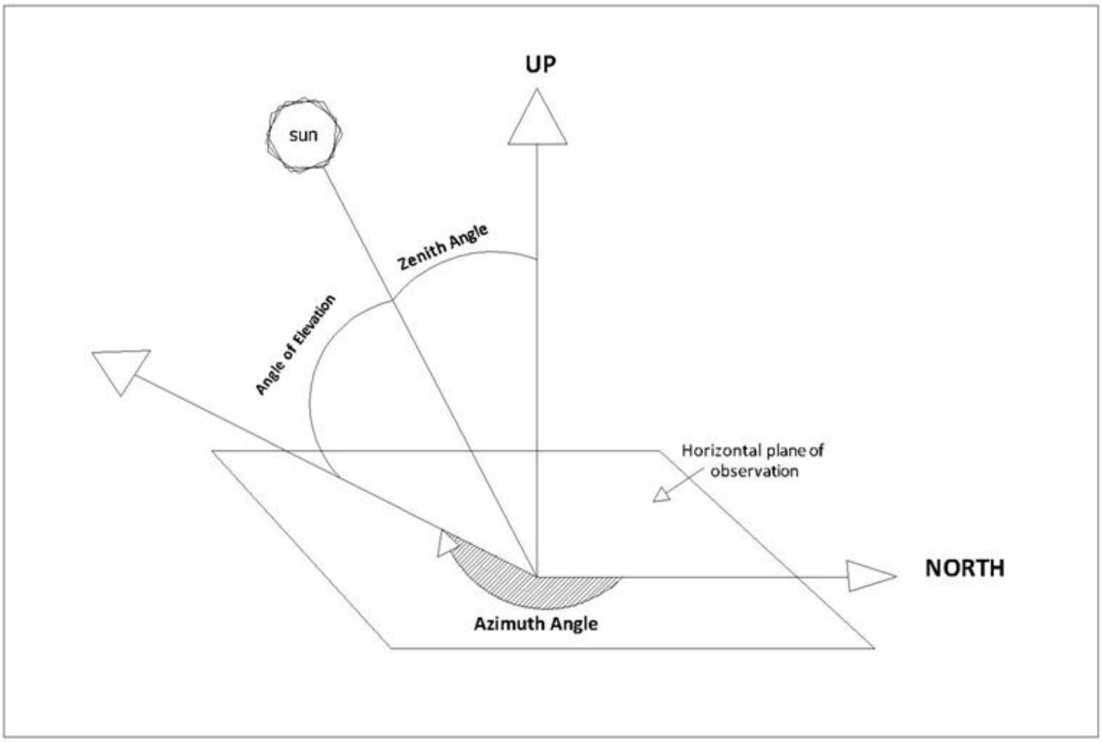


Fig. 5 Sun Position in the Sky, (Nwokoye, 2010)

Measurement of Current Output

The current output of each panel was measured using an AIDA DT-830D digital multi-meter connected in series along the positive terminal of the panel. The DT-830D is chosen because it is capable of measuring D.C current up to 10 A which is higher than the maximum current output rating (7.75 A) of the solar panels. The positive terminal of the panel is connected to the 10 A unfused Jack of the multi-meter and the negative terminal of the solar panel is connected to the COM-jack of the multi-meter. The DT-830D multi-meter connected in current measuring mode is shown in Fig 6.

Fig. 6: Digital Multi-meter in Current Measuring Mode

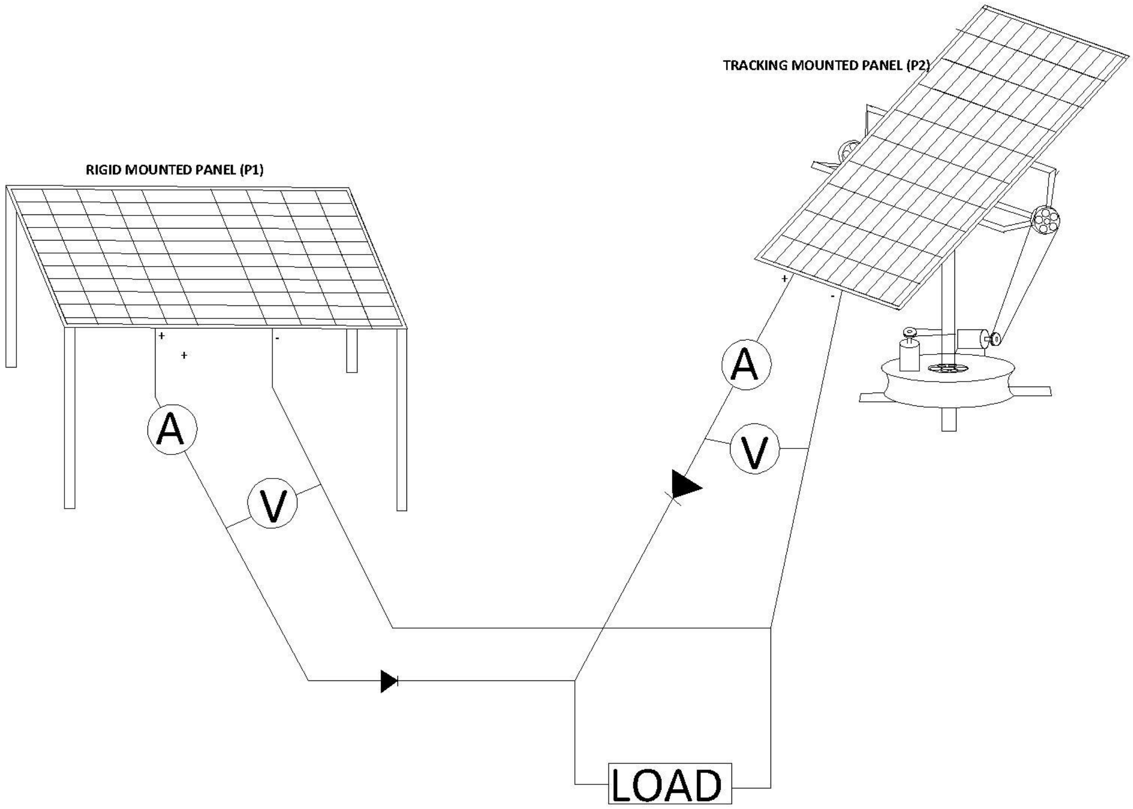
Measurement of voltage output of Panels

The voltage output of each panel was measured using an AIDA DT-830D digital multi-meter connected in parallel between the positive and the negative terminal of the panel. The DT-830D is chosen because it is capable of measuring D.C voltage in the range of 1 mV up to 1000 V which is higher than the maximum voltage output of 17.5 V of the solar panels. The positive terminal of the panel is connected to the VΩmA Jack of the multi-meter and the negative terminal connected to the COM-jack of the multi-meter. The DT-830D multi-meter connected in voltage measuring mode is shown in Fig. 7.

Fig. 7 Digital Multi-meter in Voltage Measuring Mode

Experimental Methodology

The experiment was carried out at Abakpa Nike Enugu; latitude 6.27 ^{o}N and longitude 7.32 ^{o}E for twenty days. One of the solar modules (P2) was mounted on a dual axis tracking mount to track and position its panel perpendicular to sun. The second solar panel (P1) was laid on a rigid mount which is a supportive structure that is used to hold the photovoltaic panels in a fixed horizontal position on the ground surface. On each of these solar panel is attached a liquid in glass alcohol thermometer with measuring accuracy of ± 0.5 ^{o}C to obtain the glass-air temperatures. These solar panels are spaced from each other to make sure that the shadow of one is not cast on the other yet the distance between the two panels is set so that both module experiences the same environmental condition. A blocking diode – which is a two-terminal electronic component that conducts primarily in one direction (asymmetric conductance) and has low (ideally zero) resistance to the flow of current in one direction and high (ideally infinite) resistance in the other direction – is attached to the output of each of the solar panels to ensure that the output of one panel with a higher voltage does not drive back the current in the other one thereby faulting the readings. The closed circuit current, voltage and glass-air temperatures of each panel are read every thirty minutes starting from 6:30 hrs to 18:00hrs each day for twenty days. The diagram of the system is shown in Fig. 8



A = Ammeter,
V = Voltmeter

Fig. 8 Diagram of the system

Determination of other Quantities

Electrical Power Output:
Electric power (P) is a measure of electrical work done per unit time, measured in Watt, and represented by the letter *P*. The term *wattage* is used colloquially to mean "electric power in Watt." The electric power in Watt produced by an electric current *I* consisting of a charge of *Q* coulombs every *t* seconds passing through an electric potential (voltage) difference of *V* is given by the expression

$$P = \frac{VQ}{t} = IV \qquad (4)$$

where

Q	=	electric charge in coulombs
t	=	time in seconds
I	=	electric current in amperes
V	=	electric potential or voltage in volts

The average power output of each panel is determined as the product of measured voltages and current outputs of the solar panel by its Digital Multi-meters.

Electrical Energy
Electrical energy (E) is the work done in moving electric charges round an electric circuit. Since the electric charges are moving, this is a form of kinetic energy. Electrical energy is related to electric potential and current as shown in the expression below;

$$E = Pt = IVt \qquad (5)$$

where

E = Electrical energy
P = Electrical Power
I = Electrical Current
V = Electrical Potential
t = Time

The Electrical energy collected by a solar module can be calculated by computing the product of its Voltage output, current output and time interval between two successive readings.

Efficiency of Panel

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaic process into electricity. The efficiency of each panel would be determined using the input-output model as given in the expression below

$$eff = \frac{Summation\ of\ Energy\ collected\ by\ panel\ (E_t)}{Total\ possible\ energy\ that\ can\ be\ collected\ by\ panel(E_{max})}\ x\ 100 \qquad (6)$$

IV. Result

Table 1; Average Daily Half Hour Power Outputs of the two Modules

S/N	Time of Day	Twenty Days Half Hourly average power output of Panel 1	Twenty Days Half Hourly average power output of Panel 2	Experiment Days Half Hourly Average Temperature
1.	7.00	3.2	4.7	23.6
2.	7.30	5.7	7.2	24.7
3.	8.00	9.8	12.4	26.4
4.	8.30	15.7	18.9	28.8
5.	9.00	17.7	20.3	30.5
6.	9.30	21.8	24.2	31.7
7.	10.00	30.8	31.9	33.8
8.	10.30	32.3	32.0	33.9
9.	11.00	33.9	33.7	35.1
10.	11.30	37.0	33.5	36.1
11.	12.00	40.1	35.9	37.0
12.	12.30	43.6	39.6	38.1
13.	13.00	42.1	38.5	38.5
14.	13.30	40.0	37.3	38.6
15.	14.00	35.0	36.0	39.4
16.	14.30	30.0	31.8	38.5
17.	15.00	27.0	30.9	38.0
18.	15.30	21.3	25.6	36.6
19.	16.00	16.7	22.7	35.8
20.	16.30	11.6	16.7	33.9
21.	17.00	7.5	11.5	32.9
22.	17.30	3.4	6.2	32.3
23.	18.00	0.9	1.6	29.3

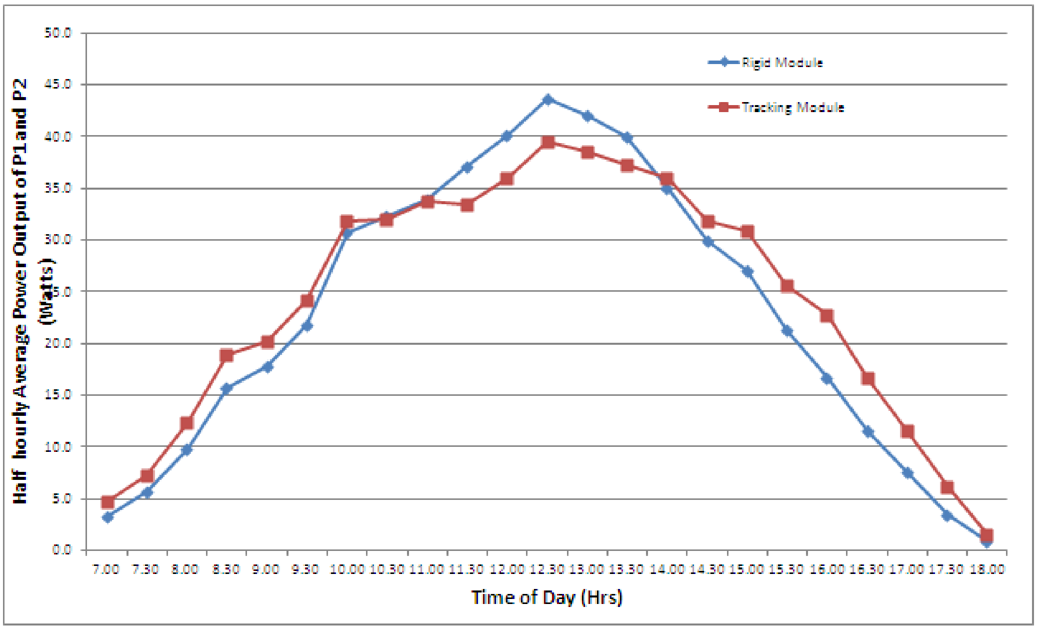


Fig. 9 Half Hourly Average Power-Output of Modules (Watt) against Time of Day (hrs)

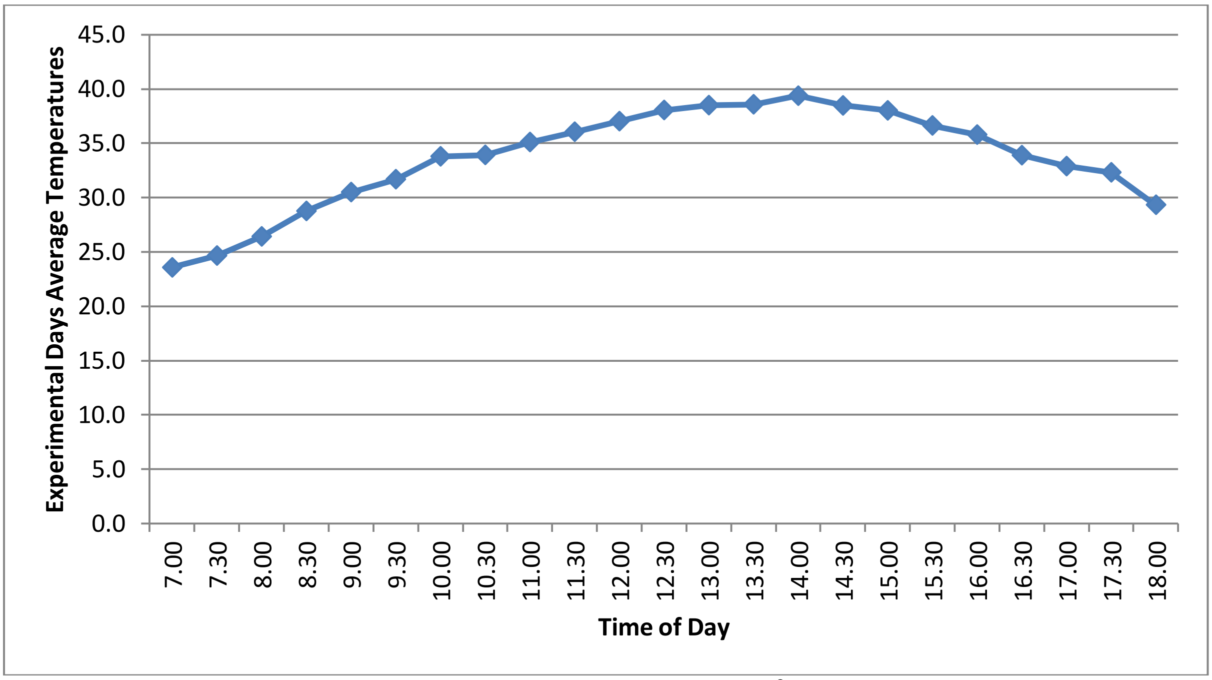


Fig. 10. Experiment Days Half Hourly Average Temperature (^{o}C) against Time of Day (Hours)

V. Discussion

In this work, the efficiency of a rigid horizontally mounted module was compared with the efficiency of a tracking module using the power output of two 130W solar modules. The experiment was carried out at Abakpa Nike Enugu; latitude 6.27 ^{o}N and longitude 7.32 ^{o}E for twenty days. One of the solar modules (P2) was mounted on a dual axis tracking mount to track and position its panel perpendicular to sun. The second solar panel (P1) was laid on a rigid mount which is a supportive structure that is used to hold the photovoltaic panels in a fixed position towards the sun. The Voltage output, current output and temperature of each panel was measured and recorded every thirty minutes starting from 6:00 hours of each day, with the data obtained, the energy produced by each panel for a day was calculated and analyzed. The efficiencies were also calculated using the summation of light energy collected and converted by each module into electrical energy. The result showed that the output of the tracking module was higher than that of the rigid module during the post meridian (noon hour) as well as during the pre-meridian hours. None the less, the rigid module power output surpassed that of the tracking module during the meridian hours by a significant amount. This result was close to the conclusion of Mahendran *et al*., (2014) that concluded that Single-axis tracking panel is more efficient than fixed panel only in pre-meridian and postmeridian. And that at noon-time or mid-day, both panels were producing comparable equal amount of power output. Furthermore, this experiment found that the rigid horizontal module produced a significant power output that the tracking module during the meridian hours as shown in Fig.9. This observed significant difference at noon hour could be attributed to difference in location at which both experiment was carried out.

VI. Conclusion

This research concludes and state as follows;

- Going by the details observed during the twenty days of the experiment, a tracking module collect more energy than the rigid horizontally mounted panel mostly when the sun was visible, intense and in the pre-meridian and post meridian hours. However, when the sun was neither visible nor intense and the atmosphere is cloudy or misty there is no significant difference between the tracking module power output and that of the rigid horizontal module as both are collecting the diffuse light only.
- Taking a holistic half hourly average of power output from the two setups, the Tracking modules collects more energy than the rigid horizontal modules during the post and pre-meridian hours but a significant difference is notice during the meridian hours in favour of the rigid horizontal modules. This suggests that there are more environmental factors that could affect the power output of a solar module.
- Also from statistical point of view, the mean difference between the power output of the Tracking module and the rigid mounted horizontal module over the period of this study is 2.33 Watt in favour of the tracking module.

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