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# DETERMINATION OF ANGLE OF INCLINATION FOR OPTIMUM POWER PRODUCTION FROM SOLAR POWER SYSTEM. A CASE STUDY

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## ABSTRACT
*This study evaluates the performance of the photovoltaic modules at different tilt angle (angle of inclination) from 5º to 90º.*
*The solar panel of 45 Watts capacity was placed on the manual tracker between the hours of 7:00am and 6:15pm on the geographical location of latitude of $4^0$ 55' 58" North and longitude of $6^0$ 59' 55" East in University of Port Harcourt environment between November and December, 2010. The protractor was used to measure the tilt angle which the solar panel made with the horizontal at an interval of 5º daily. A digital Multi-meter was employed to record the open circuit voltage $V_{OC}$ and short circuit current $I_{SC}$ of the solar panel from which the power output was determined.*
*The study shows that the maximum power output of 39.74 watts was obtained at the tilt angle of $40^0$ by 11.30a.m., a day that was characterized with high intensity of sunlight, in this geographical location. This result gives 88.31% of the full capacity of the employed solar panel. Considering the Daily Average Power Output, Tilt angle of $15^0$ recorded Optimum Daily Average Power output of 16.83 Watts throughout the period of measurement. This suggests that tilt angle of $15^0$ is considered as suitable angle for Solar panel installation for optimum daily power production in this geographical location.*

**Key words:** *Angle of Inclination, Solar Panel, Multi meter, Protractor, Manual tracker.*

## INTRODUCTION
The sun has been described as a giant fusion reactor that is continuously supplying the earth with solar power.

The flow of solar energy that arrive the earth outside the atmosphere is about 1.353 Kilowatts on an area of 1 square meter oriented at right angle to the incoming sunlight. The radiant energy changes due to changing distance from the earth to the sun during the year, atmospheric conditions, and angle of incidence of the sun rays.
(http://www.waterlinecompanies.com/alternative/FAQs/SolarFAQs.aspx)

The intensity of solar energy at noon on a clear day is about 1000W/m$^2$ (watts per square meter) with most in form of direct radiation (http://www1.eere.energy.gov/solar/photovoltaics_program.html).

Direct radiation is an incident beam, which is directly on the earth's surface. Another type of solar radiation is diffused radiation, which scattered before reaching the surface of the earth.

The solar radiation falling on a tilt plane (such as a solar panel) depends on many factors. These include Angle of orientation of the plane, Time of the day, the weather conditions.

Since the solar energy occurs as a result of nuclear fusion, this fusion takes place at the sun's interior (about 93 million miles away) and the energy gets to the earth in form of electromagnetic radiation through transmission process. This transmission process reduces the power intensity of the solar energy reaching the surface of the earth due to convective, radiative, conductive and reflective effects.

In recent times, man has used solar energy to carry out various operations. These operations are possible when converting solar energy to electrical energy i. e. generation of electric power.

A great stride over the years has been made towards directly converting the solar energy to electrical energy using photovoltaic cells (solar cells) and obtaining maximum performance of the photovoltaic cells.

The solar energy is obtained indirectly from the solar radiation from the sun. The solar radiation can be utilized indirectly by the inverter, which converts direct current to alternating current when the rays from the sun are being captured by the solar panel.

Bell Telephone (1954) discovered a photovoltaic cell and carried out an experiment to examine the sensitivity of these cells prepared with silicon wafers to sunlight.

Fuller (1976) created a silicon solar cell. These early solar cells cost 286 US Dollars per Watt and reaches efficiencies of 4.5% to 6%. The high cost solar cell was limited to terrestrial uses through 1960s but the change in the early 1970s made the photovoltaic generation competitive in remote areas without grid access.

Perez and Coleman (1993) recommended an angle that puts the panel perpendicular to the sun rays at noon but the best angle at noon does not account for best angle in capturing solar energy at other times of the day.

For solar energy, PV is identified to be of good potential for wide scale application. Port-Harcourt metropolis belongs to the subtropical climate region with typically hot and wet climate of characteristic distribution of total, diffuse and direct solar radiation (Akpabio et al, 2003).

The average solar radiation potential for a tropical climate region is about 16.4 ± 1.2 W / $m^2$ per day (Green, 2002).

Mousazadeh et al (2009) affirmed that the sun tracker could boost the collected energy 10 – 100% in different periods of time and geographical conditions. It is found that the power consumption by tracking device is about 2 – 3% of the increased energy.

This paper thus presents the effect of angle of inclination and Optimum tilt angle at which the solar panel can be installed so as to generate optimum power output from solar power system and specifically to this geographical location.

## MATERIALS AND METHODS

In this study, the materials employed are 45 Watts Multi-Silicon Solar Panel (Model Number STP045-12/Rb), Manual Pole tracker, Protractor, 0.5kVA inverter, Digital Multimeter, Spanners, Meter rule.

The manual pole tracker consists of metal fabrication designed with joint to give opportunity of swivelling the Solar panel to a certain tilt angle after inserting the Solar panel (Fig. 1). It has a pivoted neck that links the tracker to the galvanized pipes. The pivoted

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neck is being held together by bolts and nuts (Fig. 2).

The tracker was mounted temporarily facing a particular direction and the solar panel was placed on the tracker. The bolt of the protector of the tracker was tightened to prevent the solar panel from falling off the fabrication. This method of mounting is referred to as *top of pole mounting* (Fig. 3).

To measure the angle of tilt, a meter rule is placed horizontally below the tracker that the solar panel sits. The angle that the tracker makes with the meter rule is known as tilt angle ϴ, then the bolts were tightened at the pivoted joint to prevent the tracker from dangling and shifting from the angle at which it was kept. A protractor was used to measure the angle with respect to the meter rule and the tracker in position (Figs. 4 and 5). A digital multimeter was then employed to measure the open circuit voltage, $V_{oc}$ and the short circuit current, $I_{sc}$ of the photovoltaic cell from the terminals by using the probes of the multimeter. This process was repeated at every 15 minutes interval from 7 am to 6.15 pm till the short circuit current reads zero as an output. The angle was varied daily from $5^0$ to $90^0$ when solar panel was assumed parallel to the incoming solar radiation. The weather conditions were also noted for adequate reporting. The block diagram in figure 6 shows the connection set-up from the solar panel to the inverter.

**Fig. 1:** A typical Solar Cell

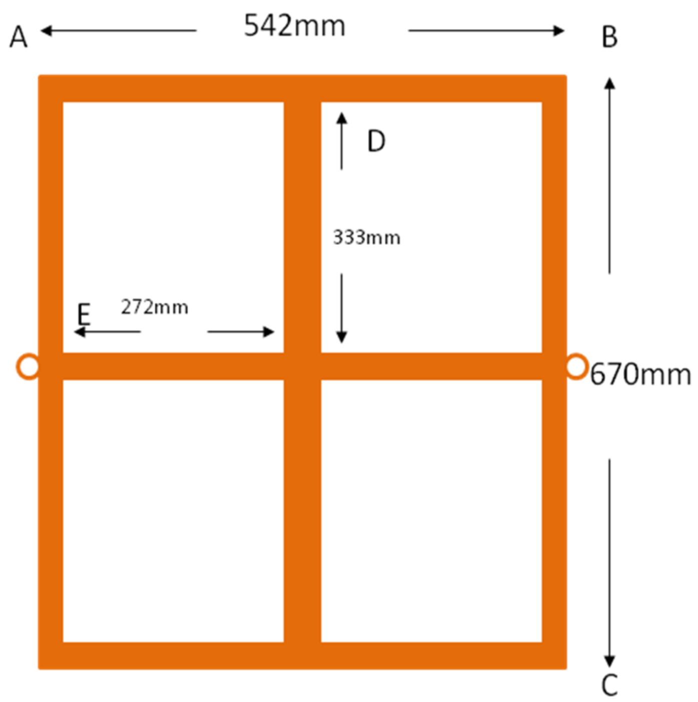


**Fig. 2:** Showing the dimensions of manually fabricated pole tracker

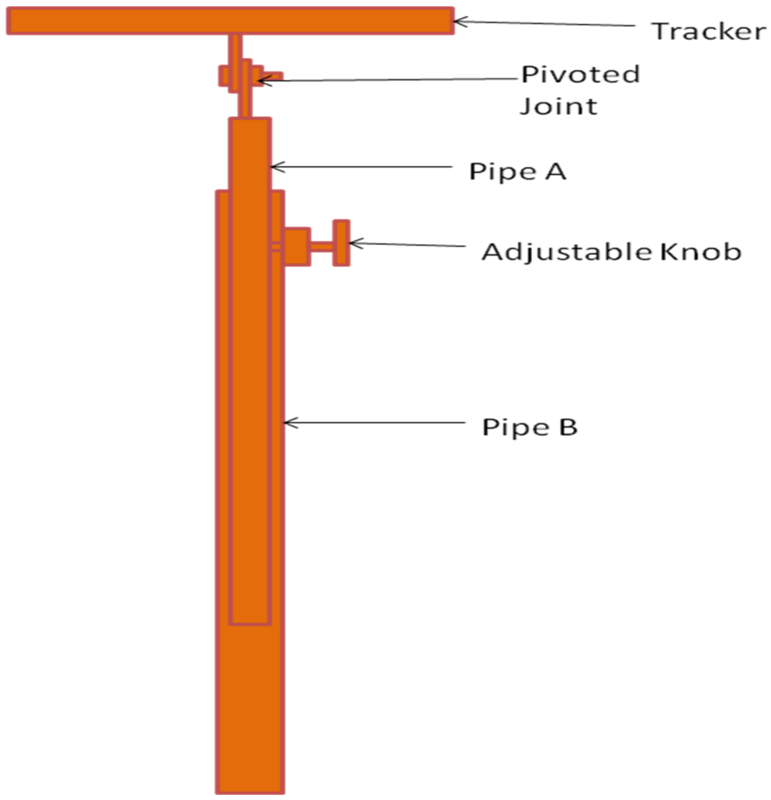


**Fig. 3:** The galvanized pole on which the Solar Panel was positioned.

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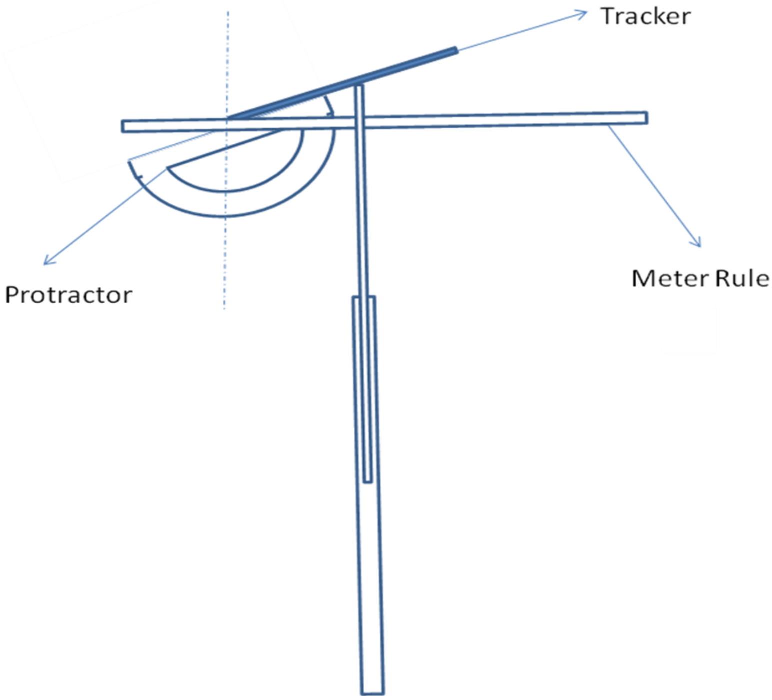


**Fig. 4:** Schematic of angle of inclination or tilt angle measurement.

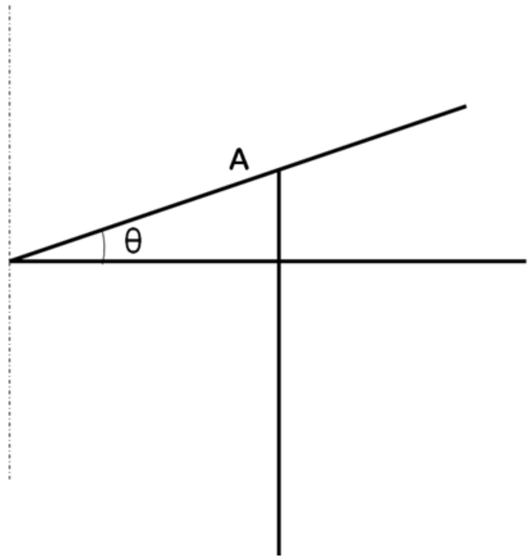


**Fig. 5:** Geometry of angle of tilt measurement

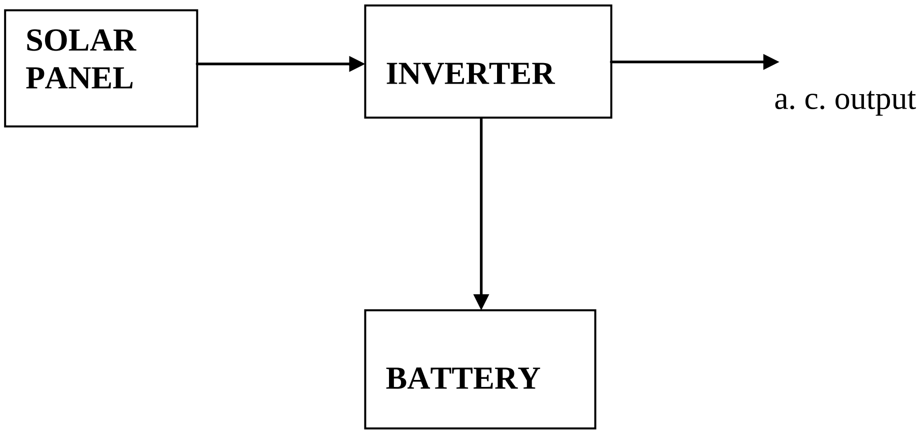


**Fig. 6:** The block diagram of the set up.

The angle Θ is the tilt angle with respect to the horizontal

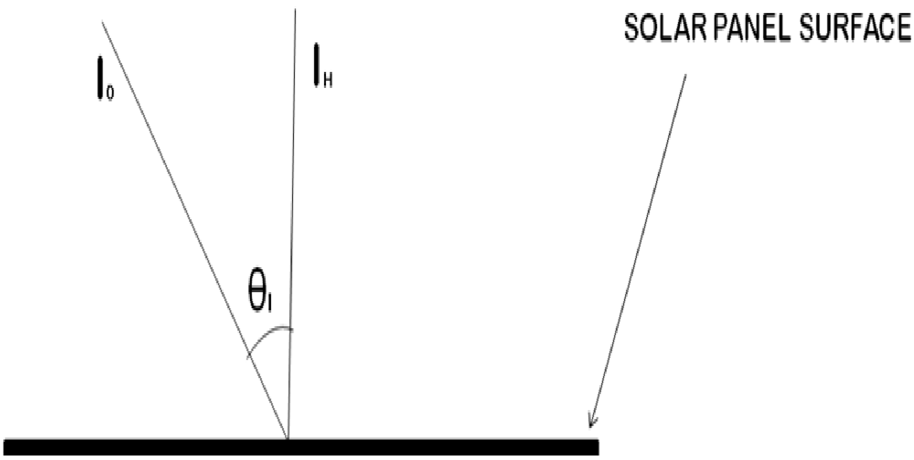


**Fig. 7:** Diagram showing incident solar radiation on a plane surface

$$I_H = I_0 Cos\theta_i \quad \text{……………………………………..} \quad 1$$

Where $I_H$ is the horizontal to the incidence (incoming) rays.

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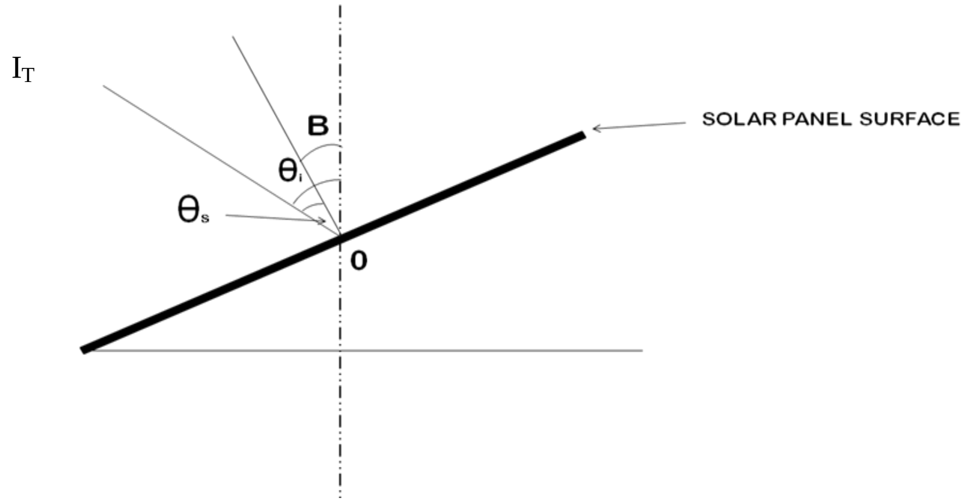


**Fig. 8:** Geometry of incident solar radiations on an inclined Solar Panel.

$$I_T = I_{OB} Cos\theta_s \quad \text{……………………………………………..} \quad 2$$

$$\theta_s = \theta i - \beta$$

Maximum, when $\theta_s = 0$

$$I_T = I_{OB} Cos(\theta i - \beta)$$

$$Cos(\theta_i - \beta) = \frac{I_T}{I_{OB}}$$

$$Cos\theta_s = \frac{I_T}{I_{OB}}$$

$$\theta_s = Cos^{-1}(\frac{I_T}{I_{OB}})$$

The typical data collected on day 3 when the Solar panel was inclined at $15^0$ to the horizontal is shown below.

**Table 3:** Data Collected on Day 3 at Angle 15°

| Time of day | V(Volts) | I(Amp.) | P(watts) |
|---|---|---|---|
| 7.00am | 18.05 | 0.07 | 1.26 |
| 7.15am | 18.41 | 0.09 | 1.66 |
| 7.30am | 19.56 | 0.26 | 5.09 |
| 7.45am | 19.97 | 0.56 | 11.18 |
| 8.00am | 19.75 | 0.58 | 11.46 |
| 8.15am | 20.21 | 1.09 | 22.03 |
| 8.30am | 20.04 | 1.32 | 26.45 |
| 8.45am | 19.41 | 0.65 | 12.62 |
| 9.00am | 20.09 | 1.52 | 30.54 |
| 9.15am | 20.24 | 1.7 | 34.41 |
| 9.30am | 19.51 | 0.9 | 17.56 |
| 9.45am | 19.64 | 0.69 | 13.55 |
| 10.00am | 20.23 | 1.03 | 20.84 |
| 10.15am | 19.86 | 2.05 | 40.71 |
| 10.30am | 19.32 | 0.5 | 9.66 |
| 10.45am | 19.25 | 0.42 | 8.09 |
| 11.00am | 19.7 | 0.69 | 13.59 |
| 11.15am | 20.05 | 1.38 | 27.67 |
| 11.30am | 19.65 | 2.4 | 47.16 |
| 11.45am | 20.07 | 1.05 | 21.07 |
| 12.oopm | 19.99 | 1.37 | 27.39 |
| 12.15pm | 19.8 | 1.4 | 27.72 |
| 12.30pm | 19.69 | 1.65 | 32.48 |
| 12.45pm | 19.77 | 1.16 | 22.93 |
| 1.oopm | 20.07 | 1.31 | 26.29 |
| 1.15pm | 19.68 | 1.41 | 27.75 |
| 1.30pm | 19.77 | 1.59 | 31.43 |
| 1.45pm | 19.65 | 1.26 | 24.76 |
| 2.00pm | 19.78 | 1.46 | 28.88 |
| 2.15pm | 19.57 | 0.86 | 16.83 |
| 2.30pm | 19.73 | 0.79 | 15.59 |
| 2.45pm | 20.06 | 1.47 | 29.49 |
| 3.00pm | 19.89 | 1.5 | 29.84 |
| 3.15pm | 18.84 | 0.35 | 6.59 |
| 3.30pm | 19.32 | 0.5 | 9.66 |
| 3.45pm | 19.1 | 0.38 | 7.26 |
| 4.00pm | 19.49 | 0.49 | 9.55 |
| 4.15pm | 19.88 | 0.85 | 16.89 |
| 4.30pm | 19.64 | 0.66 | 12.96 |
| 4.45pm | 19.11 | 0.39 | 7.45 |
| 5.00pm | 17.78 | 0.11 | 1.96 |
| 5.15pm | 17.21 | 0.06 | 1.03 |
| 5.30pm | 17.31 | 0.06 | 1.03 |
| 5.45pm | 15.81 | 0.03 | 0.47 |
| 6.00pm | 13.68 | 0.02 | 0.27 |
| 6.15pm | 4.38 | 0 | 0 |

Table 2 below shows the Total and Average Daily Power generated by the Solar Power System at each angle of inclination.

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**Table 2:** Total and Average Power Produced at each Angle of Tilt.

| Angle , θ (degree) | Daily Total Power (Watts) | Daily Average Power (Watts) |
|---|---|---|
| $5^0$ | 335.06 | 7.13 |
| $10^0$ | 662.46 | 14.09 |
| $15^0$ | 791.14 | 16.83 |
| $20^0$ | 423.46 | 9.01 |
| $25^0$ | 506.82 | 10.78 |
| $30^0$ | 510.48 | 10.86 |
| $35^0$ | 503.63 | 10.72 |
| $40^0$ | 620.34 | 13.20 |
| $45^0$ | 455.62 | 9.69 |
| $50^0$ | 435.88 | 9.27 |
| $55^0$ | 429.62 | 9.14 |
| $60^0$ | 446.93 | 9.51 |
| $65^0$ | 394.38 | 8.39 |
| $70^0$ | 340.50 | 7.24 |
| $75^0$ | 279.59 | 5.95 |
| $80^0$ | 318.12 | 6.77 |
| $85^0$ | 260.05 | 5.53 |
| $90^0$ | 263.77 | 5.61 |

## RESULTS AND DISCUSSION

The product of the Open Circuit Voltage ($V_{OC}$) and the Short Circuit Current ($I_{SC}$) gives the Power produced at each instant of measurement from 7:00 am to 6: 30 p.m. until the short circuit current gives 0.00 ampere at an interval of 15 minutes. The atmospheric conditions were also taken into consideration on each day.

The solar panel was inclined at an angle of $5^0$ on day 1 produced the maximum power of 22.67 Watts at 1:00 pm. The graph of I or V versus Time of the day shows that the inconsistent atmospheric factors affect the power generation from the solar panel (figure 9).

The maximum power output on day 5 was 39.38 Watts at 1:45 p.m. when the tilt angle was $25^0$. The day was characterized with high solar intensity. The weather conditions for the day vary from cloudy weather, rainfall to high intensity (Fig. 10).

The panel was inclined at an angle of 40 $^0$ on day 8 and the optimum power output obtained was 39.74 Watts at 11.15am. This power output was the optimum obtained throughout the period of measurement. The weather was characterized with very high intensity (Fig. 11).

On day 17 when the panel was at an angle of $85^0$, the maximum power output obtained was 10.19Watts at 9:45am. The reason for the low maximum power output on this day is attributed to little surface area at which the sun light radiation impinges the surface of the solar panel. The Solar panel orientates nearly out of phase of incoming solar radiation (Fig. 12).

**I – V Characteristic Curve**

The I – V characteristic curves show the relationship between the short circuit current and the open circuit voltage.

On day 2, the $V_{oc}$ and $I_{sc}$ obtained are 19.17 Volts and 2.64 Amperes respectively. The graph shows that the open circuit voltage and the short circuit current were affected by the atmospheric conditions such as intensity, relative humidity, dust particles, ozone e. t. c. and the conversion efficiency of the solar panel (Fig. 13).The open circuit voltage output and the short circuit currents obtained from the solar panel depend on the instant weather conditions and the angle at which the solar panel is inclined. This tilt angle enhances the efficiency of the solar panel so long it can fully harness the incoming solar radiation.

**Average Power – Angle Graph**

Daily Average power – Angle graphs suggest the angle of tilt at which the solar panel may be inclined for maximum daily power output.

From this graph, maximum average power output of 16.83Watts was attained at angle $15^{0.}$ This angle could be considered adequate for stabilized daily average power output due to atmospheric conditions in this geographical area (Fig. 14).

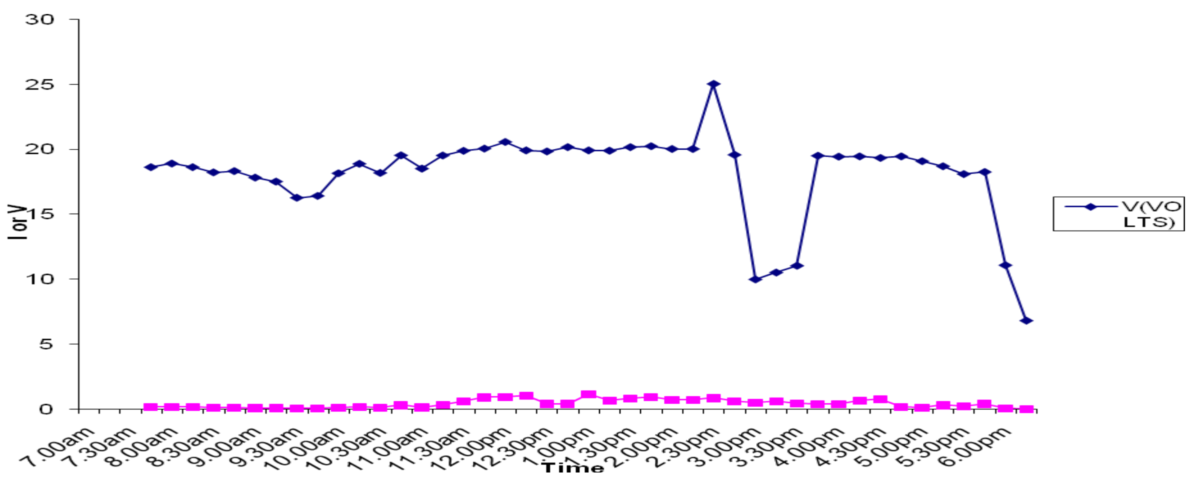


**Fig. 9**: Graph of Current and Voltage against Time at Tilt angle of $5^0$.

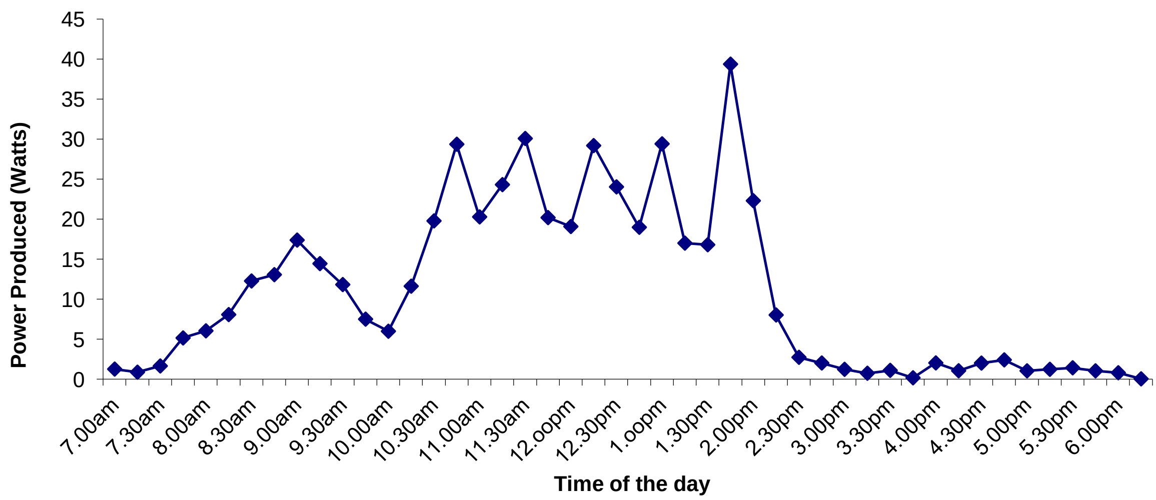


**Fig. 10:** Graph of Power produced at Tilt angle of $25^0$ against the Time of the day.

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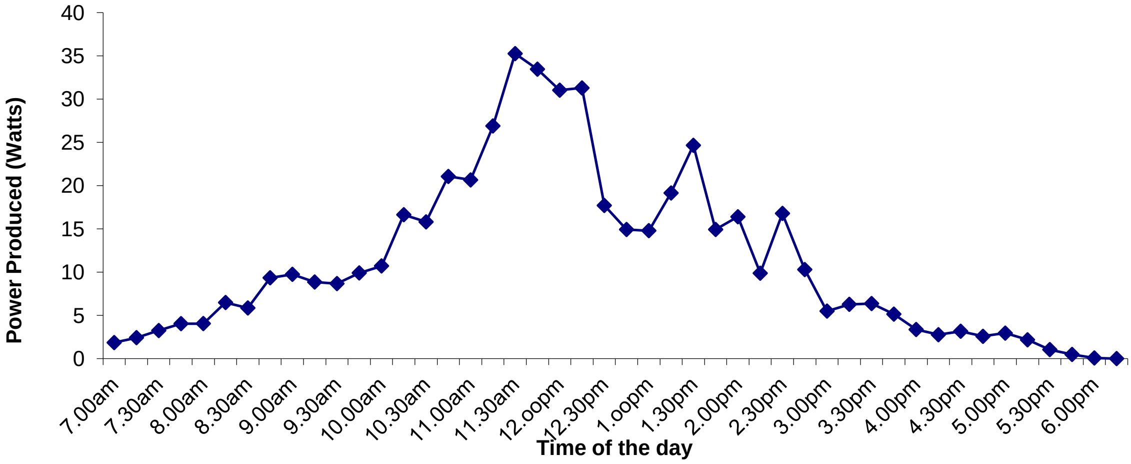


**Fig. 11:** Graph of Power produced at tilt angle of $40^0$ against Time of the day.

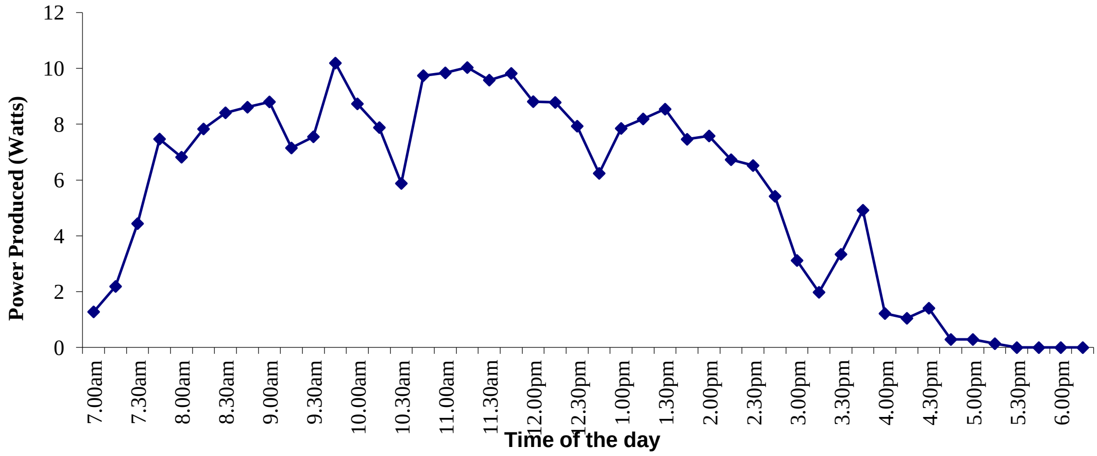


**Fig. 12:** Graph of Power produced at tilt angle of $85^0$ against Time of the day.

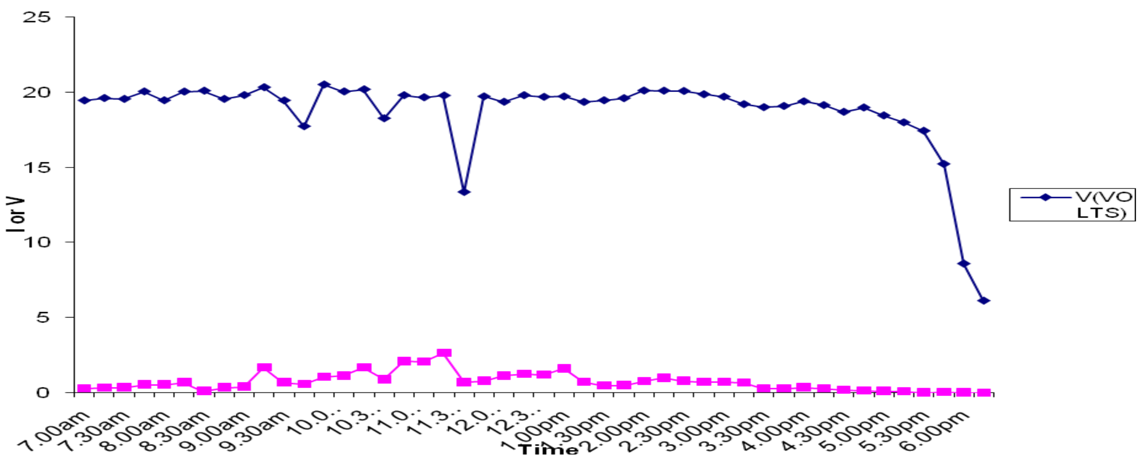


**Fig. 13:** I – V against Time of the day at an inclined angle of $10^0$

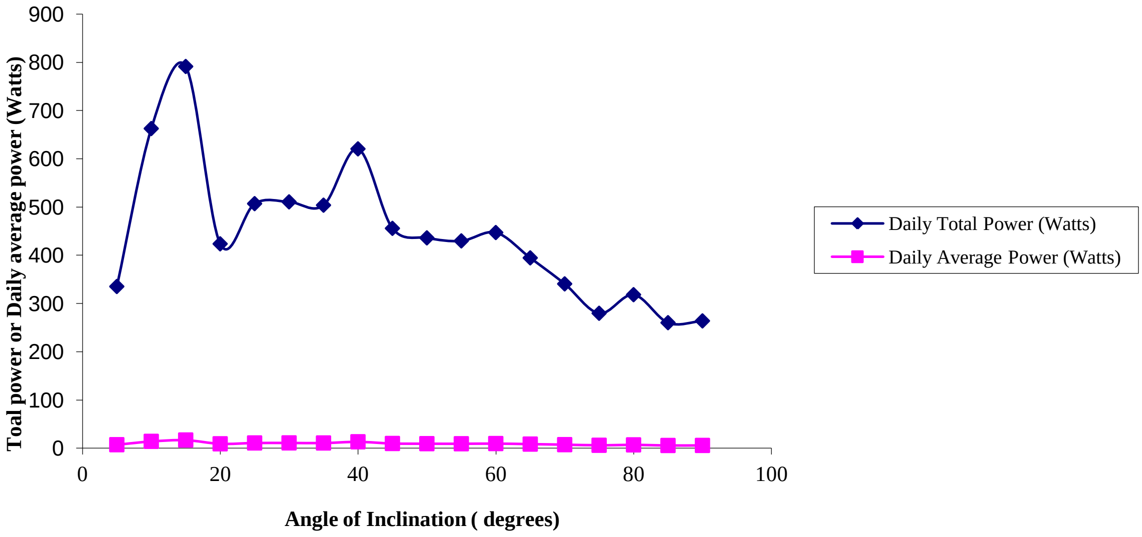


**Fig. 14:** Graph of Daily Total Power and Daily Average Power against Angle of inclination.

## CONCLUSION

The study of the effect of angle of inclination on the performance of solar power generation shows that the performance of the photovoltaic cells or solar panel in solar power generation are based on weather conditions and the angle at which the solar radiation falls on the surface of the solar panel. Since a 45 Watts solar panel was used in carrying out this study, the expected optimum value of the output performance of the panel was 45 watts or less since the panel may not be able to produce 100% efficiency due to some factors earlier stated.

On day 8, maximum power output of 39.74 Watts (88.1% of manufacturer's power rating) was obtained at the tilt angle of $40^0$. The Optimum Power produced by daily averaging was obtained at Tilt angle of $15^0$. Therefore, this study suggests that the solar panel can be inclined at an angle of $15^0$ on this geographical location for optimum, clean power production.

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## REFERECES

Akpabio, L. E. and Udoimuk, A. B. 2003: *Characteristic distribution of total, diffuse and direct solar radiation in Port – Harcourt;* Global Journal of Pure and Applied Sciences. 9(1): 45 -49.

Bell Telephone, 1954: *Photovoltaic Conversion of Solar Energy*, GIS journal; Vol 15, Page 14 –17.

Calvin Fuller ,1954 : *A study to the performance of solar cells under conditions*; American Journal of Renewable Energy; Vol. 2, page 36 – 41.

Green, M. A. , 2002 : *Photovoltaic technological overview;* Energy Policy. 28: 989 - 998.

Hossein Mousazadeh, Alireza Keyhani, Arzhang Javadi, Hossein Mobli, Karen Abrinia, Ahmad Sharifi , 2009 : *A Review of Principle and Sun-tracking Methods for Maximizing Solar Systems Output* ; Renewable and Sustainable Energy review ; doi : 10.1016/j.rser 2009.01.022.

*Scientia Africana, Vol. 11 (No.1), June 2012. pp 1-13*
 *ISSN 1118 - 1931*

Richard Perez and Sam Coleman, 1993, : *Heat Transfer,* Colher Macmillian Pub. Co. London, Page 2.

Sam Coleman, 1993: *Survey on Solar irradiation, Power Generation and Optimum inclined Angle of Cell module*, The third International Workshop on Energy and Environment of resident building, Page 29.

http://www1.eere.energy.gov/solar/photovoltaics_program.html

http://www.waterlinecompanies.com/alternative/FAQs/SolarFAQs.aspx