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# DESIGN, CONSTRUCTION AND CALIBRATION OF A SOLAR RADIATION MEASURING METER

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## ABSTRACT

*A digital solar radiation measuring instrument has been designed, constructed and calibrated. It incorporates a small rectangular silicon photocell as the sensor. On exposure to solar radiation, electromotive force which is proportional to radiation intensity is developed within the circuit. The device correlates voltage developed with available solar intensity. A standard solarimeter was therefore used to calibrate the device to translate the unit of its reading from Volt to Watt per square meter. Intensity spread obtained with respect to time of day agrees with various studies conducted previously on tropical environments. Results obtained generally conform with those obtained by Medugu, et al. [1] and Chiemeka [2]). With a calibration conversion factor of 877.19(V − 1.71) Wm$^{-2}$, the device can be used to collect reliable irradiace data which are both comparable and compatible with that of a standard solarimeter.*

**Keywords:** Solar radiation, Solar meter, Measurement, Voltage, Intensity, Solar sensor, Calibration.

## 1. INTRODUCTION

Solar radiation is important to mankind, for heating, electricity generation, water pumping for irrigation and crop drying in Agriculture. It determines the rate of photosynthesis in plants and strongly regulates the amount of evaporation from rivers and streams. It warms our planet and gives us our everyday wind and weather. Without solar radiation the earth would gradually cool in time becoming encased in layer of ice.

Solar radiation intensity is a measure of the quantity of electromagnetic radiations which are transmitted from the sun to the Earth. It varies from one point on the Earth surface to another, [3]. It is mearsured in Watt per square meter (Wm$^{-2}$).

However due to the average distance of the sun from the earth, about 150 million kilometers, the quality and intensity of solar radiation change considerably on its journey through the earth's atmosphere. These changes are usually conditioned by the solar constant, transparency of the atmosphere, length of the daily sunlight, and the angle at which the sun's rays strike the earth.

The average distance of 150million kilometers is equivalent to one earth astronomical unit (1.0 au), [4]. Due to the shape of the earth's orbit the sun is closer to earth in January at a distance of about 147million km and farther away in July at a distance of about 152million km [5]. Thus the amount of solar radiation received on earth's surface depends on the year, time of day and season [6].

This work bothers on solar radiometry which is the aspect of solar Physics concerned with evaluation of intensities of global solar radiation falling on the surface of a given location [7]. By extension, solar radiometry also involves design, construction, chacterization and calibration of various solar spectral instruments. Chineke [3] observed that the number of stations measuring solar radiation are sparse in Nigeria. This is due largely to unavailability of solar radiation measuring devices (such as Photometer, Solarimeter, Pyranometer, etc).

This work was targeted at designing, constructing and calibrating a digital solar radiation meter for measuring solar radiation intensity. Results obtained are similar to those obtained by Medugu, et al. [1] and Chiemeka [2]. The device can be used to collect reliable irradiance data which are both comparable and compatible with that obtained by a standard solarimeter.

## 2. DESIGN AND CONSTRUCTION

Materials used for the construction include;

(a) Silicon solar cell (sensor)
(b) Digital multimeter
(c) One - way switch
(d) Digital timer
(e) Sensor panel and stand
(f) Aluminum /plastic casing
(g) USB cords
(h) 9 volt dc battery

Design started by selecting a rectangular shaped silicon photocell of dimensions 3cm x 11cm. A digital timer which displays time of day and days of the week was selected. A digital multimeter of range (0 – 10) volts was selected. The multimeter with dimensions 12cm x 20cm was set permanently on the voltage mode so that it measures only voltages.

While the photocell was mounted on a panel, the timer and the multimeter were repackaged in a single aluminum/plastic encasement for ease of reading of voltage and time values. This serves as the digital display unit (DDU). The photocell was connected to the multimeter via a one – way switch. The multimeter has in – built resistor multipliers arranged as $R_{m1}$, $R_{m2}$, $R_{m3}$, etc, as shown in fig 1, to enable it read and display different values of voltages. The multipliers are selected by turning the knob to select the required scale. The photocell on exposure to radiation produces emf across the circuit. Output of the photocell serves as input to the multimeter. Both are linked by computer USB cords. The multimeter and timer system ie (DDU) are powered by a 9-volt dc battery. The entire circuit arrangement is shown in fig 1. When readings are to be taken the panel housing the photocell is mounted on a stand of about 1.5m. The stand has an in-built inclinometer used to adjust the panel's position to incline at the angle of the degree of the latitude of the location where measurement is being made. This makes for efficiency in the capture of solar radiation, [8]. The entire construction is compact.

## 3. OPERATION AND CALIBRATION

The constructed device was used to measure solar intensity at NIMET station in Umudike community in Nigeria. To do this, the panel housing the solar cell was mounted on the solar stand about 1.5m above the ground level in an open field. The in-built inclinometer of the stand was used to incline the cell at the angle of the latitude of Umudike which is about $5^{o}$ N, [2, 9]. Such adjustment is usually critical for finding maximum solar radiation intensity of a location, [10, 11]. An open field was selected to avoid obstacles blocking or affecting the experiment. This meets the condition of avoiding obstacles in the easterly and westerly directions, [12].

The solar cell was connected to the digital display unit by means of USB cords. Since the cell is essentially a p–n junction diode, radiations falling on its surface cause emf which is proportional to the intensity to be generated. To obtain the current produced by the cell you measure the voltage across a small resistor shunted to it. Thus the corresponding voltage value was read and recorded from the digital display unit (DDU). The time and date of measurements were equally read.

For purposes of calibration, the device was placed side by side with a standard solarimeter at NIMET observatory station Umudike. Hence the transferred calibration method was used, [13].

Measurement and calibration were done for a period of three months (January to April) at hourly intervals beginning from 700 hours to 1800 hours for each day. For each hour of the day the reading of the device was taken alongside the reading of the standard solarimeter at same time. Readings were collected for the 13 weeks of study on daily basis and at the end, weekly average data were obtained as shown in table 1.The entire daily data were not presented here because they are voluminous. The dark voltage of the constructed device $V_o$ was first determined to give the calibration a starting point or an origin. This corresponds to the voltage reading of the device when the reading of the standard solarimeter was $0.0Wm^{-2}$.

Table 1 shows the weekly average data. A graph of weekly average voltage was plotted against time using MINITAB statistical package as shown in fig 2. The graph indicates that voltage increases from the early hours of the morning (700 Hrs) peaking at about mid-day (between 1200 and 1300 Hrs). Thereafter it begins to come down gradually towards evening time.

Also a graph of weekly average of solar radiation intensity (SRI) against time was plotted in fig 3. It is similar to that of weekly average voltage against time in fig 2, increasing in the early hours of the morning and peaking during the mid-day, while decreasing towards the evening. Little distortions appear towards the tip between 10.00Hrs and 12.00Hrs. Another distortion appears between 16.00 and 17.00Hrs. These distortions show in the scatter of the points at those times indicating that solar radiation intensity is erratic in nature. The voltage/intensity trend shows that radiation intensity increases steadily with the rising sun from morning hours and peaks around mid-day when radiation is highest. Thereafter it begins to decrease as the sun begins to set in the evening period.

At the end, a graph of weekly average voltage(V) was plotted against weekly average solar radiation intensity(SRI) using MINITAB software package to find out the correlation between the two variables. This is shown in the graph of fig 4. The graph is a straight line graph indicating that voltage developed in the constructed device is linearly related to the available solar intensity. The intercept on the voltage axis at 1.71V shows that this is the threshold voltage value required for conversion from voltage(V) in volts to intensity (I) in watts per square meter as a calibration process. The slope of the graph is $0.00114m^2/A$. This implies that the conversion formula from voltage to Watt/meter-square is ,

SRI = 0.00114 (voltage reading – 1.71) $Wm^{-2}$.

**Fig-1.**Schematic Circuit Diagram of the Digital Solar Radiation Meter.

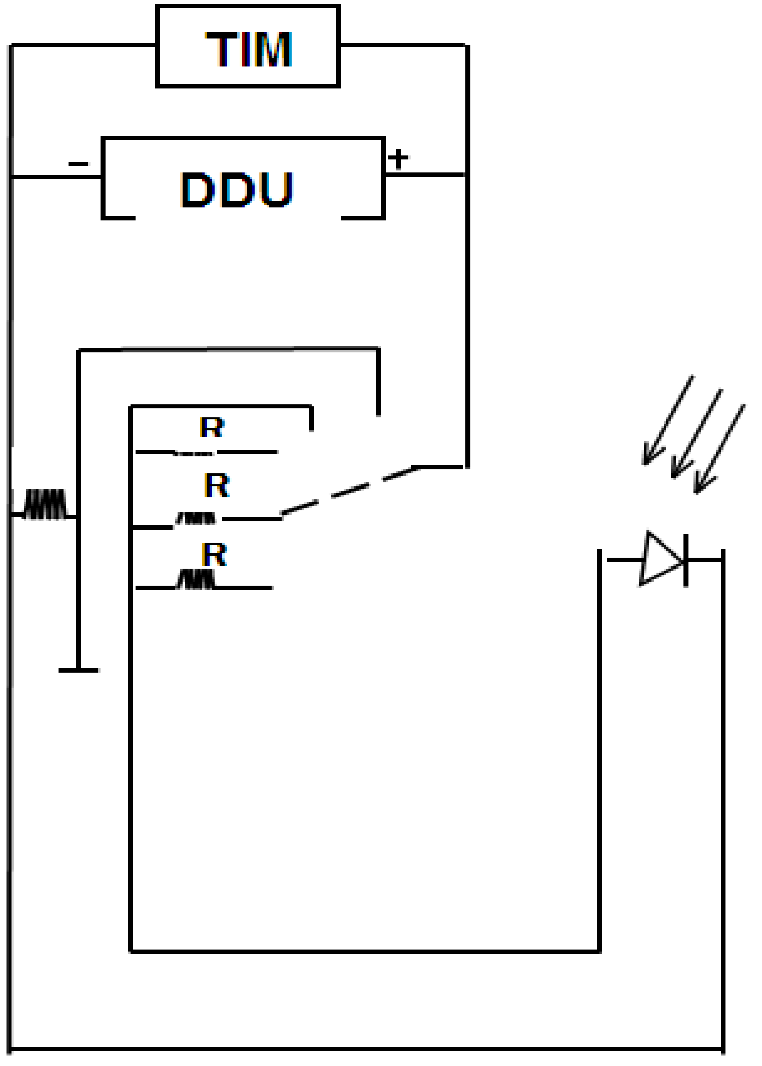


**Table-1.**Table of Weekly average (Week 1 to 13)

| | | WEEK1 | | WEEK 2 | | WEEK 3 | | WEEK 4 | | WEEK 5 | | WEEK 6 | | WEEK 7 | | WEEK 8 | | WEEK 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/N | Time (hr) | Voltage (v) | SRI (/m$^2$) | voltage | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | voltage (v) | SRI (w/m$^2$) | . Voltage (v) | Ave SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) |
| 1 | 700 | 2.01 | 230.9 | 1.99 | 176.1 | 1.97 | 205.0 | 2.00 | 225.7 | 2.05 | 218.5 | 2.05 | 228.0 | 2.05 | 216.5 | 2.09 | 219.0 | 206 | 273.5 |
| 2 | 800 | 2.25 | 453.2 | 2.28 | 472.2 | 2.36 | 384.5 | 2.24 | 443.9 | 2.28 | 486.9 | 2.26 | 456.7 | 2.30 | 505.5 | 2.30 | 505.6 | 2.22 | 406.6 |
| 3 | 900 | 2.42 | 605.6 | 2.42 | 506.3 | 2.44 | 606.1 | 2.41 | 613.9 | 2.42 | 608.9 | 2.43 | 635.7 | 2.42 | 608.5 | 2.43 | 615.0 | 2.42 | 586.0 |
| 4 | 1000 | 2.53 | 744.6 | 2.51 | 767.1 | 2.53 | 786.4 | 2.54 | 778.2 | 2.54 | 779.6 | 2.55 | 820.8 | 2.55 | 667.0 | 2.54 | 787.9 | 2.48 | 567.0 |
| 5 | 1100 | 2.55 | 795.1 | 2.55 | 784.1 | 2.56 | 805.7 | 2.57 | 822.7 | 2.60 | 816.4 | 2.63 | 908.8 | 2.61 | 819.5 | 2.60 | 819.1 | 2.54 | 794.0 |
| 6 | 1200 | 2.56 | 802.6 | 2.56 | 790.5 | 2.57 | 806.1 | 2.59 | 814.4 | 2.62 | 194.9 | 2.68 | 991.2 | 2.65 | 974.9 | 2.65 | 954.2 | 2.56 | 800.7 |
| 7 | 1300 | 2.53 | 791.3 | 2.52 | 761.7 | 2.49 | 588.6 | 2.59 | 814.4 | 2.63 | 198.6 | 2.67 | 990.9 | 2.68 | 993.3 | 2.64 | 797.5 | 2.55 | 794.8 |
| 8 | 1400 | 2.47 | 645.2 | 2.45 | 608.9 | 2.27 | 616.4 | 2.50 | 707.1 | 2.58 | 825.1 | 2.63 | 922.6 | 2.64 | 946.8 | 2.60 | 867.9 | 2.51 | 761.8 |
| 9 | 1500 | 2.43 | 615.8 | 2.40 | 592.7 | 2.39 | 574.7 | 2.45 | 641.1 | 2.69 | 606.8 | 2.56 | 808.2 | 2.55 | 817.4 | 2.52 | 813.6 | 2.52 | 675.3 |
| 10 | 1600 | 2.37 | 569.0 | 2.30 | 399.0 | 2.23 | 433.8 | 2.40 | 603 | 2.40 | 598.7 | 2.45 | 674.7 | 2.42 | 632.5 | 2.43 | 639.4 | 2.44 | 641.6 |
| 11 | 1700 | 2.00 | 250.6 | 2.03 | 277.8 | 1.99 | 241.3 | 1.99 | 229.2 | 2.15 | 356.2 | 2.29 | 506.0 | 2.49 | 472.1 | 2.26 | 440.4 | 2.33 | 529.7 |
| 12 | 1800 | 2.85 | 200.9 | 1.87 | 204.6 | 1.79 | 128.5 | 1.85 | 193.6 | 1.99 | 266.2 | 2.16 | 352.6 | 2.16 | 356.1 | 2.14 | 314.0 | 2.18 | 380.6 |

**Table-1.**Contd.

| | | WEEK 10 | | WEEK 11 | | WEEK 12 | | WEEK 13 | | | | | | FINAL AVERAGE READINGS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/N | Time (hr) | voltage | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) | Total value Voltage (v) | Total value SRI (w/m$^2$) | Average voltage (v) | Average SRI (w/m$^2$) | Voltage (v) | SRI (w/m$^2$) |
| 1 | 700 | 2.08 | 313.5 | 2.02 | 238.7 | 2.00 | 241.9 | 2.10 | 273.4 | 26.42 | 3126.7 | 2.03 | 240.5 | 2.03 | 240.5 |
| 2 | 800 | 2.28 | 500.1 | 2.22 | 408.0 | 2.24 | 401.9 | 2.28 | 476.6 | 29.5 | 5501.7 | 2.27 | 423.2 | 2.27 | 423.2 |
| 3 | 900 | 2.37 | 557.5 | 2.38 | 536.8 | 2.42 | 600.0 | 2.14 | 589.3 | 31.46 | 7710.2 | 2.42 | 593.1 | 2.42 | 593.1 |
| 4 | 1000 | 2.53 | 760.0 | 2.45 | 639.4 | 2.49 | 714.2 | 2.49 | 712.3 | 32.68 | 9549.5 | 2.51 | 734.6 | 2.51 | 734.6 |
| 5 | 1100 | 2.58 | 797.5 | 2.49 | 737.6 | 2.55 | 776.4 | 2.45 | 687.6 | 33.41 | 9664.5 | 2.57 | 743.4 | 2.57 | 743.4 |
| 6 | 1200 | 2.57 | 806.1 | 2.57 | 807.1 | 2.60 | 849.2 | 2.48 | 714.6 | 33.61 | 11026.4 | 2.59 | 848.2 | 2.59 | 848.2 |
| 7 | 1300 | 2.53 | 775.7 | 2.59 | 741.1 | 2.57 | 816.2 | 2.50 | 616.4 | 33.49 | 9870.5 | 2.58 | 759.3 | 2.58 | 759.3 |
| 8 | 1400 | 2.50 | 765.7 | 2.50 | 722.8 | 2.48 | 709.0 | 2.42 | 554.9 | 32.55 | 8911.2 | 2.50 | 685.5 | 2.50 | 685.5 |
| 9 | 1500 | 2.48 | 717.8 | 2.44 | 531.4 | 2.45 | 628.5 | 2.36 | 534.5 | 32.37 | 8057.8 | 2.49 | 620.0 | 2.49 | 620.0 |
| 10 | 1600 | 2.39 | 556.9 | 2.36 | 534.3 | 2.37 | 562.6 | 2.28 | 425.7 | 30.84 | 7271.2 | 2.37 | 559.3 | 2.37 | 559.3 |
| 11 | 1700 | 2.30 | 542.9 | 2.23 | 374.7 | 2.23 | 430.0 | 2.20 | 403.8 | 28.29 | 5060.7 | 2.18 | 389.3 | 2.18 | 389.3 |
| 12 | 1800 | 2.24 | 448.5 | 2.07 | 299.2 | 2.04 | 273.4 | 2.10 | 323.6 | 24.44 | 3741.8 | 1.88 | 287.8 | 1.85 | 287.8 |

**Fig-2.** Graph of Voltage against Time

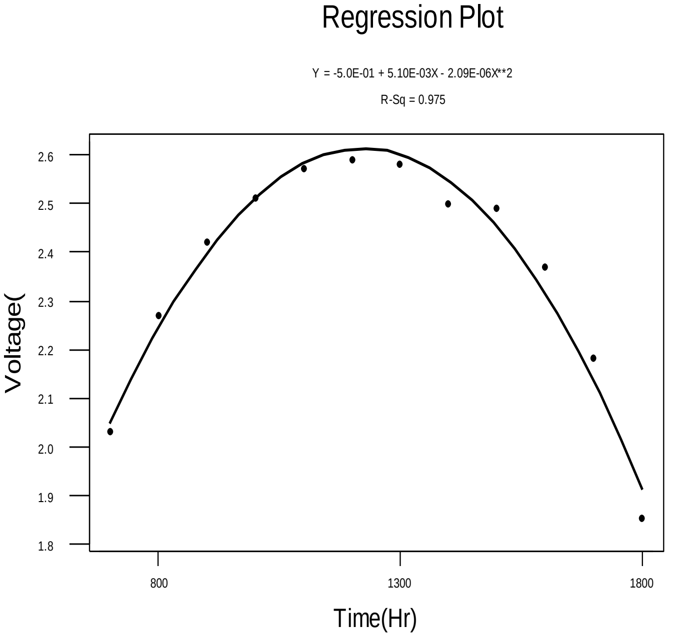


**Fig-3.** Graph of SRI againt Times

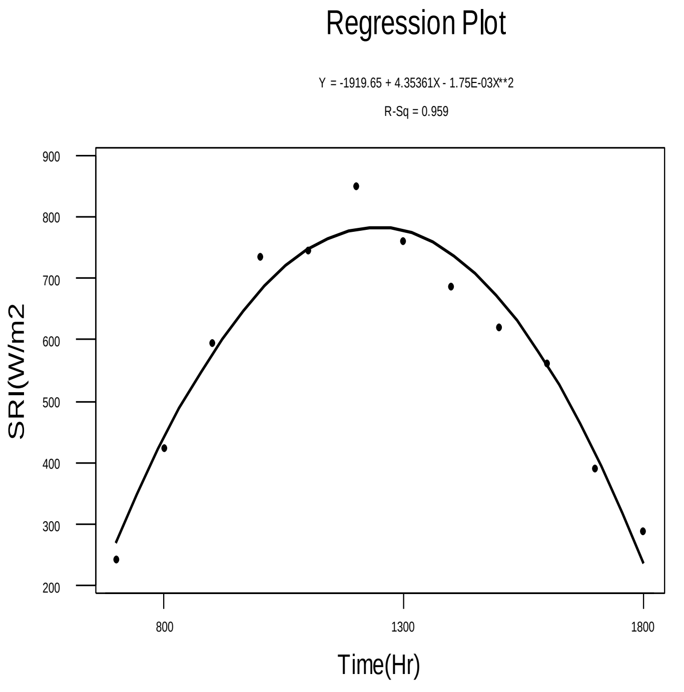
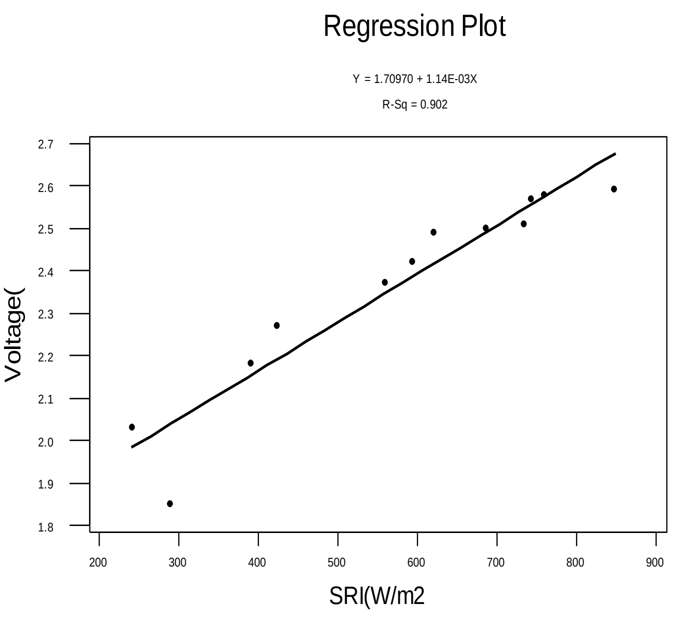



**Fig-4.**Graph of Voltage against SRI




The graph of fig4 as obtained from the MINITAB statistical package is a straight line, showing that the relationship between the measurements from the device (V) and that of the standard solarimeter (SRI) is linear. The slope of the graph as determined by the package is $0.00114 m^2/A$.

The intercept on the voltage axis is 1.71volts which is the threshold voltage. From the usual linear relationship of:

$y=mx+c$ ................................(1) .

where, y = voltage, m= slope, x = (SRI) Solar radiation intensity, c = intercept,

we obtain the conversion formula from voltage reading in volts to its equivalent intensity (SRI) reading in Watt per square meter as:

$\text{Voltage} = 1.14 \times 10^{-3}(\text{SRI}) + 1.71$

$\text{SRI}\ (1.14 \times 10^{-3}) = \text{Voltage} - 1.71$

Hence, $\text{SRI} = 877.19(\text{Voltage} - 1.71)$ ................................ (2)

Equation (2) is the conversion equation. Error in the slope of fig 4 according to Okeke, et al. [14] is obtained from the expression:

$$\text{Error in slope} = S_E = \frac{4W}{nR}$$

where W= vertical scatter

n =no of points

R =horizontal range along x-axis between first and last point.

The standard error in the slope was obtained as $7.14 \times 10^{-4}$

## 4. CONCLUSION

The design, construction and calibration of the solar radiation meter was successful. The obtained expression correlating solar radiation intensity with the measured voltage values is similar in form with an earlier measurement made in Umudike by Chiemeka [2] for the estimation of global solar radiation; which was done using Hargreaves equation. Also results obtained from calibration is similar to that obtained by Medugu, et al. [1] and has a conversion formula of , SRI = 877.19(Voltage -1.71)

Device can be used to collect radiation data which are reliable and comparable to that of a standard solarimeter.

## REFERENCES

[1] D. W. Medugu, F. W. Burari, and A. A. Abdulazeez, "Construction of a reliable model pyranometer for irradiance measurements," *African Journal of Biotechnology*, vol. 9, pp. 1719 – 1725, 2010.

[2] I. U. Chiemeka, "Estimation of solar radiation at Uturu, Nigeria," *IJPS*, vol. 3, p. 126, 2008.

[3] T. C. Chineke, "Renewable energy equation for estimating global solar radiation data spare regions science direct," pp. 1 – 13, 2007.

[4] A. O. C. Nwokoye, *Solar energy technology other alternative energy resources and environmental science*: Rex Charles and Partrick, 2006.

[5] M. Sanderson, *UNESCO source book on climatology UNESCO publication*: P16 Instrumentation Solar Energy Publication, 1990.

[6] O. Ojo, "The distribution of net radiation in Nigeria," *Nigeria Geographical Journal*, vol. 15, pp. 115 – 125, 1982.

[7] A. Anuforomu, "Construction, calibration of pyronometer and its uses in performance evaluation of silicon solar cell," *Book Hall*, p. 14, 2006.

[8] A. D. Asiegbu, "Design of a 3kVA solar energy plant for the campus community of Michael Okpara University of Agriculture, Umudike," *International Journal of Current Research, IJCR*, vol. 11, pp. 058-061, 2010.

[9] A. D. Asiegbu and O. A. Nduka, "Determination of solar insolation in Michael Okpara University of Agriculture Umudike, using a photo resistor," *GJPAS*, vol. 12, pp. 245 – 250, 2006.

[10] A. D. Asiegbu, "System sizing: Major reason for failure of most solar street lighting projects in Nigeria," *IJCR*, vol. 4, pp. 141-143, 2012.

[11] B. A. Eke, "Predication of option angle of inclination for flat plate collector in Zaria," *CIGR Journal*, vol. 13, pp. 16 – 20, 2011.

[12] O. A. Bamiro, "Empirical relation for the determination of solar radiation in Ibadan," *Nigeria Solar Energy*, vol. 31, pp. 85 – 94, 1981.

[13] D. Brooks and A. Minis, *Definition of solar radiation intensity*. New York: McGraw Hill, 2000.

[14] P. Okeke, J. Osuwa, A. Menkiti, C. Ofoegbu, C. Okeke, and H. Emereole, "Preliminary practical physics manual Nigeria University physics series," vol. 2, pp. 30 – 34, 2000.