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INSTALLATION OF PHOTOVOLTAIC ARRAYS AT OPTIMUM TILT ANGLE FOR MAXIMUM SOLAR POWER GENERATION IN ILORIN, NORTH–CENTRAL OF NIGERIA

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Abstract: The knowledge of the availability of solar radiation at any given location is important for the design and performance evaluation of solar energy generation. A prior requirement to the design of any solar–based conversion systems is the knowledge of optimum orientation and tilt surface at which peak solar energy can be collected. In many parts of the world, the solar radiation data for the surfaces of interest are not always available and have to be determined using either isotropic method or anisotropic. This study optimized the tilt angle of photovoltaic (PV) panels Ilorin. Ilorin, the study area lies on latitude from 8°30′N and 8°50′N and longitude from 4°20′E and 4°35′E of the equator and is located in North–central Nigeria. The data were taken using the Gunn–Bellani Radiation integrator from January 2014 to December, 2016. The maximum solar power generated is about 387.5W/m^2 in the month of September and 365.3W/m2 in the month of March. Month of March, April, May, October, November and December are characterized with decreased in an Optimum Tilt angle from 28.5° to 26.7° while other months are characterized with increased in an Optimum Tilt angle from 26.7° to 28.5°. for Installation of PV panel within Ilorin, the inclination angle of the solar collector should fall between the range of 26.7o to 28.5o for maximum electric power generation.
Keywords: Tilt angle, pathloss, power generation, radiation

1. INTRODUCTION

The environmental benefits in terms of greenhouse gases reductions and cost implications are the major reason why renewable energy is gaining attention over all other source of energy. Other reasons are its availability in some areas and couple with its reliability. With rapid economic growth and improvement in living standards, there has been a marked increase in energy use for many developed and developing countries (Yoshino, 2007). Renewable energy can play an essential role in meeting the ultimate goal of replacing certain parts of fossil fuels. One of the promising applications of renewable energy technology is the installation of photovoltaic (PV) systems that generate power without emitting pollutants and requiring no fuel.

In designing and evaluating PV systems, it is necessary to know the output energy performances. It has been reported in the literature that the performance of a PV system is a function of available solar radiation in an area and the tilt angle of the PV module (Durisch, Tille, orz and Plapp, 2000). The tilt angle is defined as the angle of the solar plane of the PV module and horizontal plane as shown in Figure 1.0. Moreover, when tilt angle is positive, the positioning of the module plane is toward the equator, and when the tilt angle is negative, it is toward the pole. The reflected component is difficult to determine, and in general, is not usually a major constituent in most of the solar energy determinations. Hence, for easiness, the reflex component is ignored. This provides the most conventional estimate of insolation on the PV module.

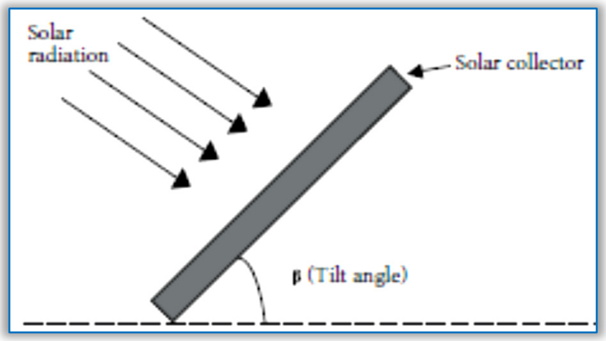

Figure 1.0: angle of inclination for the Photovoltaic panel (Ainah and Afa, 2013)

In the last few years, many models that allow calculating global radiation on a tilted surface from the available data on a horizontal surface have been presented. Some of these models require special measurements; and some apply to only specific cases. These models calculate the beam and the ground reflected radiation incident on an inclined surface using the same method. The

only difference among these models is the treatment of the sky diffuse radiation. The estimation models are either isotropic or anisotropic depending on the assumption of the sky diffuse component (Liu and Jordan, 1962).
Many papers address the issue of converting sky diffuse radiation from a horizontal surface into an inclined surface, (Kamali, Moradi and Khalili, 2005, Notton, Poggi, Cristofari, 2006). The assumption commonly used in calculating diffuse radiation incident on inclined surface from the value of the diffuse component on a horizontal surface is that sky radiation is always isotropically distributed ((Liu and Jordan, 1962, Duffie and Beckman, 2006). This study presents the work on the prediction of solar radiation for various inclined angles and orientations using the measured sky radiances. The maximum power generations, at an optimum tilt angle per day of the year were determined for solar panels installation. The optimum tilt angles and orientations are computed and analyzed.

2. METHODOLOGY

Data and Study Area Description

The raw data used for this work were obtained from Nigerian Metrological Agency (NIMET) Oshodi Lagos, as daily average on solar radiation from 2014 to 2016. The data were taken using the Gunn-Bellani Radiation integrator measuring the radiations in millilitres (ml). The data were converted to Watt per sq. metres (W/m^2) covering from January 2014 to December, 2016. The solar radiation and sunshine hour of Ilorin for the three years were collected and further daily, monthly, quarterly average for the specified years were computed using Microsoft excel .
Ilorin the capital city of Kwara state is located within the north central geopolitical zone commonly referred to as the middle belt. It is located on latitude from 8^{o}30’N and 8^{o}50’N and longitude from 4^{o}20’E and 4^{o}35’E of the equator. The daily average temperatures are in January within 25oC, May 27.5^{o}C and September 22.5^{o}C. The vegetation type found here is derived savannah with riparian forest along the river bank. The general elevation of land on the western varies from 273m to 364m (900 to 1200ft) above sea level.

Sky Radiation Model

Daily solar radiation on a tilted surface for a given month can be estimated as follows (Hassane and Driss, 2013):

$$H_T = H_B + H_R + H_D \tag{1}$$

Where, H_T, H_B, H_R and H_D are respectively the monthly average daily total, beam, diffuse, and reflected radiation on a tilted surface in (MJ/m^2/day).
The daily direct radiation on a tilted surface H_B can be obtained by means of R_b, the ratio of the average daily direct radiation on a tilted plane to that on a horizontal plane and the parameters to it correlated (Yadav and Chandel, 2013)):

$$H_B = \frac{\cos\theta}{\cos\theta_z} H_b = H_b R_b \tag{2}$$

For due south surfaces in the northern hemisphere, sloped towards the equator, the equation for R_b is expressed as:

$$R_b = \cos\beta - \frac{\sin\beta(\sin\delta\cos\phi\cos\gamma - \cos\delta\sin\phi\cos\omega\cos\gamma - \cos\delta\sin\gamma\sin\omega)}{\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega} \tag{3}$$

Where, β is the slope of the panel as to the horizontal plane, γ is the azimuth, ω is the solar hour angle, φ is the latitude, and θ and θz are the solar incidence angle on the considered plane and the solar zenith angle, respectively.
Daily ground reflected radiation incident on an inclined surface in (MJ/m^2/day) is given by:

$$H_R = \frac{1}{2} H_g \rho (1 - \cos\beta) \tag{4}$$

Where, ρ represents the diffuse reflectance of the ground (also called ground albedo) and it range is given by $0.1 \le \rho \le 0.8$.
The sky diffuse radiation incident on an inclined surface in (MJ/m^2/day) is given by:

$$H_D = R_d H_d \tag{5}$$

The total radiation incident on an inclined surface in (MJ/m^2/day) is given by:

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$$H_T = H_b R_b + \frac{1}{2} H_g \rho(1-\cos\beta) + H_d R_d \quad (6)$$

The daily clearness index, K_d is defined as the ratio of a particular day's radiation H_g on a horizontal surface, to the extraterrestrial radiation H_0 for that day. Mathematically it is expressed as

$$k_d = \frac{H_g}{H_0} \quad (7)$$

The direct and diffuse components of solar radiation can be estimated using empirical relationships between H_d and H_g by means of the clearness index K_d. H_d is the daily diffuse component of the total global radiation, H on that particular day, J/m2

Indeed, the most considerable cause of error in the computation of the optimum tilt and orientation of a solar panel depends on the model of diffuse solar radiation which is used.

(Muneer and Hawas, 1984) proposed and recommended the model for the desert and tropical locations:

$$\frac{H_d}{H_g} = 1.35 - 1.61 K_d \quad (8)$$

The isotropic models assume that the diffuse sky radiations are uniformly distributed over the sky dome. Hence, the diffuse radiation is dependent on the portion of the sky dome which can be seen by the collector. Different models were proposed by researchers

Liu and Jordan model (1962) proposed that the R_d is given by:

$$R_d = \frac{1}{2}(1-\cos\beta) \quad (9)$$

4. RESULTS AND DISCUSSIONS

For better application for photovoltaic modules and solar thermal systems in Ilorin, the best possible tilt angle is the key to optimal performance. Figure 2–13 show the optimum daily tilt angles of the month for January to December of the year. The tilt angles range between 26.7^o and 29.4^o throughout the year. From Figure 2 and Figure 3, it can be seen that the tilt angle increases from January to February in each day of the month. In Figure 4, the tilt angle continue to increased tilt around ending of March. This is characterized by early rain fall. Meaning new season begins 28th of March, i.e, rainy season.

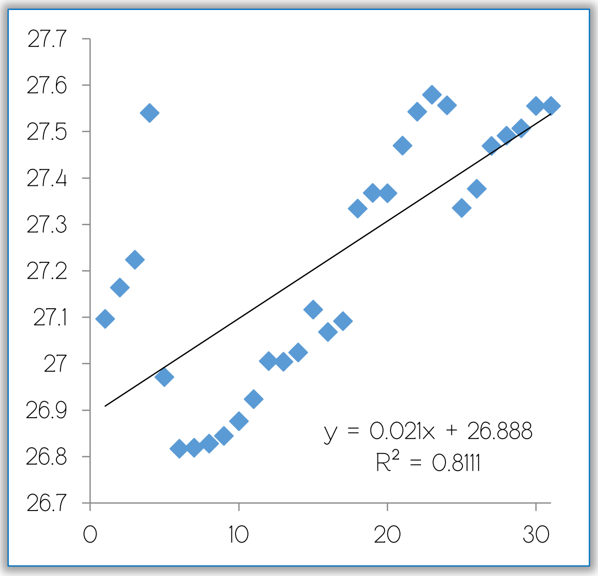

Figure 2. Tilt angle against day of the month for January

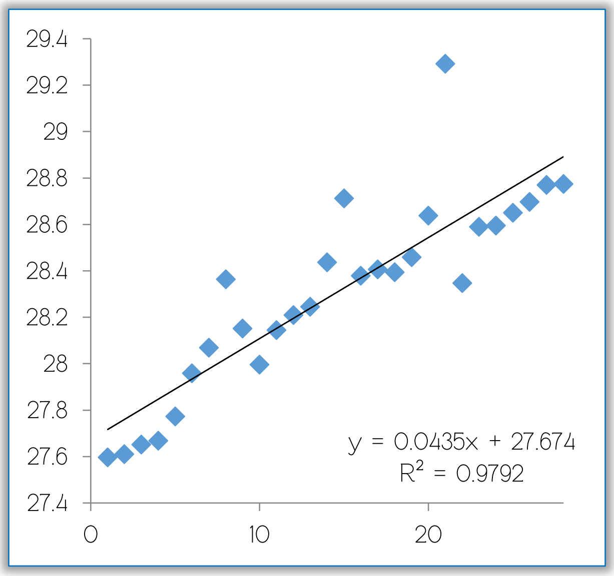

Figure 3. Tilt angle against day of the month for February

Figure 5 and Figure 6 show continuous decrease in the tilt angle from 29.5^o to around 26.5^o for the month of April and May. The same thing happened in the month of October, November and December in Figure 11–13. These months corresponded to early dry season. Meaning at the early season of both rainy and dry season, the tilt angles decreased with the day of the month in the month March, April, May, October, November and December, while every other month the tilt angle increased with day of the month.

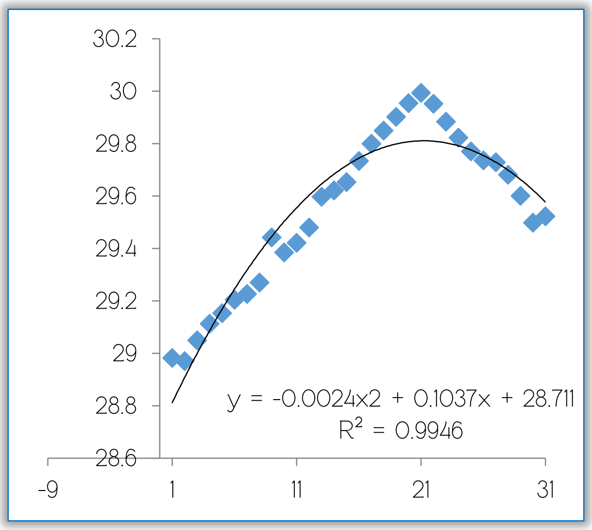

Figure 4: Tilt angle against day of the month for March

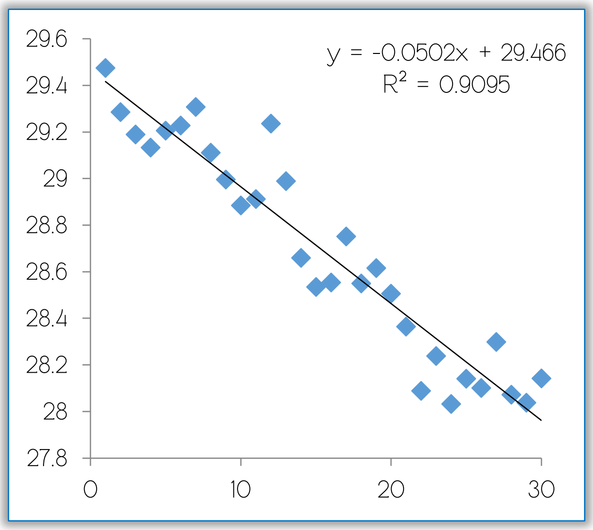

Figure 5: Tilt angle against day of the month for April

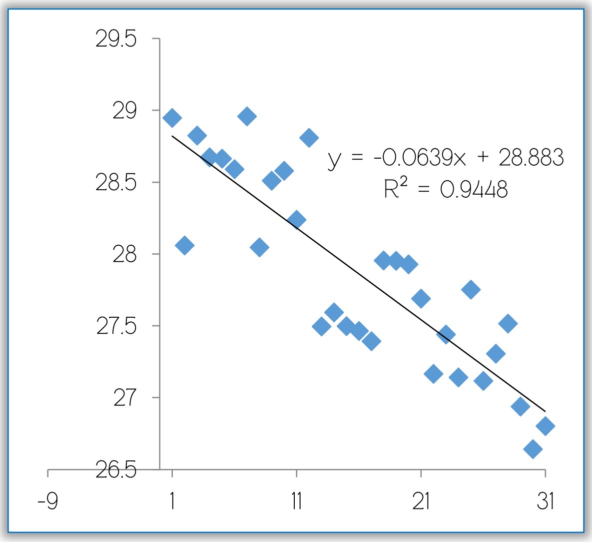

Figure 6. Tilt angle against day of the month for May

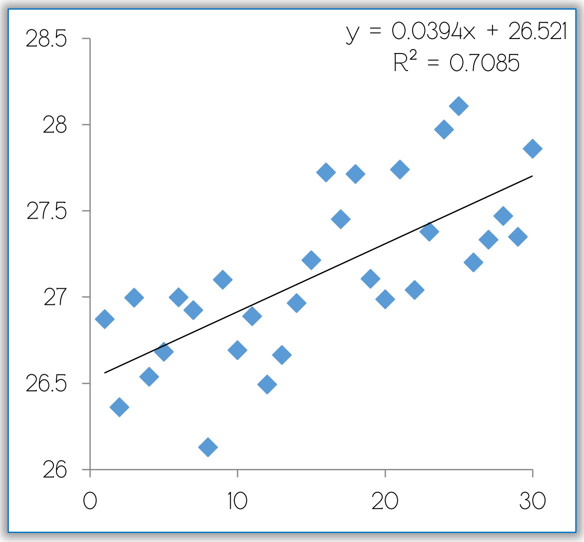

Figure 7. Tilt angle against day of the month for June

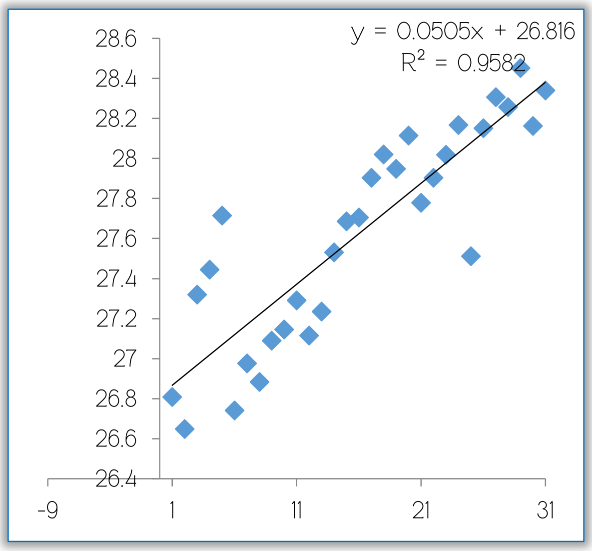

Figure 8. Tilt angle against day of the month for July

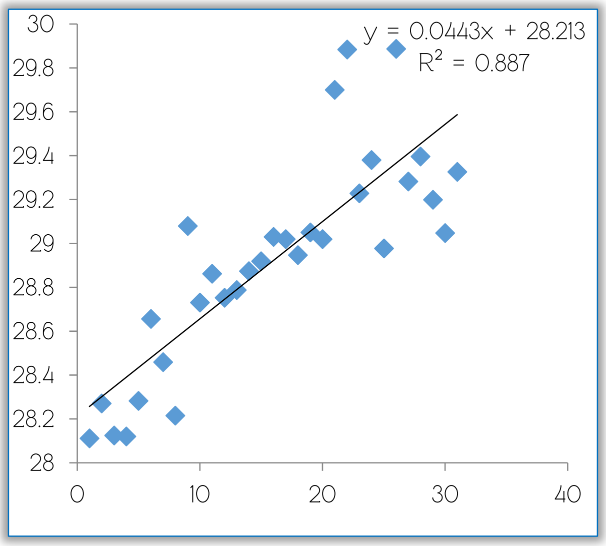

Figure 9. Tilt angle against day of the month for August

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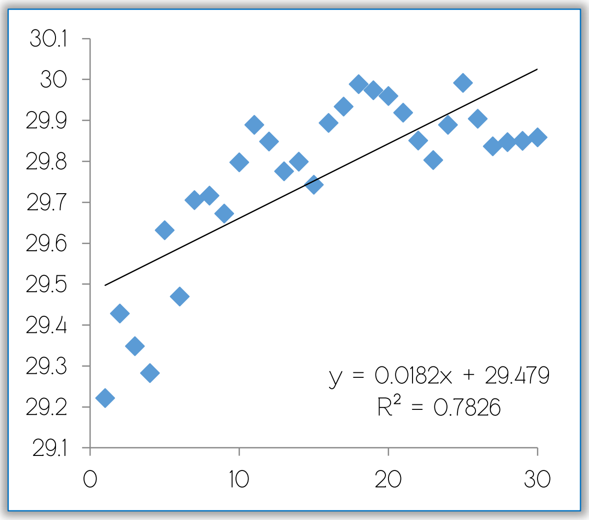

Figure 10. Tilt angle against day of the month for September

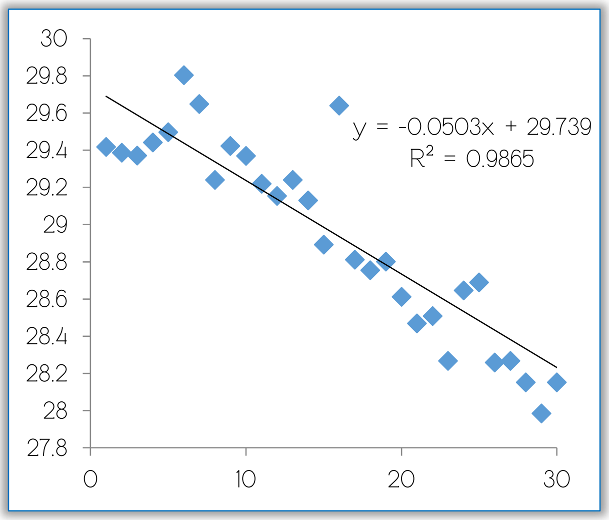

Figure 11. Tilt angle against day of the month for October

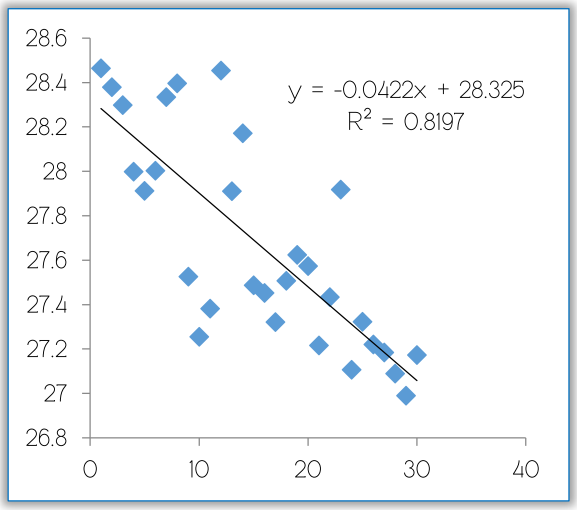

Figure 12. Tilt angle against day of the month for November

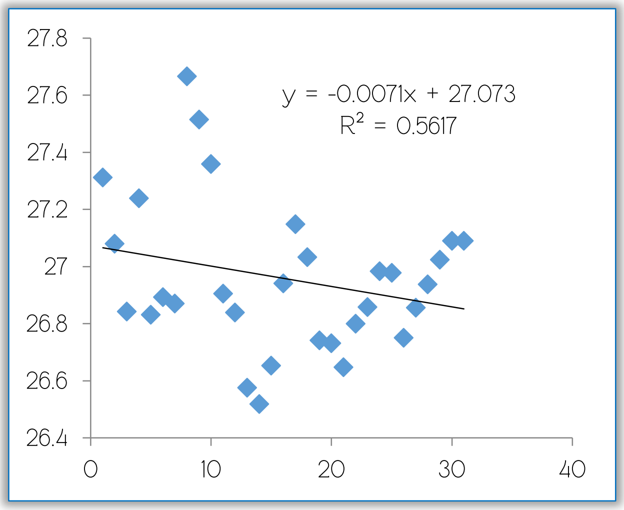

Figure 13. Tilt angle against day of the month for December

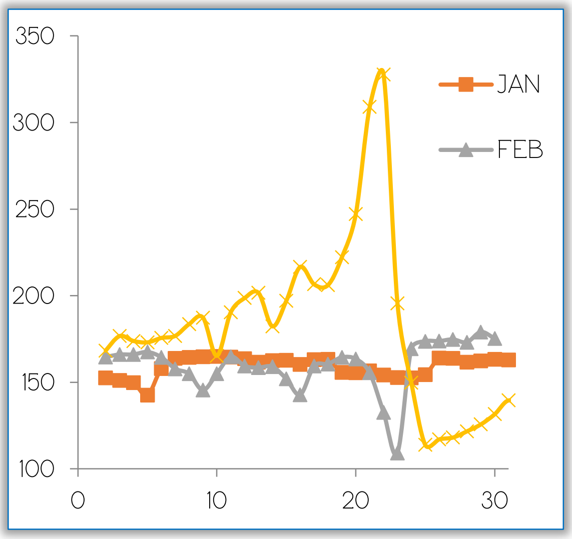

Figure 14. Maximum Solar Power generated at the optimum daily Tilt angle for the month January to March

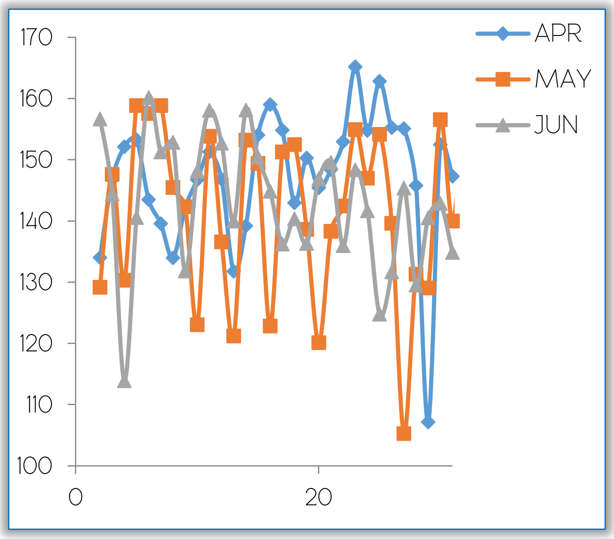

Figure 15. Maximum Solar Power generated at the optimum daily Tilt angle for the month April to June

From Figure 14–17, the maximum solar power generated is around387.5W/m^2 in the month of September and 365.3W/m2 in the month of March. These two month are the late dry season and late rainy season of the year.

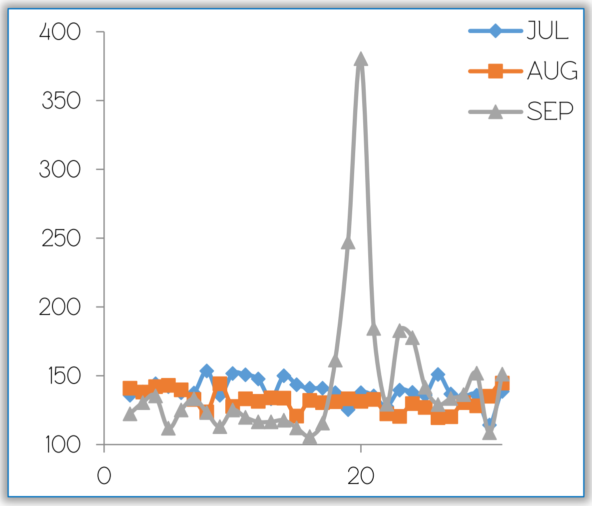

Figure 16. Maximum Solar Power generated at the optimum daily Tilt angle for the month July to September

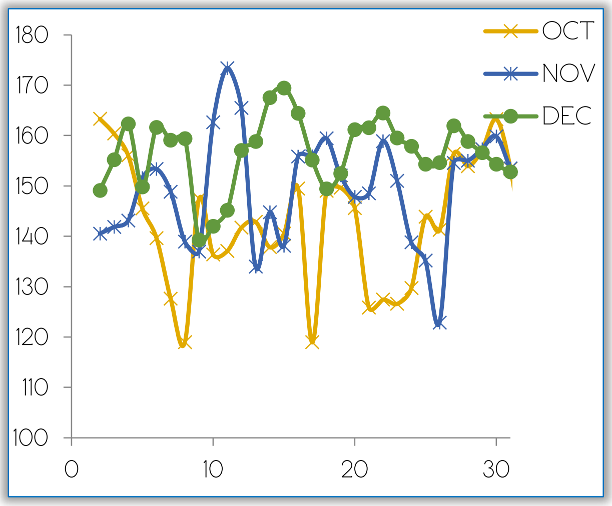

Figure 17. Maximum Solar Power generated at the optimum daily Tilt angle for the month October to December

5. CONCLUSION

Using relevant meteorological parameters and the methods described in this study, monthly averages of the beam irradiation, the diffused radiation, the albedo radiation and the global irradiation at different tilt angles for Ilorin was determined. The effects and contributions of each of the components (beam, diffuse and albedo) for the general case and at their optimum angles were highlighted. Result from the study shows that the tilt angle for maximum electric power generation from solar panel varies with day of the year. It is concluded that the best possible tilt angle is within the range of 26.7° to 28.5° tilt. The maximum solar power generated is around387.5W/m^2 in the month of September and 365.3W/m2 in the month of March. Month of March, April, May, October, November and December are charcterised with decreased in an Optimum Tilt angle from 28.5° to 26.7° while other months are characterized with increased in an Optimum Tilt angle for installation of PV panel within Ilorin, the inclination angle of the solar collector should fall between the range of 26.7o to 28.5o for maximum electric power generation

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