Solar Radiation as Alternative Power Supply for Electricity Generation and Sustainable Development in Adamawa State

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Abstract- In this study Angstrom-Prescott model was used to estimate the global solar radiation based on the monthly mean sunshine hour for Mubi town, Adamawa State. Several models have been proposed to estimate global solar radiation. The Angstrom constants a and b of Angstrom-type correlation used in estimating monthly average global solar radiation was estimated to be 0.27 and 0.54 respectively. Global radiations obtained in this study are higher with mean value of 22.90 MJm^{-2} and the measured value 21.39 MJm^{-2} which shows the presence of high global solar energy potential in Mubi, Nigeria. The mean monthly solar radiation which was obtained is within the threshold for which Photovoltaic cell can be used to generate power. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria and the world at large.

Indexed Terms- Global Solar Radiation, Power Generation, Regression Constants, Electricity.

I. INTRODUCTION

Energy is a vital and important necessity for all earthly processes. The socio-economic activities of modern society revolved around the hub of energy availability. The 1973 oil crises, chaos caused by the Arab oil embargo, in western countries brought a sudden global realization to use renewable energy resources such as solar energy, hydropower, wind energy, wave energy, biomass and biofuels (Animalu and Adekola, 2002). This campaign for using renewable energy resources is becoming stronger today because of the finite nature of fossil fuel energy resources as well as the greenhouse gases emission which many scientists believe cause global warming. (Nwoke *et al.,* 2008). Effective applications of renewable energy resources to augment energy supply from fossil fuel energy resources (using cleaner for fossil fuel technologies) will enhance availability of energy with minimum environmental effect.

Solar energy can be defined as the energy obtains from the sun, which is electromagnetic in nature covering all wavelength of the sun (Ilenikhena, *et al.,* 2008). The sun is about 1.4 x 10^{14} m in diameter emits its energy at the rate of about 3.8 x 10^{23} Js^{-1} of solar energy of which about 1.7 x 10^{14} Js^{-1} reaches the earth, warming the ground, ocean, atmosphere and drilling the photosynthesis process that maintain the biological life. Most of the solar radiation is confined within the wavelength of 3.8 and 0.7nm. Solar energy occupies one of the most important places as many among the various possible alternative energy sources it is the only option left to be developed and utilized. It is an inexhaustible source, potentially capable of meeting a significant portion of the world future energy needs with a minimum of adverse environment consequences.

The maximum intensity of solar radiation at the earth's surface is about 1.2 kW/m^2 but it is encountered only near the equator on clear days at noon. Under these ideal conditions, the total energy received is from 6-8 kWh/m^2 per day (Gungor and Yildirim, 2012, Okonwkwo, 2014, Garba, Amusat and Ngadda (2015).

For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. It has been found that there is an estimated 3,000 h of annual sunshine (Augustine and Nnabuchi, 2010) and average solar radiation received in Nigeria per day is as high as 20MJ/m2 depending on the time of the year and location (Offiong, 2003). Despite this abundant availability of solar energy, Nigeria with over 97,000 rural communities, her population is characterized with deprivation from conventional energy, arising from poor supply of infrastructure. Where conventional energy is available, its supply is unreliable.

This is the major reason among many others prompted the emergence of study. This erratic nature of electric power supply has caused the economy to fall, unless it is supplemented. The way out of this lies in the use of renewable source of energy for power generation, as they contain enormous, largely untapped and sustained opportunity for meeting the energy need as they are environmentally friendly as they do not contribute harmful and toxic emission to it. The solar energy is one of the cleanest and most environmentally sources of energy capable of generating a high amount of electricity. The aim of this study is to assess solar radiation as an alternative energy for electricity generation in Mubi, Adamawa State.

II. METHODOLOGY

- Study Area

This city has a tropical climate. There is significant rainfall throughout the year in Mubi. Even the driest month still has a lot of rainfall. The climate here is classified by the Köppen-Geiger system. The average annual temperature is 23.9 °C in Mubi. In a year, the average rainfall is 1629 mm. The least amount of rainfall occurs in July. The average in this month is 77 mm. Most precipitation falls in November, with an average of 179 mm. The temperatures are highest on average in April, at around 24.4 °C. In July, the average temperature is 23.2 °C. It is the lowest average temperature of the whole year. The monthly mean daily data for sunshine hours were obtained from Department of Geography metrological unit situated in Adamawa State University, Mubi Nigeria. The data obtained covers a period of five years (2009 – 2013) for Mubi Town, Nigeria located on latitude 10.26° N and longitude 13.26° E.

The Angstrom- Prescott regression equation which has been used to estimate the monthly average daily solar radiation on a horizontal surface in Nigeria or other places is given as (Angstrom, 1924; Prescott, 1940):

$$\frac{\bar{H}_m}{\bar{H}_o} = \left[a + b\frac{\bar{S}}{\bar{S}_o}\right] \quad (1)$$

$\bar{H}_m$ is daily mean values of global radiation (MJm^{-2}day^{-1}), $\bar{S}_o$ the daily average value of day length, and ‘a’ and ‘b’ values are known as Angstrom constants and they are empirical. $\bar{H}_o$ is daily mean values of extraterrestrial radiation (MJm^{-2}day^{-1}), calculated using equation (2) as described by (Neuwirth, 1980; Duffie, and Beckman, 1991).

$$\bar{H}_o = \frac{24\times3{,}600}{\pi} I_{sc}E_o\left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \quad (2)$$

$$I_{sc} = \frac{1{,}367\times3{,}600}{1{,}000{,}000} MJm^{-2}day^{-1} \quad (3)$$

I_s the solar constant, The units in kWhm^{-2}day^{-1}
E_o represents the eccentricity correction, and described using Eq. (3.4) in Eq. 3.2

$$E_o = 1 + 0.033\cos\frac{360n_d}{365} \quad (4)$$

n_d is the day number of the year /Julian day (1 Jan, n_d = 1 and 31st December, n_d = 365), φ is the latitude of the site, δ the solar declination and, ω_s, the mean sunset hour angle for the given month. The solar declination (δ) and the mean sunset hour angle (ω_s) can be calculated:

$$\delta = 23.45\sin 360\frac{284+n_d}{265} \quad (5)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (6)$$

For a given day, the maximum possible values of day length can be computed by using Cooper’s formula (Cooper, 1969):

$$\bar{S}_o = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \quad (7)$$

Tiwari and Sangeeta (1997), computed regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

$$a = -0.110 + 0.235\cos\varphi + 0.323\left(\frac{\bar{S}}{\bar{S}_o}\right) \quad (8)$$

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(\frac{\bar{S}}{\bar{S}_o}\right) \quad (9)$$

compute estimated values of the monthly average daily global radiation H_m, the values of computed a and b from equations (8) and (9) were used in equation (1).

III. RESULTS AND DISCUSSION

The extraterrestrial solar radiation H_o ($MJm^{-2}day^{-1}$) and the monthly day length S_o (hr) were computed for each month using equations (2) - (5).

Table 1: Metrological data and Global Solar Radiation for Mubi

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	H_m	H_o	$\frac{H_m}{H_o}$	$\frac{H_e}{H_o}$
Jan	6.26	12.55	0.58	21.42	39.41	0.54	0.53
Feb	5.92	7.01	0.84	22.32	27.95	0.79	0.76
Mar	7.61	13.56	0.64	23.89	39.70	0.60	0.65
Apr	5.48	12.54	0.53	22.39	33.67	0.66	0.56
May	6.18	12.55	0.57	21.20	39.28	0.53	0.59
Jun	5.42	12.54	0.43	19.62	33.87	0.57	0.47
Jul	5.12	12.55	0.42	19.05	39.14	0.48	0.47
Aug	5.22	12.55	0.40	17.67	37.71	0.46	0.45
Sep	5.62	12.54	0.45	18.67	33.81	0.55	0.52
Oct	5.81	12.55	0.46	19.39	39.54	0.49	0.52
Nov	5.75	12.54	0.45	19.47	33.76	0.57	0.54
Dec	4.97	12.55	0.48	19.60	39.34	0.49	0.48

Table 2: Monthly mean average of regression constants, extraterrestrial solar radiation, measured and calculated values, measured and calculated clearness index for Mubi.

Month	a	b	H_m	H_o	H_e
Jan	0.27	0.54	21.42	39.41	21.06
Feb	0.40	0.43	22.32	27.95	21.27
Mar	0.30	0.56	23.89	39.70	26.13
Apr	0.25	0.60	22.39	33.67	19.12
May	0.28	0.55	21.20	39.28	23.31
Jun	0.25	0.53	19.62	33.87	16.18
Jul	0.25	0.54	19.05	39.14	18.66
Aug	0.25	0.52	17.67	37.71	17.27
Sep	0.26	0.52	18.67	33.81	17.60
Oct	0.27	0.55	19.39	39.54	20.67
Nov	0.27	0.56	19.47	33.76	18.52
Dec	0.23	0.53	19.60	39.34	19.05

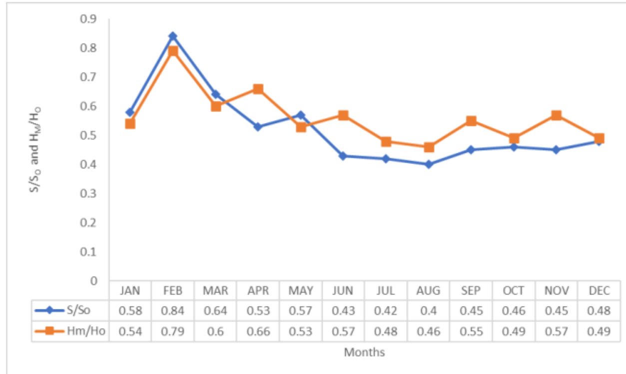

Figure 1: Variation of S/S_o and H_m/H_o (The clearness index) for Mubi

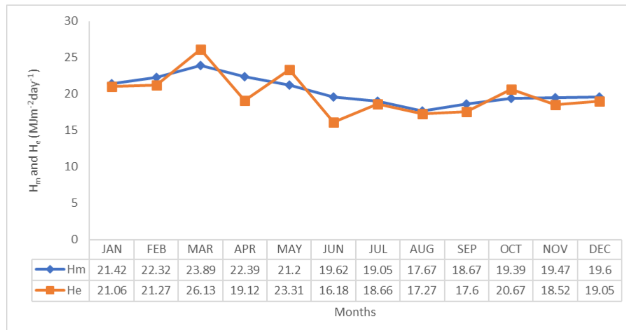

Fig. 2: Comparison between measured and predicted Solar Radiation

The extraterrestrial solar radiation H_o ($MJm^{-2}day^{-1}$) and the monthly day length S_o (hr) were computed for each month using equations (2) - (5), the input parameters for the calculation of the mean monthly global solar radiation for Mubi are shown in the Table 1 and 2. Using these parameters, the regression constants 'a' and 'b' evaluated as 0.27 and 0.54 respectively. Substituting these values into equation (1), we now established the empirical correlation for the estimation developed for Mubi as:

$$\frac{H_m}{H_o} = 0.27 + 0.54\left(\frac{S}{S_o}\right) \quad (10)$$

The model developed has a good correlation coefficient with r = 0.87, the coefficient of determination, R^2, (70.68%) obtained for this analysis shows the model best fits the data. The value of H_e/H_o (= 0.45) corresponding to the lowest value of S/S_o (= 0.40) and H_e (17.27$MJm^{-2}day^{-1}$) in the month of August is an indication of poor sky condition. These conditions correspond to the general wet or rainy season (June - September) observed in Nigeria, during which there is much cloud cover.

The regression constants (Table 3), a and b of different months were evaluated from equations (7) - (8). To compute the calculated values of the mean monthly average of global solar radiation H_e, the values of a and b were inserted into equation (1) and the correlation may be used to compute H_e at other locations having the same altitude. Looking at these values of measured and calculated clearness indexes; it is observed that both of them had the lowest values in the month of August. (Throughout the year) H_m/H_o (= 0.46), H_e/H_o (= 0.45) with H_m (17.67$MJm^{-2}day^{-1}$) and H_e (= 17.27 $MJm^{-2}day^{-1}$) which can be traced to the meteorological conditions for Mubi.

The value of the clearness index and the relative sunshine duration in Table 2 were observed to be 0.45 and 0.40 respectively. The results suggest that the rainfall in Kebbi is at peak during the month of July - August when the sky is cloudy and the solar radiation is fairly low. However, just immediately after the August minimum, the clearness index and the relative sunshine duration increased remarkably with the cloud cover crossing over the clearness index. Both the values of the clearness index and relative sunshine duration in November reached peaks at 0.45 and 0.46 respectively. This implies that a clear sky will obviously fell within the dry season and hence a high solar radiation is experienced. Obviously, this is generally the dry season period in Nigeria. This provides favorable condition for solar energy. Global radiations obtained in this study are higher with mean value of 22.90 MJm^{-2} and the measured value 21.39 MJm^{-2} which shows the presence of high global solar energy potential in Maiduguri, Nigeria. According to Offiong, (2003) reports that an average solar radiation for Nigeria per month needs to be as high as 20 MJm^{-2} depending on the time of the year which required for which is within the threshold for which Photovoltaic cell can be used to generate electricity.

CONCLUSION

In line with world concern about the economic importance of global solar radiation as an alternative renewable energy, the models for estimating monthly global solar radiation of Mubi, Nigeria have been developed to be: $\frac{H_m}{H_o} = 0.27 + 0.54\left(\frac{S}{S_o}\right)$. The estimated global solar radiation data and its correlation will provide a useful source of information to designers of renewable energy, air conditioning systems and other solar energy related systems. The Angstrom-Prescott model developed in this study can also be applied to other cities to predict global solar radiation. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria and the world generally.

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