International Journal of Physical Sciences Vol. 4 (3), pp. 115-119, March, 2009
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 © 2009 Academic Journals

Full Length Research Paper

Evaluating the global solar energy potential at Uturu, Nigeria

I. U. Chiemeka[1] and T. C. Chineke[2]

[1]Department of Physics, Abia State University, Uturu, Abia State, Nigeria.
[2]Department of Physics, Imo State University, Owerri, Nigeria.

Accepted 19 February, 2009

Evaluation of the global solar energy potential at Uturu, latitude 0.5.33°N and 06.03°N was carried out in this work. The temperature data were obtained from 1st - 30th November, 2007 using the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above ground level. The Hargreaves equation was used to evaluate the solar energy potential at Uturu. The mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 KWh m^{-2} per day. A comparison of the mean global solar potential obtained at Uturu and that reported by Offiong (2003) showed that the insolation potential obtained at Uturu was 44.1% less. This difference may be attributed to the hilly nature of Uturu, coupled with the fact that the climate at Uturu varies significantly with the seasons of the year.

Key words: Hargreaves equation, insolation, solar energy potential.

INTRODUCTION

Solar radiation is the radiant energy that is emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The knowledge of the amount of solar radiation in a given location (area) is essential in the field of solar energy physics. This in effect helps one to have a fair knowledge (idea) of the insolation power potential over the location. The demand for oil may sooner or later outweigh the available resources associated with oil production and distribution logistics. With the dwindling supply of oil, coal and natural gas, increased emphasis on the use of solar energy and other renewable energy sources in generating electricity should be developed. Bearing in mind the very well documented problems associated with other forms of energy, the use of solar energy should be paramount now. Solar energy is abundant, free and clean. Now that there is the campaign for the popularization of solar energy for domestic and industrial uses, the need to know how to evaluate insolation levels for any site becomes paramount. When that is done, the introduction and sustainability of solar energy technology will be assured (Chineke, 2002). In Nigeria, only few stations have been measuring daily solar radiation on a consistent basis. It is therefore, necessary to approximate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperatures, cloud cover and geographic location. In this work, the Hargreaves equation was used to estimate the global solar energy potential at Uturu based on available climatic parameters of measured maximum and minimum temperature and the computed values of extraterrestrial solar radiation (EXRAD) and maximum day light duration (N). Uturu has been chosen for this study primarily due to its geographic location, being bound on the west and south by a hilly escarpment as high as 240 m above sea level. Secondly, the climate of Uturu varies significantly with the seasons of the year (Chiemeka, 2008). Offiong (2003) reported that the average solar radiation received in Nigeria per day is as high as 20 MJ/m^2 depending on the time of the year and location.

Solar energy modeling focuses upon the level of solar radiation incident at a given location on the earth's surface.

This is simply a function of; (i) the level of solar intensity reaching the top of the earth's atmosphere; (ii) the transmission of radiation through the earth's atmosphere and; (iii) the location and orientation of collecting surfaces on the earth's surface with respect to the position of the sun with time (Guy et al., 2000). The

*Corresponding author. E-mail: chiemeka_iu@yahoo.co.uk. Tel: +2348063285560.

Table 1. Equation for computing theoretical radiation (R_a) and maximum daylight (N).

Location specific functions	Equation
PHI	Latitude *pi/180
DEL	(23.45* pi/180)*sin (2.0*pi*(284.+Julian Day)/365.)
WS	ACOS(-TAN(PHI)*TAN(DEL))
N	(2.0/15.0) *WS* 180/Pi
DF	1.0 + 0.033* COS (2.0*Pi*(Julian Day/365.0))
R_a	(Calories/cm^2/day) = (1440.0/Pi)*SC*DF*(COS(PHI)* COS(DEL)*SIN(WS)+WS*SIN(PHI)*SIN(DEL))

Constants; solar constant (SC) = 1367 W/m^2; Pi = 4.0* ATAN (1.0). Abbreviations: DEL, Solar declination; PHI, latitude of the location; WS, sunset hour angle; N, maximum daylight duration at the top of the atmosphere where there is no cloud; DF, day factor; SC, solar constant; January 1, day 1; Dec. 31, day 365; Feb. 1, day 32;180°, π.

sun emits energy at an extremely large and relatively constant rate; 24 h per day, 365 days per year. If all of this energy could be converted into usable forms on earth, it would be more than enough to supply the world's energy demand. However, this is not possible because; (i) the earth intercepts only a small fraction of the energy that leaves the sun; (ii) the earth rotates such that a collection device on the earth's surface is exposed to solar energy for only about half of each 24 h period and; (iii) conditions of the atmosphere such as clouds and dust, sometimes significantly reduce the amount of solar energy reaching the earth's surface.

Weather patterns and other atmospheric conditions which scatter incoming rays also affect the rate at which solar energy reaches the earth's surface. The summation of the amount of solar energy arriving at a unit of area (1 m^2) during 1 h is called the solar radiation or insolation (U.S. Technology White Paper, 2006).

SOLAR RADIATION ESTIMATION EQUATION

The equation that is applicable in both urban and rural areas according to Chineke (2007) is:

$$Rs = k3\ RaTd^{0.5} \tag{1}$$

where

Td = daily temperature difference (maximum minus minimum)
Ra = extraterrestrial solar radiation
k3 = calibration constant (Chineke, 2007).

Extraterrestrial solar radiation requires that the latitude of the site be input in decimals of degree (Table 1). Hargreaves (1985) used climate data from 4 stations in the Senegal River Basin (Richard-Toll, Guede, Kaedi and Same) to calibrate the equation and obtained the constant (k3) as 0.16. The value of k3 obtained for Nigeria is 0.16 (Chineke et al., 1999).

The temperature difference should be less when cloud cover is greater. This is because day temperatures remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range (difference) during the day. The Td takes into account changes in radiation due to proximity to oceans, mountains and the latitude of the location (Chineke et al., 1999). The advantage of this equation is that it uses temperature data that is available at many locations (rural and urban) and requires a single calibration constant.

MATERIALS AND MEASUREMENT PROCEDURE

The temperature data was collected for a period of one month from Abia State University's meteorological station at Uturu. The temperature data of maximum and minimum temperatures were obtained using the maximum and minimum thermometers which records at the same time of observation the maximum and minimum temperatures. Presently at Abia State University meteorological station, Uturu, the daily global solar radiation is not measured consistently and hence we resorted to the estimation method of obtaining it using equation (1) making use of the measured maximum and minimum temperature data.

In this work, we made use of maximum and minimum thermometers because it is easy to read and readily available too. Over the years, it has been the most frequently used instrument for solar radiation estimation due to its accuracy and simplicity. Maximum and minimum thermometers were used to measure the highest and lowest daily air temperature for the month of November, 2007 when the harmarttan season is in course.

The maximum and minimum thermometers were placed in the chamber of the Stevenson screen and readings were taken at 09 00 h GMT (10 am local time) in conformity with world meteorological standard time of reading in synoptic hours. This measurement was taken once every day for four weeks, from November 1 - 30, 2007. The thermometers were placed horizontally inside the Stevenson screen which shelters them and helps to prevent interference by rain, dew and sun's direct rays. The Stevenson screen is painted white so that it would reflect sunlight. It has louvered sides so as to ensure free movement of air in and out of the Stevenson screen and to ensure that the temperature inside and outside the Stevenson screen are the same. The Stevenson screen was raised to a height of 1.5 m above the ground at Abia State University, Uturu Weather observatory site. The reading of the daily temperature variables that is, the maximum and minimum temperatures were taken at 10 am prompt (Chiemeka, 2008).

RESULTS AND DISCUSSIONS

The values of daily extraterrestrial solar radiation (EXRAD) on a horizontal surface that is computed over the month of November, 2007 at Uturu, located at latitude 0.5.33°N and 0.6.03°N outside the earth's atmosphere is as shown in Figure 1. The values that were obtained ranged from 9.35 kWh on the 30th day to 9.80 kWh on the

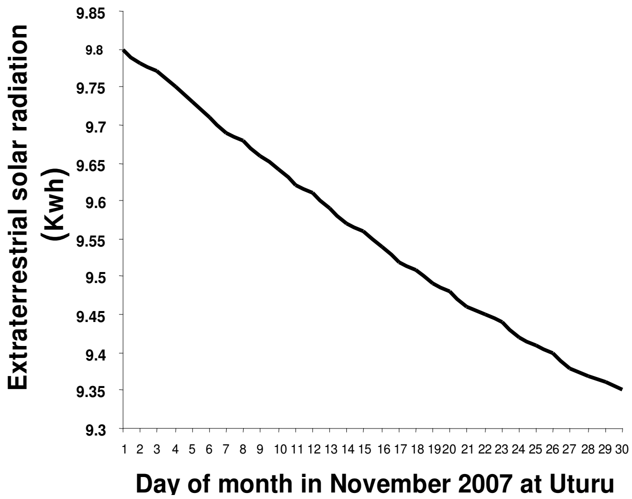

Figure 1. Extraterrestrial solar radiation at Uturu from November 1 – 30, 2007.

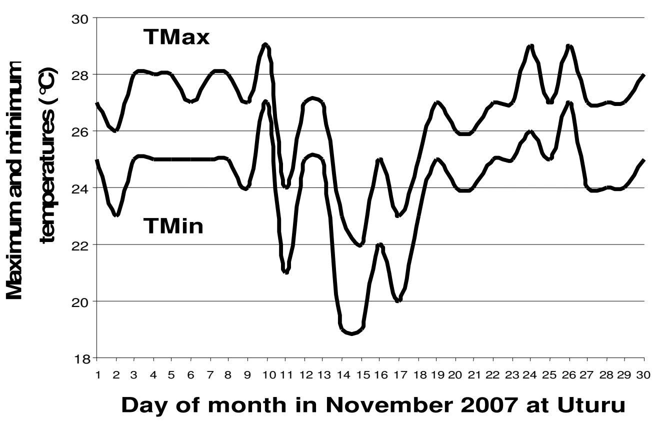

Figure 2. Measured maximum and minimum temperatures (°C) at Uturu.

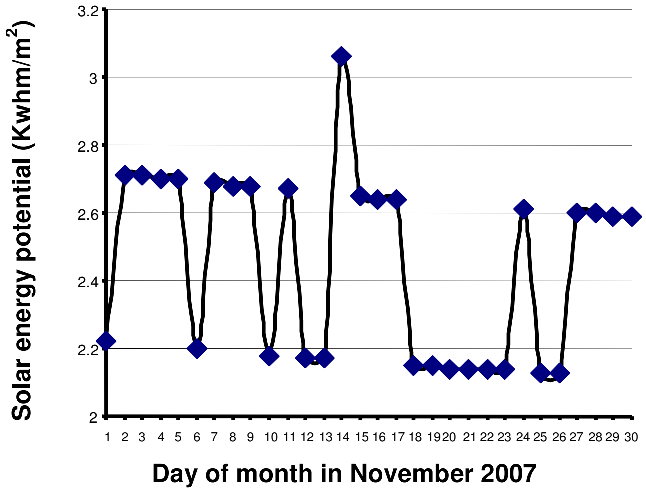

Figure 3. Global solar energy potential from November 1 – 30, 2007 at Uturu.

1st day thus, providing a pattern that is expected at a low latitude site. The mean extraterrestrial solar radiation for the period at Uturu was 9.56 ± 0.23 KWh. The level of solar radiation at any surface is dependent on water vapour, CO_2, cloud and the presence of aerosols. During the month of November at Uturu, there are lots of aerosols in the atmosphere, which reduce the amount of solar radiation that is incident on any surface (Chineke, 2007). Figure 1 showed however, that the EXRAD was on a continual decrease throughout the period of the study. This may be as a result of the reduction of solar radiation by the cosine of the angle between solar radiation and a surface normal which is called cosine effect, or as a result of reduction by the atmosphere due to absorption, scattering and reflection by water vapour, CO_2, clouds, smog and particulates.

Figure 2 shows the measured maximum and minimum temperatures at Uturu from November 1st – 30th, 2007.

The values were obtained making use of the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above the ground. The maximum temperature was highest on days 10, 24 and 26 at a temperature of 29°C while it is lowest on day 15 at a temperature of 22°C. The minimum thermometer recorded the highest minimum temperature of 27°C on days 10 and 26 and the lowest minimum temperature of 19°C on days 14 and 15. These variations may be as a result of changes in the amount of solar radiation as descried in Figure 3.

Figure 3 shows the global solar energy potential at Uturu from November 1st - 30th, 2007. The values were calculated making use of the Hargreaves equation. Global solar energy potential (GLORAD) at Uturu was highest on day 14 (3.06 kWh) and lowest on day 6 (2.13 kWh). The mean global solar energy potential obtained for the period at Uturu was 2.45 ± 0.29 KWh m^{-2} per day.

On the surface of the earth, we perceive a beam or direct solar irradiance that comes directly from the disc of the sun and a diffused or scattered solar irradiance that appears to come from all directions over the entire sky. In this work we will use the term direct to signify solar irradiance coming directly from the sun's disc, and the term diffuse to indicate solar irradiance coming from all other directions. The sum of direct and diffuse solar irradiance is called the global or total solar irradiance. In this work we will use the term global to indicate this sum. The values computed with the Hargreaves equation are shown in Table 2 and plotted in Figure 3. As of 1999, the Nigerian power grid serviced 34% of the population, including 19% of the rural population. The average electricity consumption per capita as of 1999 in Nigeria was 168 kWh/capita/yr. Comparing this with industrialized countries, the per capita electricity consumption in

Table 2. Temperature measurement and solar energy potential (kwh m^{-2}) at Uturu.

DMON(NOV)	DYEAR	EXRAD	GLORAD	TMAX(°C)	TMIN(°C)
1	305	9.8	2.22	27	25
2	306	9.78	2.71	26	23
3	307	9.77	2.71	28	25
4	308	9.75	2.7	28	25
5	309	9.73	2.7	28	25
6	310	9.71	2.2	27	25
7	311	9.69	2.69	28	25
8	312	9.68	2.68	28	25
9	313	9.66	2.68	27	24
10	314	9.64	2.18	29	27
11	315	9.62	2.67	24	21
12	316	9.61	2.17	27	25
13	317	9.59	2.17	27	25
14	318	9.57	3.06	23	19
15	319	9.56	2.65	22	19
16	320	9.54	2.64	25	22
17	321	9.52	2.64	23	20
18	322	9.51	2.15	25	23
19	323	9.49	2.15	27	25
20	324	9.48	2.14	26	24
21	325	9.46	2.14	26	24
22	326	9.45	2.14	27	25
23	327	9.44	2.14	27	25
24	328	9.42	2.61	29	26
25	329	9.41	2.13	27	25
26	330	9.4	2.13	29	27
27	331	9.38	2.6	27	24
28	332	9.37	2.6	27	24
29	333	9.36	2.59	27	24
30	334	9.35	2.59	28	25

Error = ± 0.5°C

Nigeria is less than 1% (Karekezi, 1998; Adeoti et al., 2001). The low level of electricity consumption per capita is due to the fact that more than 70% of the population resides in rural areas which have little or no access to grid electricity (Adeoti et al., 2001). In the 21st century, diversification of electricity power generation and supply in Africa will help to boost development in rural areas and in the urban areas where electricity supply is very unreliable which has resulted in cities polluted both by noise and gases released from petrol and diesel generators. The solution is for a shift towards renewable energy since the potentials of solar for example, is very attractive.

Conclusion

Evaluating global solar energy potential at Uturu, latitude 0.5.33°N and 06.03°N was carried out in this work. The temperature data were obtained from 1st - 30th November,

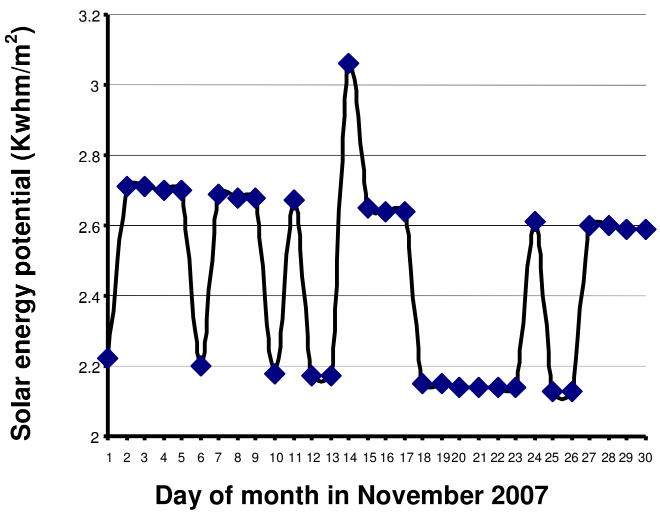

Figure 3. Global solar energy potential from November 1 – 30, 2007 at Uturu.

2007, using the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above the ground level. The Hargreaves equation was used to evaluate the solar energy potential at Uturu. The mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 KWh m^{-2} per day. A comparison of the mean global solar potential obtained at Uturu and that obtained by Chineke (2002) at Owerri (5° 28'N, 7° 2'E) in November, 1997, showed that the insolation power potential at Uturu is 54% less. This difference may be attributed to the hilly nature of Uturu, coupled with the fact that the climate at Uturu varies significantly with the seasons of the year. In Nigeria, problems like poor funding very often, militate against radiation data collection (Ihebunachi, 1995).

The Hargreaves equation, a method recommended for estimating global solar radiation and evaluating the insolation potentials of rural areas where measured global solar radiation data may not be available nor measurement of sun shine hours, was used in this work for evaluating solar energy potential at Uturu for possible photovoltaic (PV) applications based on the available climatic parameters of measured maximum and minimum temperatures. The equation is useful in accessing the solar electricity potential in Nigeria and in other parts of the world. Figure 3 could be used to estimate the amount of solar energy that can be recovered by a solar collector in a given period of time if the collector's efficiency is known. The result of this work will be helpful in drawing up daily and monthly averages of solar irradiance and for accessing the PV potential in different parts of Nigeria. A comparison of the global solar energy potential obtained at Uturu and that reported by Offiong (2003) showed that the insolation potential obtained at Uturu is 44.1% less.

ACKNOWLEDGEMENT

The authors thank Mr. Onyekwere Chinedu, Mr. Ndubuisi Chibuikem and Miss Nwokeocha Onyinyechi for their assistance in this work.

REFERENCES

Adeoti O, Oyewole BA, Adeboyega A (2001). Solar Photovoltaic Based Home Electrification System for Rural Development in Nigeria; Domestic load Assessment. Renewable Energy, 24: 155-161.

Chineke TC (2002). A Robust method of evaluating the solar energy potential of a data sparse site. The Physical Scientist. 1(1): 59-69.

Chineke TC (2007). Equations for estimating global solar radiation in data sparse regions. Renewable Energy pp. 1-13.

Chineke TC, Aina JI, Jagtap SS (1999). Solar radiation data base for Nigeria, Discovery and innovation, 11(3/4): 207-210.

Chiemeka IU (2008). Estimation of solar radiation at Uturu, Nigeria. Intl J. Physical Sci., 3(5): 126-130.

Guy D, Peter M (2000). Modeling Solar Potential for Energy Generation in Cold Region. A paper presented at the sixth International Symposium on Cold Region Development, Hobart, Tasmania, Australia.

Hargreaves GL, Hargreaves GH, Riley JP (1985). Irrigation water requirements for Senegal River Basin. J. irrig. and drain. Engr. 111(3): 264-275.

Ihebunachi GA (1995). A review of solar research in Nigeria B.Sc. Project, Abia State University, Uturu.

Karckezi S, Mutiso D (1998). Restructuring and privatization of the power sector in Africa. African energy policy research network (Afrepren) No. 203.

Offiong A (2003). Assessing the economic and environmental prospects of stand-by solar powered systems in Nigeria. J. Appl. Sci. and Env. Management, 7(1): 37-42.

US Technology White Paper (2006). Solar Energy Potential on the U.S. outer Continental Shelf Minerals Management Service, Renewable Energy and Alternate Use Program U.S. Department of the Interior. http://ocsenergyy.anl.gov