Int. J. of Thermal & Environmental Engineering
Volume 13, No. 2 (2016) 129-133

A Study of Solar Energy Potential in Sapele, Nigeria

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Abstract

In this paper, a study was carried out on solar energy potential in Sapele, Nigeria. Five photovoltaic solar panel (cell) connected in series where used to generate data on maximum and minimum temperature readings, voltage and current readings for a period of 50 days. The result obtained shown that a mean average temperature readings of 30.01 °C, mean average voltage readings of 14.23 V and mean average current reading of 4.206 A were obtained. The global solar radiation and extraterrestrial solar radiation were calculated as 11.09 kwh/m^2/day and 5.31kwh/m^2/day respectively. Considering the average power deposited (0.060 kW and 0.180 kWh) daily, enough energy can be obtained from solar power system and this can help to solve part of Nigeria energy crisis.

Keywords: *Solar energy potential, temperature, power deposited, global solar radiation, Sapele, Nigeria*

1. Introduction

Nigeria is a country located in West Africa with an estimated population of 170,123,749 and a reported annual growth rate of 2.55% with a land area of 923,768 km^2 [1]. Energy is a major challenge in Nigeria and this has huge negative effect on the nation economy. The major source of energy in Nigeria is fossil fuel and wood fuel which had led to deforestation and environmental pollution [2, 3, 4].

There is an increase world-wide awareness and concern about the environmental impacts of fossil fuels, nuclear power considering the danger particularly the one recorded in Japan (tsunami), which led to the meltdown of a nuclear reactor at Fukushima an eye opener to the world and this has made scientist and researchers across the world to divert their attention to renewable energy [5, 6, 7, 8]. The area of renewable energy has been proven by researchers as a vital development of a given nation. Thus, this has necessitated renewable energy processing and optimization across Nigeria and the entire world especially from the year 2000 to 2015 as shown in Table 1 [9, 10].

Renewable energy are all forms of energy generated from natural resources such as sunlight in form of solar power, wind in form of wind power, water (hydro power), tide, geothermal heat, biomass and biofuels. Renewable energy is obtained from natural processes that are renewed over time and each of them possesses properties that determine where and how they are used [17]. Solar energy is seen as a pedestal for various forms of renewable energy. It supports hydro power in which the hydrological cycle is controlled by the sun and wind power where the movement of air is cause by the heating effect of the sun on the environment. Generally, energy in form of; heat, kinetic energy, electrical energy and chemical energy are provided via solar energy conversion [13, 16].

Nigeria lies between latitudes 4^0 and 14^{0}N, and longitude 2^0 and 15^{0}E of the equator, hence Nigeria is located in a tropical hot climate. Nigeria receives an average of about 3.5kwh/m^2/day (12.6MJ/m^2/day) in the coastal latitudes and about 7.0kwh/m^2/day (25.2MJ/m^2/day) in far north of the country of incident solar energy [11]. Considering Nigeria land mass of about 923,768km^2 and an average of 5.25kwh/m^2/day, Nigeria has an average of 1.804 $\times$ 10^{15}kwh of incident solar energy annually [12]. Based on Nigeria population as estimated 2012 [1], a value of 1.06$\times$10^{7}kwh per capitals per annum can be obtained from incident solar energy (equation 1). The above value is far above the minimum recommendation for standard of living by the World Energy Council (WEC). According to the

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DOI: 10.5383/ijtee.13.02.008

World Energy Council (WEC), electricity consumption for minimum standard of living is 500kwh per capita per annum [14].

$$S_e = \frac{\sum S_e}{P} \pi r^2 \quad (1)$$

Where,

S_e = Incident solar energy per capital per annum

$\sum S_e$ = Average incident solar energy annually

P = Population

Solar energy technology can be classified as either active solar or passive solar depending on their capture, conversion and distribution. Active solar techniques include the use of photovoltaic panels and solar power collectors to harness the available energy. Active solar energy is classified into five types;

i. Mono silicon (mono-si)
ii. Poly silicon (poly-si)
iii. Candmium telluride (cdTe)
iv. Copper indium disellinide (CIS)
v. Copper indium gallium diselenide (CIGS)

On the other hand, passive solar techniques include orienting a building to the sun. A solar cell (panel) is made of semiconductor materials such as silicon, germanium, cadmium sulphide and arsenide. The following factor affects the performance of solar cell (panel):

i. Panel Orientation
ii. Temperature
iii. Shading
iv. Front Surface Soiling
v. Climatic Conditions

A photovoltaic solar energy is the energy in form of electrical power obtained from the sun's radiation using solar photovoltaic cell (panel). It converts solar radiant energy photons to electricity. With Nigeria location in the tropical hot climate couple with her energy challenges, plus the fact that the available energy sources for heating and lighting is from fossil fuel and wood fuel which is hazardous to our health, there is need to sorts for alternative energy source that is environmental friendly just like the solar power system. This research work is aim at investigating the solar energy potential in Sapele, Nigeria.

Table 1. Final Energy consumption of energy sources globally (in EJ)

Year	Total	Coal	Oil	Natural Gas	Nuclear	Renewable	Renewable %
2000	270	44.4	115	55.5	7.64	47.8	17.7
2005	301	54.9	125	60.7	8.23	52.1	17.3
2010	332	64.8	130	68.9	8.26	60.0	18.1
2011	338	67.6	131	69.9	7.74	61.4	18.2
2012	345	68.7	132	70.3	7.39	63.0	18.4

2. Materials and Method

2.1. Materials

The materials used are as follow:

i. Photovoltaic solar panel of 80 watts (5)
ii. A digital multimeter
iii. Thermometer
iv. Deep cycle battery
v. Inverter
vi. Charge control
vii. Accessories/wiring system

The experimental set up is shown in Fig. 2.1

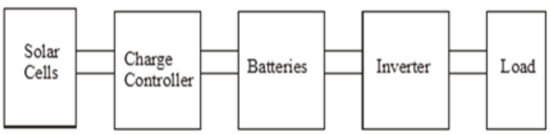

Fig.2. Block diagram of the process

2.1. Method

Five (5) photovoltaic solar cells (panels) were connected in series mainly to generate solar radiation. A thermometer was used to measure the ambient temperatures and solar panels temperatures on a daily basis within duration of three (3) hours from when the sunrise towards evening (6pm). A 2KVA power inverter was used to convert the DC power for the purpose of running household appliances such as air conditioner, fans, refrigerator etc. Also, a digital multimeter was used to measure both the voltmeter and ammeter reading within a period of two (2) hours. Two 12V, 150Ah batteries fully discharged were connected to the solar panels through the charger controller and monitored until the batteries are fully charged. The charge time was based on the amount of energy that was discharged from the batteries when they were fully discharged. The total Energy stored in the two batteries is calculated from equation (2.1).

$$T_E = B_C \times V_B \quad (2.1)$$

Where,

T_E= Total energy

B_C= DC battery capacity

V_B= Voltage of the battery

Also, the power generated from the solar panel in watt is calculated from equation (2.2).

$$P_{SP} = V_{SP} \times I_{SP} \quad (2.2)$$

Where,

P_{SP}= Power deposited on solar panel, V_{SP}= Solar panel voltage

I_{SP}= Solar panel current

According to Hargreaves and Samani daily global radiation could be estimated from the difference between daily maximum and daily minimum air temperatures (ambient temperatures) and extraterrestrial radiation [15, 18] as show in equation (2.3)

$$R_s = K_r(T_{max} - T_{min})^{0.4} R_a \quad (2.3)$$

Where,

T_{max}= Daily maximum air temperature (°C)

T_{min}= Daily minimum air temperature (°C)

R_a= Extra-terrestrial radiation ($MJm^{-2}d^{-2}$)

K_r= Empirical coefficient =0.17 for arid and semi-arid climate and values of Kr is 0.16 for interior regime and 0.19 for coastal regime

R_s= Global solar radiation ($MJm^{-2}d^{-2}$)

For the value of extra-terrestrial radiation, it is calculated from equation (2.4)

$$R_a = \frac{1440}{\pi}[G_{sc}d_r]\varphi_z sin\emptyset sin\delta + cos\emptyset cos\delta sin_{\emptyset z} \quad (2.4)$$

G_{sc}= Solar constant=0.0820 ($MJm^{-2}min^{-1}$)

d_r= Inverse relative distance from the earth to the sun

φ_z= Sunset angle hour (rad)

δ=Solar declination angle (rad)

The values of G_{sc}, d_r, δ, φ_z are calculated as follow

$$d_r = 1 + 0.033cos\frac{2\pi JD}{365} \quad (2.5)$$

$$\delta = 0.409sin\frac{2\pi JD}{360} - 1.39 \quad (2.6)$$

$$\varphi_z = arcos(tan \propto tan\delta) \quad (2.7)$$

Where,

JD= Day of the year

3. Results and Discussion

The daily maximum and minimum temperature reading of photovoltaic solar panel, solar panel voltage, solar panel current and average minimum and maximum values for a period of fifty (50) days of; temperature, current and voltage are shown in Table 2. The average means value of temperature, solar panel voltage and current (Table 3.) were calculated as follow:

$$\bar{y} = \frac{\sum x}{n}$$

Where,

ȳ = Average mean

∑x = Summation of temperature, voltage and current

n= Total number of days =50days

A mean average value of maximum and minimum temperature of 30.01°C was obtained for a period of fifty (50) days. Also, 14.23V and 4.206Amp were obtained as the mean average values for solar panel voltage and current. This implies that for a mean average temperature of 30.01°C, a mean average voltage and current of this 14.23V and 4.206A are produced daily and this generated 0.060kw and 0.180kwh of power for mean average duration of three (3) hours as calculated from equation 2.2 and 3.2 as

$$P_{SPh} = V_{SP} \times I_{SP} \times T \quad (3.2)$$

$$= 14.23 \times 4.206 \times 3 \approx 180 = 0.180kwh$$

Where,

P_{SPh}= Power deposited on solar panel in kilowatt hour

V_{SP}= Solar panel voltage, I_{SP}= Solar panel current, T=Time duration= 3hrs

The average value of power deposited in kilowatt and kilowatt hour shown that sufficient energy can be obtained from solar power system in Sapele, Nigeria. The extraterrestrial solar radiation and global solar radiation of Sapele, Nigeria for a period of fifty days were calculated from equation 2.3 to equation 2.7 as follow:

$$d_r = 1 + 0.033cos\frac{2\pi JD}{365} = 1 + 0.033cos\frac{2\times3.142\times1}{365} = 1.33rad$$

$$\delta = 0.409sin\frac{2\pi JD}{360} - 1.39 = 0.409sin\left(\frac{2\times\pi\times1}{365}\right) - 1.39 = -0.401rad$$

$$\varphi_z = arcos(-tan \propto tan\delta) = arcos(-tan0.122tan - 1.3830) = 1.52rad$$

$$R_a = \frac{1440}{\pi}[G_{sc}d_r]\varphi_z sin\emptyset sin\delta + cos\emptyset cos\delta sin_{\emptyset z}$$

$$= \frac{1440}{\pi}(0.0820 \times 1.33)1.512sin0.122sin - 0.401$$

$$+cos0.122cos - 0.401sin1.52$$

$$= \frac{39.95MJ/m^2/day\times1000}{3600m/s} = 11.09kwh/m^2/day$$

$$R_s = K_r(T_{max} - T_{min})^{0.4} R_a$$

$$= 0.16(37.74 - 22.29)^{0.4} \times 39.95$$

$$= 19.11MJ/m^2/day$$

$$= \frac{19.11MJ/m^2/day\times1000}{3600ms^{-1}} = 5.31kwh/m^2/day$$

Global solar radiation and extraterrestrial solar radiation of Sapele, Nigeria was calculated as 5.31kwh/ m^2 /day and 11.09kwh/m^2/day respectively. This agrees with the research work of Iloeje, 1997 that reported a range of an average of about 3.5kwh/m^2/day in the coastal latitudes and about 7.0kwh/m^2/day in far north of Nigeria.

Table 2. Daily maximum and minimum temperature, solar panel current and voltage reading

S/N	Temp. (°C)			V_{SP} (volts)			I_{SP} (Amp)			Duration (hours)	Power deposited (kw)	Power deposite (kwh)
	Max	Min	Ave. Temp.	Max	Min	Ave.(V_{sp})	Max	Min	Ave.(I_{sp})			
Day 1	41.5	23.0	32.25	18.0	14.0	16.00	5.7	3.4	4.55	3	0.073	0.219
Day 2	39.5	25.6	32.55	22.0	15.0	18.50	6.2	4.1	5.15	3	0.095	0.285
Day 3	38.7	26.2	32.45	21.5	15.3	18.40	5.9	3.8	4.85	3	0.089	0.267
Day 4	41.3	27.5	34.40	24.7	16.8	20.75	6.8	4.9	5.85	3	0.121	0.363
Day 5	39.3	26.4	32.85	23.1	16.4	19.75	6.6	4.7	5.65	3	0.112	0.335
Day 6	38.3	25.2	31.75	17.6	13.8	15.70	5.1	3.0	4.05	3	0.064	0.191
Day 7	37.2	24.6	30.90	15.2	12.8	14.00	4.9	3.0	3.95	3	0.055	0.165
Day 8	37.4	23.2	30.30	15.1	12.4	13.75	4.6	2.9	3.75	3	0.051	0.153
Day 9	38.3	26.2	32.25	17.9	14.0	15.95	5.7	3.5	4.60	3	0.073	0.219
Day 10	36.3	24.5	30.40	15.0	12.6	13.80	4.8	2.9	3.85	3	0.053	0.159
Day 11	37.4	27.3	32.35	20.0	15.0	17.50	5.3	3.5	4.40	3	0.077	0.231
Day 12	39.5	23.6	31.55	16.9	13.0	14.95	5.0	2.9	3.95	3	0.059	0.177
Day 13	38.6	26.6	32.60	22.8	15.9	19.35	6.8	4.6	5.70	3	0.110	0.330
Day 14	40.2	22.1	31.15	16.0	13.0	14.50	4.9	2.7	3.80	3	0.055	0.165
Day 15	39.1	24.2	31.65	17.0	13.1	15.05	5.1	2.9	4.00	3	0.060	0.180
Day 16	37.2	26.9	32.05	17.8	15.0	16.40	5.1	3.1	4.10	3	0.067	0.201
Day 17	38.3	23.4	30.85	15.1	12.7	13.90	4.8	3.0	3.90	3	0.054	0.162
Day 18	36.1	22.4	29.25	14.8	12.0	13.40	4.5	3.0	3.75	3	0.050	0.150
Day 19	38.2	21.8	30.00	14.9	12.1	13.50	4.3	2.7	3.50	3	0.047	0.141
Day 20	37.3	24.4	30.85	15.1	12.7	13.90	4.8	3.0	3.90	3	0.054	0.162
Day 21	41.5	23.2	32.35	15.0	12.3	13.65	4.5	2.9	3.70	3	0.051	0.153
Day 22	39.2	22.1	31.15	16.0	13.0	14.50	4.9	2.7	3.80	3	0.055	0.165
Day 23	37.6	25.8	31.70	17.6	13.7	15.65	5.1	3.0	4.05	3	0.063	0.189
Day 24	36.3	23.1	29.70	14.8	12.1	13.45	4.6	3.1	3.85	3	0.052	0.156
Day 25	41.7	23.6	32.65	22.8	15.9	19.35	6.8	4.6	5.70	3	0.110	0.330
Day 26	35.2	22.5	28.85	14.4	11.9	13.15	4.3	3.1	3.70	3	0.049	0.147
Day 27	36.1	21.4	28.75	14.0	11.6	12.80	4.1	2.8	3.45	3	0.044	0.132
Day 28	37.8	24.3	31.05	15.9	12.8	14.35	4.7	2.6	3.65	3	0.052	0.156
Day 29	38.4	22.4	30.40	15.0	12.6	13.80	4.8	2.9	3.85	3	0.053	0.159
Day 30	39.3	23.5	31.40	16.7	12.9	14.80	5.0	2.8	3.90	3	0.058	0.174
Day 31	36.8	26.3	31.55	16.9	13.0	14.95	5.0	2.9	3.95	3	0.059	0.177
Day 32	37.5	22.4	29.95	14.6	12.2	13.40	4.5	3.1	3.80	3	0.051	0.153
Day 33	38.4	25.6	32.00	14.8	12.1	13.45	4.3	2.9	3.60	3	0.048	0.144
Day 34	40.6	23.1	31.85	17.9	13.8	15.85	5.6	3.0	4.30	3	0.068	0.204
Day 35	40.2	24.2	32.20	14.9	12.2	13.35	4.4	2.9	3.65	3	0.049	0.147
Day 36	39.6	24.2	31.90	17.9	14.1	16.00	5.7	3.2	4.50	3	0.072	0.216
Day 37	41.4	23.3	32.35	15.0	12.3	13.65	4.5	2.9	3.70	3	0.051	0.153
Day 38	37.7	24.7	31.20	16.1	13.1	14.60	4.9	2.8	3.85	3	0.056	0.168
Day 39	38.3	23.3	30.80	15.1	12.5	13.80	4.8	2.7	0.75	3	0.052	0.156
Day 40	39.6	24.8	32.20	14.9	12.2	13.35	4.4	2.9	3.65	3	0.049	0.147
Day 41	41.3	25.3	33.30	24.2	16.6	20.40	6.6	4.4	5.45	3	0.111	0.333
Day 42	35.9	22.3	29.10	14.6	11.9	13.25	4.5	3.1	3.80	3	0.050	0.150
Day 43	37.8	27.1	32.45	21.5	15.3	18.40	5.9	3.8	4.85	3	0.089	0.267
Day 44	38.1	21.7	29.90	14.5	12.1	13.30	4.5	3.0	3.75	3	0.049	0.147
Day 45	41.4	24.3	32.85	23.1	16.4	19.75	6.6	4.7	5.65	3	0.112	0.335
Day 46	40.3	23.4	31.85	17.9	13.8	15.85	5.6	3.0	4.30	3	0.068	0.204
Day 47	36.4	23.5	29.95	14.6	12.3	13.45	4.6	3.1	3.85	3	0.052	0.156
Day 48	39.2	22.7	30.95	15.2	12.8	14.00	4.8	3.1	3.95	3	0.055	0.165
Day 49	35.6	20.3	27.95	12.2	10.5	11.35	3.3	2.7	3.00	3	0.023	0.069
Day 50	38.3	24.6	31.45	16.7	12.8	14.75	5.1	2.8	3.95	3	0.058	0.174

Table 2. Average mean value of temperature solar panel current and voltage reading

	Temp. (°C)			V_{SP} (volts)			I_{SP} (Amp)			Duration (hours)	Power deposited (KW)	Power deposite (KWh)
	Max	Min	Ave. Temp.	Max	Min	Ave. (V_{sp})	Max	Min	Ave. (I_{sp})			
∑	1887	1114.3	1500.65	757.1	665.8	711.45	255.3	165.3	210.3	150	149,617.94	22,442,6
n	50	50	50	50	50	50	50	50	50	50	2500	125,000
ȳ	37.74	22.29	30.01	15.14	13.32	14.23	5.106	3.306	4.206	3	59.85 =0.060kw	179.54 =0.180k

4. Conclusion

The results obtained from this research work show that Sapele, Nigeria has abundant solar energy potential. Besides, sufficient energy was generated with just five solar panels connected in series. Therefore, with proper policy and management, enough energy can be produce from solar power system in Sapele, Nigeria and the generated energy can be harnessed and used in form of heat and lightening for homes and industry in Nigeria. This will not only help in reducing Nigeria energy crisis but it will as well reduce deforestation and minimize the effect of pollution from fossil and wood fuels.

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