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Characterizing the Photovoltaic Solar Panel for Maximum Power Output

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Abstract A study has been conducted on fixed photovoltaic solar panel towards achieving maximum power output. The power output of PV solar panels is examined with different tilt angle (5°, 20°) and oriented towards the north, south, east and west during the month of February and March 2017 in Rivers State University, Port Harcourt, Nigeria (Latitude = 4.78°N). The open voltage and short circuit current generated with the corresponding ambient temperature was recorded on a daily basis from 09:00 – 16:00 hrs GMT+1 West Africa over the entire measurement period. Horizontal global radiation data recorded from a Nigerian Environmental Climate Observatory Project (NECOP) station at the University was used to calculate the tilted global irradiation on the PV panel. The results showed that for fixed PV panel the maximum power output is when equal to the latitude of the location. It was found that tilting the Photovoltaic panel to equal the latitude of the location will lead to an average power yield of 4.50W (south-facing panel), 3.52W (west-facing panel), 3.51W (east-facing panel), 2.64W (north-facing panel). This value represent about 36 percent increase when compared to 3.11W (south-facing panel), 2.11W (west-facing panel), 2.03W (east-facing panel), 1.80W (north-facing panel) when the angle is further from the latitude. The daily average global tilted irradiation incident on a PV panel is not affected directly by the maximum or minimum temperature of the day but by the difference between the daily maximum and minimum temperature of the region.

Keywords Latitude, Orientation, Temperature, Solar Irradiation, Tilt Angle

1. Introduction

The increasing energy demand globally is beyond installable generation capacity limits. Solar energy is clearly a promising alternative. Its eco-friendly device will benefit the environs and also the economy of developing countries [1]. There is an appreciable decline recorded in the use of fossil fuel and conventional energy in many developed countries of the world for their domestic and industrial activities due to the negative impact on our environment [2-3]. However, most developing countries and several countries in Africa still use fossil fuel. The challenges arising from climate change experiences has led to the quest for renewable energy sources that are eco-friendly to maintain a green environment [4-5].

Generally, the coordinate, latitude, temperature, orientation, solar irradiance, tilt angle of a photovoltaic solar panel have significant effect on the extent of maximum power output of photovoltaic solar panel and as a result it affects its performance. Several researches have been conducted to determine the most favourable fixed positions for solar collectors the world over [6]. This project involves a fixed tracking of the sun's radiation. A fixed mount (PV) panels are aligned facing a rigid position and inclined to a specific angle to the line at which the earth's surface and the sky appear to meet [7]. Areas between latitude 15° N and 35° N will receive more sunlight [8]. This shows that areas closer to the earth's equator receive more sunshine compared to areas nearer to the earth's poles. Nigeria is located in the northern hemisphere with coordinate of 10° N and 8° E. Also Port Harcourt, Nigeria coordinate are 4.816°N and 7.050° E.

Tilt angles are selected to achieve maximum daily or annual insolation during the year [9]. For instance, the research to choose the best tilt angle that will receive the maximum irradiation in Madinah station in Saudi Arabia using measured daily global and diffuse radiation data on a horizontal surface. The obtained results show that the annual average tilt angle of 23.5° (degree) is approximately equal to the research site latitude [10]. In the same vein, sunshine hours and ambient temperature data were used in predicting the energy output of photovoltaic panel in Enugu, Nigeria using developed Matlab code and mathematical equation in simulating the varying inclination angles. The results revealed that monthly variation of the tilt angle will yield better energy output whereas a fixed tilt angle of 6^0 (degree) equivalent to the site latitude will yield annually maximum energy output [8]. Another investigation to evaluate the best inclination angle that produces the highest power output on fixed and LDR sensor (light dependent resistor) tracking system mounted at different inclination angles facing south coordinate. The results show that the power output and current are influenced by the sun positional change from morning to evening. They concluded that the PV panel can be adjusted twice annually to enhance its efficiency [11]. Fixed PV panel should be inclined to approximately the same latitude of the research site to obtain annual maximum energy output [12-15]. Several other researchers have also suggested choosing tilt angles based on seasonal variations. For instance, several solar collectors fabricated and mounted in Nigeria were based on latitude of the site while few others are based on latitude plus seasonal variation [16]. Kern and Harris, [17]; Lunde, [18] recommended inclining the PV panel to approximately equal to site latitude plus (+) 10°, and latitude plus (+) 15° for winter season respectively. Duffie and Beckman, [19]; Elminir et al., [20] recommended a PV panel inclination of approximately equal to site latitude plus (+) 15° and latitude minus (-) 15° for winter and summer seasons respectively.

The optimum orientation of a PV module surface in the northern hemisphere is when the panel is facing the south coordinate, while in the southern hemisphere it is when the panel is facing the northern coordinate [12]. For instance, in the northern hemisphere the south facing surface receives optimal solar radiation during midday because the south surfaces are almost perpendicular to the sun rays [21]. Li and Lam, [22] investigated the energy output of three (3) multicrystalline module facing south, east and west respectively using numerical approach and simulated computer program in the evaluation. Their results show that south facing panel obtained the highest annual and monthly solar radiation whereas the output energy for east and west facing module were almost the same**.** However, the investigation left out the north facing panel in its evaluation. Obviously, most literature has proven that in the northern hemisphere the south facing position has the highest in terms of energy generation and north as the least **[23]**.

The temperature of a photovoltaic solar panel has a significant impact on its performance. An experimental research conducted in NnamdiAzikiwe University, Awka, Nigeria on the influence of ambient temperature on photovoltaic panel power output showed an indirect relationship between ambient temperature and power output [24]. Also Hanif et al., [25] investigated the maximum power output of PV modules installed as different inclination angle facing south axis in Jamrud Khyber Agency, Pakistan. The panel temperature, tilt angle and solar irradiance data were used for the analysis. Their results show that panels almost equal to latitude of the research site received the highest power output and that installing PV panels at place where they can receive more air current will allow the ambient temperature to remain low while the current output remains high. Similarly, Sethi et al., [26] investigated the maximum power output of a PV panel by experimental and simulation method, at varying solar irradiance and temperature. The results show that maximum power produced decreases as solar irradiance, and that ata constant solar radiation the maximum power decreases as the temperature of the panels is reduced. In the same vein, Ayegba et al., [28] determined the daily global solar radiation of Port Harcourt using the Hargreaves-Samani estimation model. The results obtained show that the global solar irradiation is not affected directly by the maximum or minimum temperature of the day but by the difference between the daily maximum and minimum temperature of the region.

In Port Harcourt, Nigeria, the development and practical use of solar power is minimal due to the problems associated with the technology of installation of solar systems, fabrication, awareness, and government policies among other factors. The growing increase in poorly installed solar panels in the city of Port Harcourt, Nigeria is appalling. Several Solar panels are installed with varying orientations and tilt angle. For instance, most of the standalone panels were installed on roof tops of building without recourse to the best orientation or best tilt angle for solar panel installation. It was discovered that these poor installation has resulted to a gradual increase in the amount of radiant energy lost and less power output produced by the panels. Therefore installing the solar PV panel systems at the right direction and orientation will generate the optimum power output in Port Harcourt, Nigeria and provide alternative source of electricity.

Numerous analysts have investigated the radiant energy yield generated by PV panels based on various influencing factors but with limited concentration on the power output of solar modules mounted in all orientation (north, south, east and west) at same time. It has been established that mounting a fixed PV panel inclined to equal the latitude of the site and positioned to the south axis will yield better annual energy output. However, there are cases where the front roof top of buildings has its orientation not in the south facing position. This is the main motivations for the current research of which an attempt is made to investigate the maximum power output from solar panels positioning (north, south, east and west) at two selected tilt angles (5°, 20°) degree in Rivers State University, Port Harcourt, Nigeria (4.7958°N, 7.0244°E).This research work was carried out between the month of February to March 2017 and the cardinal direction, and tilt angle that the PV panel recorded the maximum power with respect to the location, and time of the day was verified.

Materials and Methods

The experiment carried out between the month of February and March 2017 was set-up using four(4) identical 10W monocrystalline PV modules, four (4) PWM solar charge controllers, four (4)12v, 7.0Ah lead acid battery, 6W solar light (as load), atmospheric thermometer (0℃-100℃),a protractor, an engineering prismatic compass, voltmeter, ammeter, 5 in 1 auto ranging digital multimeter and horizontal solar radiation data from Nigerian environmental climatic observatory project (NECOP) station in same place housing where the experiment was been conducted.

For this research, the photovoltaic panels were mounted on a galvanized pole in an open space almost 1.5m high facing the sun with the aid of a compass to determine the cardinal position of the solar panel at an azimuth of 0 ^{o} north, 90 ^{o} east, 180 ^{o} south and 270^{o} west in such a way that it can be tilted from 5^{o} to 20^{o} (degree) to the horizontal. The output terminals were connected to the input terminals of the solar controller which is connected to the battery and the solar light is connected to the battery. An ammeter, voltmeter and a digital multimeter were used for monitoring and measuring the output current, and voltage. The power output for all orientations was also calculated. The solar panels were first mounted at 5° (degree) to the horizontal according to [8, 12-15] in the month of February corresponding to the latitude of installation site which is Rivers State University, Port Harcourt, Nigeria. Short-circuit current and open-circuit voltage generated with ambient temperature at an interval of one hour every day from 09:00 hrs to 16:00 hrs were recorded. The same procedure was repeated for approximately 20°according to seasonal variation which corresponds to latitude plus 15° (degree) according to [18-20, 28] in the month of March. These researchers recommended the use of a PV inclination equal to the site latitude plus 15° in winter season. The data collated was analyzed using equation (1-2) to estimate the hourly and daily average values of the output currents, voltages and maximum power output of the PV solar panels for all the cardinal positions. The average daily maximum and minimum temperature of the area were analyzed. Global irradiations on the tilted PV panel were calculated and analyzed using the parameters in equations (3-10) to estimate daily and weekly averages of the global irradiation at the different tilted angles. The analyzed results were then presented in tables and graphs.

Maximum Power Output of PV Panel

The maximum power point (MPP) is attained in the I-V curve as a product of current and voltage**.** The performance of the solar cell is characterized by the fill factor (FF), described as the ratio of the products of current, voltage at maximum power point to short circuited point [25-26]. Given mathematically as

$$FF= V_{MPP} \times I_{MPP} / V_{OC} \times I_{SC} \quad (1)$$

The solar panel maximum power output is given as

$$P_{Max} = V_{OC} \times I_{SC} (FF) \quad (2)$$

Where V_{oc} is the open circuit voltage; V_{mp} is the maximum voltage, $I_{sc}$is the short circuit current, I_{mp} is the maximum current.

Solar Irradiation Analysis for a Tilted Surface

The circum-solar model allows straight forward calculations of the global irradiation on tilted surface from the horizontal global irradiation data [29-30]. Standard equations for estimating the hourly tilted global irradiation are presented in equations (3 - 4) according to Udoakah and Okpura, [8] and equation (7 – 10) by Notton et al., [29].

Declination angle (δ)

$$\delta = 23.43 \sin\left[360 \frac{284+n}{365}\right] \quad (3)$$

Solar zenith angle **(**θz)

$$\cos\theta z = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega \quad (4)$$

Incidence angle **(**θ)

$$\cos\theta = \sin\delta\sin(\varphi - \beta) + \cos\delta\cos(\varphi - \beta)\cos\omega \quad (5)$$

Sunrise and sunset angles **(**ω's)

$$\omega's = \cos^{-1}(-\tan(\varphi - \beta)\tan\delta \quad (6)$$

The global irradiation on tilted surface is the summation of the direct, diffuse and reflected components.

$$I\beta = Ib,\beta + Ir,\beta + Id,\beta \quad (7)$$

$$Ib,\beta = Ib(\cos\theta/\cos\theta z) = (I - Id)(\cos\theta/\cos\theta z) \quad (8)$$

$$Id,\beta = Id(\cos\theta/\cos\theta z) \quad (9)$$

$$I\beta = Ib,\beta + Ir,\beta + Id,\beta = (I - Id)(\cos\theta/\cos\theta z) + \frac{1}{2}\rho I(1 - \cos\beta) + Id(\cos\theta/\cos\theta z)$$

$$= I\left[\left(\frac{\cos\theta}{\cos\theta z}\right) + \frac{1}{2}\rho(1 - \cos\beta)\right] \quad (10)$$

Where, Ib, β is the hourly beam radiation on the tilted surface, Ir, β is the hourly reflected radiation on the tilted surface (diffuse radiation), Id, β is the hourly sky diffuse radiation on the tilted surface. Where φ is the latitude and ω is the hour angle and β is the tilt angle, the albedo is taken equivalent to 0.2. The calculated parameters are expressed in Tables 1 and 2.

Results and Discussion

Tables 1 and 2 show the daily average power output, solar irradiation, minimum and maximum temperature generated by the solar panel at the various tilt and orientation for the month of February and March respectively.

Table 1: Daily average measured parameters in February at 5° (degree)

Daily Average Parameters for the Month of February							
Day	**North Facing Panel (W)**	**South Facing Panel (W)**	**East Facing Panel (W)**	**West Facing Panel (W)**	T_{max} (°c)	T_{min} (°c)	**Daily average global irradiation (MJ/m^{2}day)**
1	3.808	5.288	4.735	4.649	40.28	29.85	35.165
2	4.312	5.159	4.452	4.190	40.57	30.65	28.063
3	4.378	5.663	4.298	4.503	41.99	31.35	31.635
4	3.477	4.210	3.777	3.672	40.15	31.23	20.712
5	4.366	5.419	4.588	4.579	39.83	31.48	33.407
6	3.537	4.138	3.395	3.229	41.56	31.98	29.782
7	3.452	3.999	3.674	3.388	41.36	31.77	24.835
8	2.363	3.946	2.942	3.484	35.24	31.47	15.460
9	3.521	5.603	5.084	5.139	53.51	31.12	25.930
10	4.612	5.686	5.423	4.673	47.33	31.75	25.631

Table 2: Daily average measured parameters in March at 20° (degree)

Daily Average Parameters for the Month of March							
Day	**North Facing Panel (W)**	**South Facing Panel (W)**	**East Facing Panel (W)**	**West Facing Panel (W)**	T_{max} (°c)	T_{min} (°c)	**Daily average global irradiation (MJ/m^{2}day)**
1	1.977	2.679	1.858	2.129	37.58	31.77	25.756
2	2.752	4.786	3.763	3.741	39.03	31.85	32.706

3	3.727	4.077	3.415	3.414	39.07	32.49	19.188
4	2.748	3.015	2.874	2.509	37.09	30.14	34.804
5	3.248	3.789	3.272	3.264	36.97	30.83	40.517
6	0.919	1.272	0.945	0.960	31.37	30.81	5.393
7	3.492	4.799	4.534	4.247	36.18	29.25	36.518
8	2.966	3.261	2.980	2.970	38.55	29.85	34.776
9	1.244	1.598	1.297	1.318	31.41	30.45	7.068
10	1.957	3.507	3.489	3.979	35.10	29.07	27.975

Table 3: Monthly average power generated for each tilt angle and orientation

Panel Position	**Average Power Generation in February at 5°**	**Average Power Generation in March at 20°**
North Facing Panel (NFP)	3.618	2.461
South Facing Panel (SFP)	6.167	4.263
East Facing Panel (EFP)	4.871	2.792
West Facing Panel (WFP)	4.830	2.891
Total Power (W)	**19.486**	**12.407**

Table 3 is the summary of monthly average output power been generated for each tilt angle and orientation. The results in Table 3, is clearly in conformity with literature that increases in latitude leads to a reduction in power output and support that a solar panel with the tilt angle approximately equal to latitude of the location will receive maximum annual solar radiation [22]. It is observed that the south facing panel produced the highest power output for 5 degrees and 20 degrees inclination respectively whereas the north has the least power output for all orientation and inclination.

However, for 5 degrees inclination, the east facing panel produced more power output compared to the west facing panel, whereas the west facing panel is more compare to the east facing panel for the 20 degrees inclination. Additionally, the total average power output generated from all orientation of PV solar panels inclined at 5° (degree) in February was 19.486W and at 20° (degree) in March was 12.407W. This increase in the power generated by 7.079W is about 36% more at the 5^o inclination compared to 20^o inclination indicating that the difference is quite significant when the PV panel is almost equivalent to latitude of the research site than further from it for a fixed PV panel. The maximum power produced is increased when the global solar irradiance is increased from 25.31MJ/m^2 to 27.54MJ/m^2 which shows that direct solar radiation is another most important feature for calculating the power generated by a PV panel [11]. The analysis show that the south facing panel produced the highest power output for 5 degree and 20 degree inclination respectively, whereas the north has the least power output for all orientation and inclination.

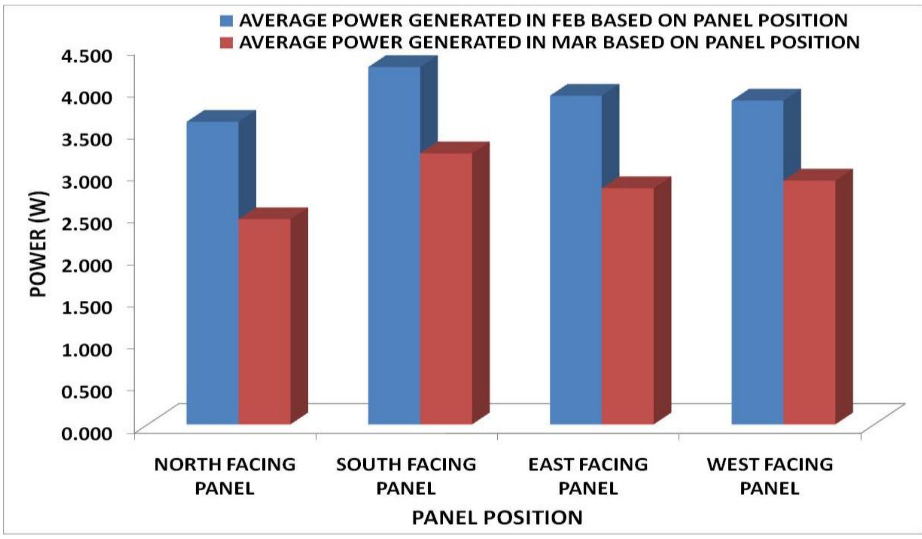

Figure 1: Monthly Average Power Generated for Different Orientation at 5^o and 20^o Inclination

It is also very clear from the graph of figure 1, that average solar power output is higher all over the month of February at a tilt angle of 5° (degree) which is equal to the latitude of Rivers State University Port Harcourt, Nigeria, which serves as the location of the study as compared to a tilt of approximately 20° (degree) which is equal to latitude plus 15° (degree). These results are in accordance with results given by Udoakah and Okpura, [8]; Hanif et al., [25]; Ajao et al., [28] where the average yearly energy yield is when tilt angle corresponds to the latitude of the location. The results clearly shows that the south facing panel offers better solar energy collection for the areas placed in the northern hemisphere and vice versa in accordance to results given by [23, 31].

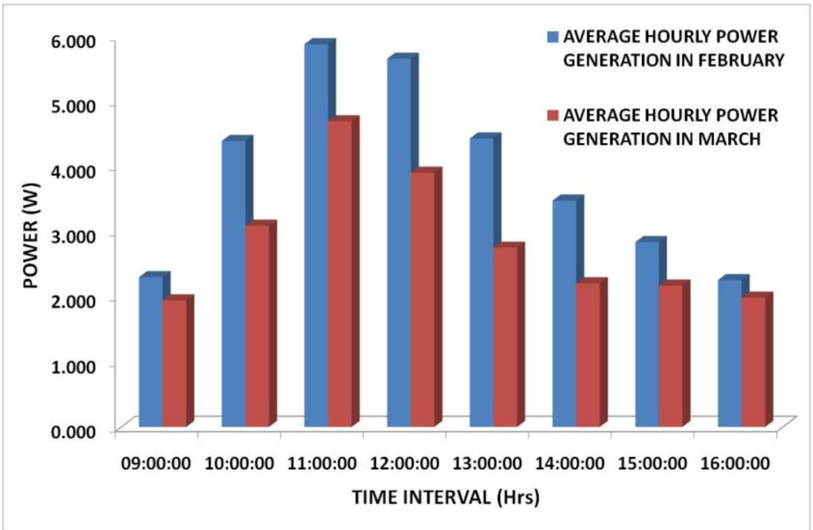

Figure 2: Average Hourly Power Generation in February and March

Similarly, Figure 2 shows the graph of hourly average power generated by the solar panel at the tilted angle of 5°and 20° daily, between the hours of 9:00 hr to 16:00 hrs. The comparison between both angles show that there is significant increase in the hourly average power generated at 5°, as compared to the hourly average power generated at 20° at same period. The maximum peak voltage and current readings are obtained at around 11:00 hrs to 12:00 hrs which clearly implies that there is a steady increase in power output between this period and a decrease afterwards.

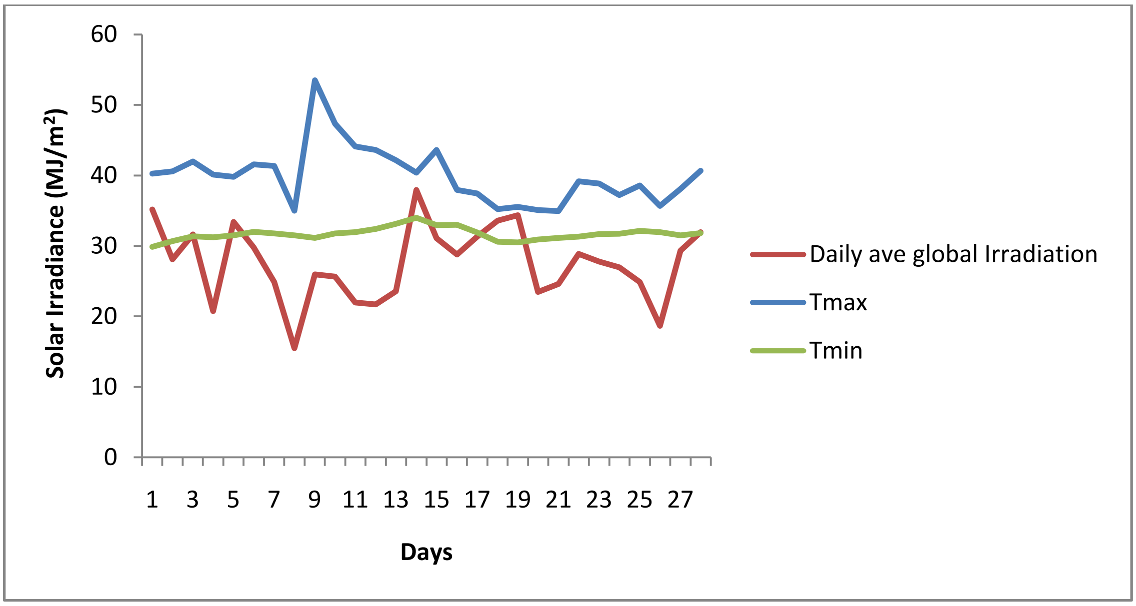

Figure 3: The Tilted Global Solar Irradiation, Maximum and Minimum Temperature for the Month of February 2017

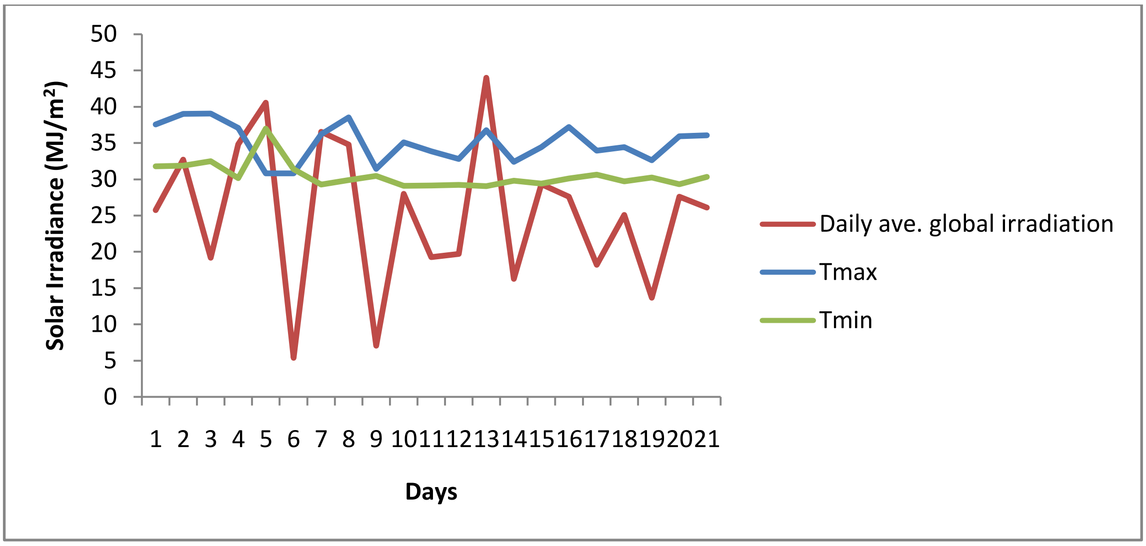

Figure 4: The Tilted Global Solar Irradiation, Maximum and Minimum Temperature for the Month of March 2017

The monthly average irradiation of 27.54MJ/m^2 and 25.31MJ/m^{2}was received in the month of February and March respectively. It was observed that the highest irradiation is attained when the inclination angle of the fixed Photovoltaic panel is equivalent to the site latitude. Figures3 and 4 signify the relationship between the global tilted irradiation, minimum and maximum temperatures for the month of February and March 2017. The maximum power point keeps changing with solar radiation and temperature such that it is difficult maintaining ideal matching at all radiation levels [32]. The global tilted irradiation was at its maximum level when the difference between the highest and lowest daily average temperatures of a specific day was at its maximum among the differences, and also at its minimum level when the difference between the maximum and minimum temperature of a specific day was at its minimum. The maximum and minimum global tilted irradiation occur when the temperature differences were 6^{o}C and 4^{o}C respectively for February, and 8^{o}C and 1^{o}C for March. Furthermore, global tilted irradiation is not affected directly by the maximum or minimum temperature of the day but by the difference between the daily maximum and minimum temperature of the day [27].

Conclusion

The maximum power output is obtained for fixed solar panels when the inclination is equal to the latitude of location yielding about 36 percent increase than further from it. Maximum power output for fixed PV solar panels is highest in the south facing orientation and least for the north facing panel. The daily average global tilted irradiation incident on a PV panel is not affected directly by the maximum or minimum temperature of the day but by the difference between the daily maximum and minimum temperature of the region. The maximum power produced is increased when the global solar irradiance is increased from 25.31MJ/m^2 to 27.54MJ/m^2.

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