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Modelling of Solar Power Production in Dry and Rainy Seasons Using Some Selected Meteorological Parameters

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Abstract

In this paper, we deployed the multiple linear regression method in developing a solar power output model for solar energy production, where the meteorological parameters are the independent variables. We fitted the model and found that the meteorological variables considered accounted for 94.88% and 99.61% of the power output in both dry and rainy seasons. We observed from the work that the solar panel performs well in all seasons but slightly better in the rainy seasons. This could be attributed to the washing away of dust particles from solar panels by the rain and higher operating temperature different from the specified manufactured temperature of 25˚C. We observed that other factors such as the cloud slightly affect the optimal performance of the system. Panels inclined at an angle of 5˚ (Tilt) and facing south azimuth performs optimally, periodic washing of the surface of solar panels enhances optimal performance.

Keywords

Solar Energy, Solar Panel, Meteorological Parameters, Photovoltaic Cell, Multiple Linear Regression

1. Introduction

The global warming and climate change caused mainly by the use of fossil fuel as a source of energy is a thing of concern to the global community. In the midst of this disturbing scenario is the demand for renewable and green energy as a source of energy supply in order to reduce the effect of global warming. Solar renewable energy has become a viable energy alternative. The sun is the earth's primary source of energy, its energy is both free and environmentally friendly. Energy from the sun does not produce greenhouse gases and hence, does not deplete the ozone layer. The solar photovoltaic technique is gaining popularity due to its availability, reduced cost, easy installation, and maintenance. As a result, solar PV boosts the use of solar energy and helps to reduce the demand for fossil fuels such as gasoline, diesel, petroleum, etc. and also limiting carbon dioxide emissions and preventing pollution. But contrary to the fact that Nigeria is blessed with many renewable resources in its surroundings, approximately 60 - 70 percent of the Nigerian population lacks access to electricity, since the renewable energy alternatives are still not being completely exploited for increased electricity provisioning [1]. The Nigerian government has a plan to reduce CO_2 emissions by more than 80% by the year 2050 compared to 1991 levels [2].

Over the last two decades, the rapid evolution of renewable energy sources (RESs) has led to the installation of numerous RES power systems all over the world. And because the installation cost of RES systems is still expensive, it is desirable to optimize their design to reduce cost. However, such an attempt necessitates a thorough understanding of the meteorological data for the location where the system will be deployed [3]. One of the two main technologies for creating energy from solar power generation is concentrated photovoltaic technology (CPV). The CPV's high photoelectric conversion efficiency has sparked and aided research into the technology. As a result, CPV technology is one of the most important and current solar energy power generation instruments. The main downside of this technology is the high cost of installation, which necessitates the extensive understanding of meteorological data for the area where the system will be installed [2]. Improved photoelectric conversion and the efficiency of the CPV power generating system are dependent on meteorological parameters.

This paper seeks to analyze the photovoltaic cell and its interaction with meteorological variables to produce optimal solar power as a boost to green energy production on one hand and the other hand to develop a power output model that relates solar power production with the meteorological variables (the sun, temperature, wind speed and humidity). The model will forecast future solar energy production and the significance of each of the parameters to optimal solar power production. The model will help us to understand the nature and workings of solar PVCs and the factors that limit their performance. The specific objectives of the paper are:

1) To develop a power output model that will relate solar power output with the meteorological variables.

2) To determine the parameters measuring the effects of the various meteorological variables on solar power output.

3) To establish the trend equation (model) for solar power output.

4) To fit a trend line for the power and meteorological variables.

5) To test for the significance of the parameters of the fitted model.

6) To forecast future solar power output.

The paper is divided into five sections as follows: Section one gives the general introduction of the work; Section two is devoted to literature review; Section three treats material and methods, Section four treats data presentation, analysis and interpretation of results, and finally, Section five treats conclusion.

2. Literature Review

Renewable energies are environmentally friendly and do not contribute to the warming of the environment and the production of greenhouse gases. Solar energy remains the foremost significant of all renewable energy sources because of its capability to sustain, maintain and support the life of plants and animals, and supplies of warmth to the environment, land and oceans [4]. The sun is the biggest body in the solar system containing about 99.8 percent of the system mass. It emits an enormous amount of heat and sunlight on the earth and the universe. The visible part of the sun is about 5500˚C while the temperature in the core reaches more than 15,000,000˚C [5]. Solar radiation is electromagnetically radiated by the sun. The solar beam energy is classified as visible light, near-infrared, and ultraviolet rays of the spectrum. The earth intercepts only a fraction of the vast amount of sunlight from the sun.

In many developing countries, power generation has become a major factor. Demand for energy has reached its peak due to the high energy need in the industrial and commercial sectors. Hence the need for renewable energy source to produce green energy for meeting the energy consumption need. This can help the society to decrease greenhouse gas emission and ozone layer depletion for future generation. As opposed to fossil source of energy generation which causes climate change, solar energy is at the fore-front of clean energy sources and does not contribute to climate change. It is cheap because it is renewable and cannot be exhausted. According to research, the world energy consumption in 2015 was 17.4 TW altogether [6].

There has been a minimal increase in the energy consumption every year, approximately 1% - 1.5% annual growth. The world's total energy consumption is expected to grow by 56% by the year 2040 [7]. Comparing consumption, projected growth in two decades, and the amount of solar radiation received in an hour we can imagine the potential that solar energy holds. The total energy consumed is a small fraction of what we receive in an hour. Despite this energy potential available to us the current utilization of solar energy is less than 5% globally. There are countries that are taking initiatives to switch from using fossil fuels to solar applications. For example, Germany is one of the G20 countries that has switched its energy needs to approximately 38% of solar, and aims to completely stop its dependency on nuclear and replace it with solar by the year 2050 [8]. Consequently, most of the other countries have abundant solar potential and can take a lesson from Germany.

The African continent is endowed with the maximum amount of average yearly radiation and it obtains additional hours of sunshine throughout the year more than other continents and 95% of the daily global radiation is above 6.5

kWh/m^2 impacts on Africa in the winter season [9]. This shows that Africa continent has the best potential for solar renewable energy. The climate conditions are mainly hot and dry seasons, although small regions experience cool temperature at the farthest north and south. Nigeria is positioned in an area (equatorial region) with a lot of sunshine, which implies that she has a lot of solar energy potential [10]. The daily annual average sunshine hour in Nigeria is about 6.25 hours, varying between around 3.50 hours at coastline and 9.00 hours at the northern frontiers. The average irradiation is around 5.25 KW/m^2 daily ranging between 3.50 kWh/m^2 daily in coastline areas and 7.00 kWh/m^2 at the northern borders [11]. In the months of November to February, the northern part experience cool and dusty atmosphere during harmattan [12]. With an average solar radiation of 19.8 $MJ \cdot m^{-2} \cdot day^{-1}$ and 6 hours of sunshine per day, solar radiation is reasonably evenly distributed [10]. This showed that if solar collectors or modules were employed to cover 1% of Nigeria's surface area, 1850×10^3 GWh of solar electricity might be generated each year. This is more than a hundred times the country's current grid electricity in use today.

Global solar radiation measurement has been quantified in several stations all over the world by utilizing various measuring instrument and techniques. Instruments such as pyrheliometer, pyranometer, and satellite remote-sensing instrument such as Moderate-Resolution Imaging Spectroradiometer (MODIS) products, and meteosat-images installed at specific locations measure and record its daily readings [13] [14]. Horizontal radiation measurement is achieved by the aid of an instrument known as pyranometer which measures global solar irradiance in all directions [15]. It also measures the global solar irradiance on inclined surfaces [16]. Irradiation or sometimes simply radiation is the radiant energy per unit area on a surface and is measured in J/m^2 or Wh/m^2. The word irradiance is termed the power per unit area received over a given time and measured in W/m^2 [17]. The horizontal solar radiation is characterized into direct and diffuse radiation [18]. Solar radiation data can be obtained from weather stations through direct measurements techniques on a location over a time period. However, in Nigeria, not many stations gather solar radiation data routinely [19]. Consequently, the accessibility of solar radiation data obtained through direct measurement techniques is extremely uncommon for different places all over Nigeria and indeed the world over. Therefore, several estimation procedures have been developed to evaluate global solar radiation by using various solar radiation models.

Angstrom-Prescott-Page model has been adopted globally by several solar researchers as a basis for future development of empirical models for predicting global solar radiation using same parameter, meteorological, geographical, geometrical, and astronomical parameters that is best for their location [14]. Artificial neural network was developed to estimate global radiation on horizontal surface. Some researchers have investigated global solar radiation from available meteorological parameters which has grown from local to regional and global scale.

Several meteorological based models have been developed based on the parameter available which can be in form of a single parameter or a combination of two or more parameters. These include sunshine-based models, cloud-based models, temperature-based models, relative humidity-based models, precipitation-based models, hybrid parameter-based models [14]. Among all these models, no researcher has modeled the relationship between the power output and several meteorological parameters, in other words, no researcher has used multiple linear regression model to establish the relationship between the power output and the meteorological parameters, estimate the parameters of the model and fit the trend line for forecasting for future solar power generation.

3. Materials and Methods

Development of Power Output Model

Power output is directly proportional to the inputs. The power output is the dependent variable and the inputs are the independent variables. This relationship is of the form taken by the multiple linear regression model. This model is of the form:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon_i \tag{1}$$

where Y_i is solar power output, it is the dependent variables. β_0 is the universal constant or an intercept on Y-axis, otherwise known as the general mean. β_i; $i = 1, 2, \cdots, n$, are the parameters measuring the average effect of the respective meteorological (independent) variables, X_i. If β_i; $i > 1$, we have multiple linear regression [20]. Then ε_i is the random error associated with the measure of the solar power output. And X_i is the meteorological variables called independent or predictor variables. We are aware that there are some errors to be minimized in the development of the model and this inform the choice of multiple linear regression model where the error is minimized while estimating the parameters of the model. The test on the parameters of the model will show the relevance of each of the meteorological variables to solar power output.

Assumptions:

The following are the assumption of the model.

Normality: All the meteorological variables in the model are normally distributed, that is, $\varepsilon_i \sim N\left(0, \sigma_e^2\right)$; $x_i \sim N\left(0, \sigma_x^2\right)$ and $y_i \sim N\left(\mu_y, \sigma_y^2\right)$.

Independence: All the meteorological variables in the model are independently distributed, that is $\mathrm{Cov}\left(\varepsilon_i, x_i\right) = 0$; $\mathrm{Cov}\left(x_i, x_j\right) = 0$; $\mathrm{Cov}\left(y_i, y_j\right) = 0$ $\forall i \neq j$

Constant Variance: All the meteorological variables in the model have constant variance, that is, $\mathrm{Var}\left(x_i\right) = \sigma_x^2 \quad \forall i$; $\mathrm{Var}\left(\varepsilon_i\right) = \sigma_e^2 \quad \forall i$; $\mathrm{Var}\left(y_i\right) = \sigma_y^2$ $\forall i$ [21].

To derive all the estimators needed in the estimation of the parameters of the model, we use matrix approach.

The model:

$$Y = X\beta + \varepsilon \tag{2}$$

$$\varepsilon = Y - X\beta \tag{3}$$

Squaring the error and summing both sides, we have

$$\begin{aligned} \varepsilon^{|}\varepsilon &= (Y - X\beta)^{|}(Y - X\beta) \\ \sum \varepsilon^{|}\varepsilon &= Y^{|}Y - Y^{|}X\beta - \beta^{|}X^{|}Y + \beta^{|}X^{|}X\beta \\ S &= Y^{|}Y - 2\beta^{|}X^{|}Y + \beta^{|}X^{|}X\beta \end{aligned} \tag{4}$$

Minimizing the error sum of square, we take the derivative of both sides with respect to β_i.

$$\frac{\partial S}{\partial \beta} = -2X^{|}Y + 2X^{|}X\hat{\beta} = 0 \tag{5}$$

Equation (5) is called the set of normal equations, and solving the equation, we have

$$X^{|}Y = X^{|}X\hat{\beta} \tag{6}$$

Pre-multiplying Equation (6) by $(X^{|}X)^{-1}$, we have

$$\begin{aligned} (X^{|}X)^{-1} X^{|}Y &= (X^{|}X)^{-1} X^{|}X\hat{\beta} \\ (X^{|}X)^{-1} X^{|}Y &= \hat{\beta} \end{aligned} \tag{7}$$

where

$$\hat{\beta} = \begin{bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \vdots \\ \hat{\beta}_n \end{bmatrix} \tag{8}$$

Hence, the fitted model is

$$Y = X\hat{\beta} \tag{9}$$

Writing Equation (9) in a scalar form, and since we have one response and four predictor variables, we have

$$Y_i = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \hat{\beta}_2 X_{2i} + \hat{\beta}_3 X_{3i} + \hat{\beta}_4 X_{4i} \tag{10}$$

Equation (10) is the fitted trend line and will be used to forecast the future solar power output.

where: $i = 1, \cdots, 81$; Y_i = Power (W) (5˚ Tilt), X_1 = average irradiation (mj/m^2), X_2 = average temperature (˚C), X_3 = wind speed (m/s), X_4 = Humidity (%) and $\hat{\beta}_i$ are the estimators of the parameters β_i. Hence, the power output model is given in Equation (10).

Hypothesis:

H_0: $P > 0.05$ Vs H_1: $P < 0.05$; Take $\alpha = 0.05$.

H_0: the effect of the parameter to the solar energy production is negligible at 5% level of significance. H_1: the parameters are significant in solar energy production at 5% level of significance.

4. Data Presentation, Analysis and Interpretation of Results

4.1. Data Presentation

In this section, we present the Meteorological data for the first quarter (January-March, 2021) in Table 1, and second quarter (April-June) in Table 2.

4.2. Data Analysis

We analyzed the data with Minitab statistical package. We tested for Normality assumption on the data presented in Table 1 and Table 2 respectively; these were done in Figure 1 and Figure 2. From the figures, we observed that the normality assumptions were satisfied. On the assumption of independence, each variable are independently distributed and hence has its covariance to be zero; also constant variance assumption were satisfied.

The fitted regression equation is

$$Y_i = 14.1367 + 0.876389 X_1 + 0.81526 X_2 + 0.423331 X_3 + 0.830089 X_4 \tag{11}$$

Summary of Model 1:

S = 1.95818; R-Sq = 94.88%; R-Sq (adj) = 94.61%;

PRESS = 343.254; R-Sq (pred) = 93.96%.

The fitted regression equation is

$$Y_i = 0.857006 + 0.961393 X_1 + 0.998358\, X_2 + 1.01508 X_3 + 0.998345 X_4 \tag{12}$$

Summary of Model 2:

S = 0.500225; R-Sq = 99.63%; R-Sq (adj) = 99.61%;

PRESS = 24.3712; R-Sq (pred) = 99.53%.

Decision Rule:

Reject H_0: if p-value > 0.05 and accept if otherwise.

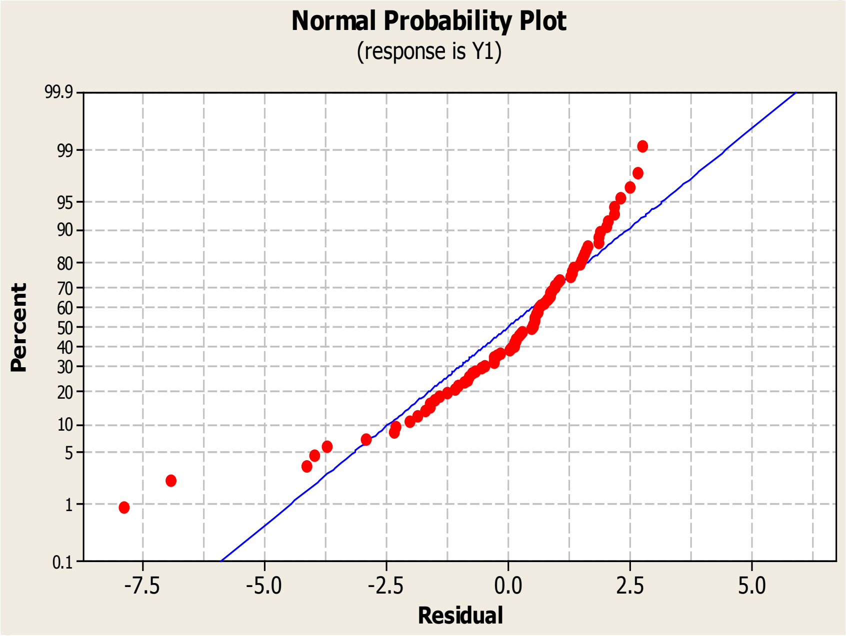

Figure 1. Normplot vs residuals for Y_i.

Table 1. Data on power (w), irradiation, temperature, wind and humidity.

Days	Power (W) (5˚ Tilt)	Ave. irradiation (MJ/m^2 days)	Average Temp. (˚C)	Wind speed (m/s)	Humidity (%)
1	80.79	24.88	32.75	0.10	23.06
2	85.42	27.72	32.67	3.21	21.82
3	76.35	23.81	30.39	1.37	20.77
4	95.26	29.41	35.89	3.51	26.45
5	72.21	19.40	32.87	1.66	18.28
6	67.12	19.67	33.99	2.00	11.45
7	81.75	21.19	31.44	3.69	25.43
8	90.15	29.60	30.72	4.03	25.80
9	97.33	41.64	34.22	5.05	28.42
10	83.62	23.89	37.01	2.54	20.18
11	93.3	25.36	33.29	1.41	33.24
12	74.38	16.84	31.90	3.08	22.56
13	76.91	22.57	33.30	4.41	16.63
14	93.46	33.84	35.61	3.38	32.64
15	83.72	27.97	30.71	3.16	21.88
16	81.73	31.41	30.69	1.43	18.20
17	96.44	37.23	34.58	3.61	29.02
18	80.33	24.49	32.76	3.39	19.69
19	70.83	14.62	34.17	1.87	20.17
20	85.71	26.76	37.14	2.15	19.65
21	74.91	20.28	33.46	1.10	20.06
22	77.47	18.81	35.12	2.72	20.82
23	97.11	35.61	35.38	2.31	23.81
24	72.86	9.94	34.66	3.49	24.78
25	94.94	36.56	32.66	3.09	22.64
26	73.29	21.43	33.29	3.55	15.01
27	71.29	17.64	33.26	1.85	18.54
28	82.99	21.19	33.20	3.64	24.97
29	82.15	21.88	32.53	3.02	24.71
30	89.74	35.19	32.25	2.20	20.10
31	89.34	23.30	33.56	3.44	29.03
32	98.58	32.55	30.90	2.42	35.70

Continued

33	86.65	30.17	36.27	2.66	17.55
34	91.03	27.27	33.99	3.14	26.63
35	82.18	26.24	30.17	2.66	23.11
36	83.15	30.78	33.09	2.37	16.90
37	87.51	30.15	35.82	2.87	18.67
38	79.13	15.72	31.97	3.81	27.63
39	72.46	12.39	36.13	3.36	20.57
40	74.77	18.98	32.46	1.79	21.54
41	68.74	13.69	32.94	0.70	21.40
42	86.45	26.66	31.67	3.65	24.46
43	96.02	35.48	35.89	3.98	28.67
44	95.38	29.97	34.05	2.35	34.02
45	83.05	23.23	33.20	3.55	23.06
46	80.81	30.40	32.36	3.70	14.35
47	64.79	18.51	30.76	1.50	14.01
48	96.13	34.46	32.57	4.50	32.60
49	75.67	13.40	36.97	2.60	22.70
50	84.46	24.40	32.55	2.26	25.26
51	84.85	33.51	31.56	2.70	17.09
52	95.88	29.70	34.20	3.59	28.39
53	73.84	23.12	30.06	3.38	17.29
54	81.57	24.42	30.60	3.76	22.79
55	87.5	29.63	31.76	3.65	22.46
56	93.98	35.39	31.48	2.10	25.01
57	82.42	21.83	31.89	1.21	27.49
58	81.2	25.19	33.13	3.06	19.81
59	90.89	33.83	35.37	1.49	20.20
60	95.06	37.48	31.98	3.75	26.84
61	83.31	15.80	35.19	0.79	31.53
62	97.5	33.54	35.14	2.23	26.58
63	79.51	19.22	32.89	0.33	27.09
64	97.29	31.87	36.74	1.34	27.33
65	90.34	31.90	33.27	2.69	22.47
66	92.68	24.92	35.60	2.90	29.26

Continued

67	81.02	16.84	35.21	2.78	26.18
68	87.08	30.73	32.77	4.48	19.10
69	84.68	26.72	29.85	2.91	25.19
70	76.59	23.82	28.54	2.43	21.79
71	85.89	19.57	32.08	3.76	30.48
72	91.17	34.71	31.52	3.13	21.81
73	88.4	21.76	32.59	1.48	32.58
74	83.34	18.39	32.88	2.18	29.89
75	72.27	21.23	33.78	1.57	15.70
76	98.23	38.64	32.02	3.07	24.49
77	86.33	21.71	35.85	3.83	24.93
78	89.36	34.47	34.84	2.66	17.40
79	75.19	15.79	35.39	3.15	20.86
80	89.79	23.15	35.12	1.88	29.64
81	83.24	17.41	35.84	2.34	27.65

Source: Nigeria Environmental Climatic Observatory Project (NECOP), Rivers State University, Port Harcourt.

Table 2. Meteorological data on irradiation, temperature, wind and humidity.

Days	Power (W) (5˚ Tilt)	Ave. irradiation (MJ/m² days)	Average Temp. (˚C)	Wind speed (m/s)	Humidity (%)
1	5.78	24.26	32.41	2.27	20.79
2	8.44	16.89	35.52	2.02	19.33
3	5.40	24.20	32.50	3.28	28.86
4	4.70	25.45	38.13	3.86	19.14
5	5.11	19.77	31.99	0.54	20.60
6	5.37	33.52	30.47	2.03	26.62
7	3.78	33.93	35.46	3.94	25.92
8	5.68	24.55	32.47	1.44	29.51
9	4.38	24.93	33.41	2.50	23.39
10	5.43	23.25	35.88	3.27	15.03
11	6.66	24.24	34.34	2.55	27.51
12	5.02	20.39	32.96	2.04	20.57
13	6.66	34.73	30.91	2.13	22.12
14	5.14	16.82	31.71	3.92	17.14

Continued

15	4.97	18.25	35.21	0.22	15.45
16	4.56	16.53	33.07	3.29	22.89
17	6.56	34.99	32.20	3.55	20.25
18	3.11	28.71	33.54	3.73	24.95
19	4.28	27.24	33.02	2.77	13.77
20	5.18	25.50	33.34	2.97	29.70
21	3.96	28.59	33.72	2.46	16.07
22	4.90	8.73	38.52	2.73	21.68
23	6.57	18.09	35.64	2.92	15.53
24	5.39	11.16	33.72	2.35	23.68
25	4.61	41.84	34.06	2.94	21.55
26	5.65	23.43	34.35	2.98	33.80
27	7.45	20.81	34.44	2.51	28.15
28	5.72	19.37	32.22	2.08	19.69
29	4.94	19.66	34.51	2.55	18.87
30	6.16	22.83	32.88	2.67	19.47
31	3.65	22.33	36.19	3.50	22.33
32	5.01	24.18	34.65	2.16	19.00
33	6.13	14.80	37.53	4.55	28.92
34	7.24	24.90	31.51	2.91	22.31
35	6.17	17.93	33.62	2.52	18.33
36	5.69	14.58	31.33	3.42	20.47
37	5.73	13.05	37.68	3.15	18.77
38	6.08	18.59	34.42	1.19	27.98
39	4.47	19.37	33.12	3.20	16.28
40	4.73	24.41	31.72	3.47	21.70
41	5.61	27.02	30.84	1.70	29.65
42	6.30	15.20	36.02	3.17	22.05
43	5.43	20.29	32.18	1.92	29.59
44	4.55	31.21	33.68	2.45	19.13
45	2.05	17.63	37.93	3.24	18.63
46	5.42	25.91	32.96	0.38	24.45
47	5.73	19.42	35.28	2.00	18.32
48	6.61	19.82	32.77	2.50	26.91
49	4.05	13.47	33.68	0.81	21.25

Continued

50	5.79	21.25	32.93	2.98	22.27
51	5.34	18.43	29.65	3.89	22.03
52	4.93	31.01	35.48	3.45	17.87
53	5.25	17.88	34.24	3.14	21.07
54	5.91	31.51	38.37	4.43	9.76
55	5.53	24.30	36.56	0.66	26.40
56	4.40	24.94	33.11	4.48	20.90
57	8.02	18.92	26.68	1.35	21.89
58	7.37	19.71	35.85	3.98	20.06
59	6.21	12.34	37.56	3.98	24.90
60	6.39	38.99	35.17	2.24	20.25
61	7.07	31.17	33.53	0.85	20.22
62	5.24	24.99	31.38	1.95	28.69
63	5.23	27.48	34.25	3.75	29.14
64	4.46	18.30	36.37	1.98	11.94
65	3.87	28.68	33.78	3.72	19.36
66	5.88	35.13	34.83	2.21	24.16
67	5.89	29.45	34.45	4.87	29.29
68	5.82	20.82	30.14	4.82	20.61
69	4.33	21.85	34.52	2.16	18.61
70	6.67	18.07	35.45	0.97	27.92
71	4.98	20.38	38.71	4.19	23.12
72	4.03	25.88	36.12	2.42	18.95
73	4.93	26.01	33.10	4.29	28.16
74	6.08	43.87	31.57	2.41	24.58
75	6.14	22.63	31.98	2.94	15.76
76	5.69	20.62	36.67	3.47	18.14
77	5.77	17.21	35.45	3.54	27.68
78	5.95	22.72	39.13	4.09	13.93
79	5.97	18.37	37.61	2.60	18.21
80	5.12	20.36	35.35	3.94	21.85
81	6.56	24.37	33.53	2.45	21.40

Source: Nigeria Environmental Climatic Observatory Project (NECOP), Rivers State University, Port Harcourt.

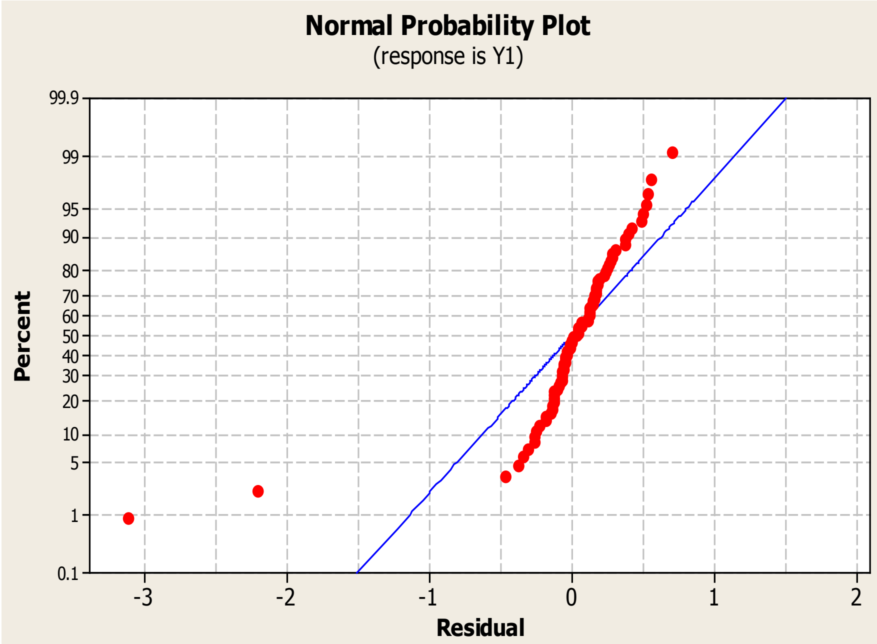

Figure 2. Normplot vs residuals for Y_1.

4.3. Interpretation of Results

From the analysis in the data presented in **Table 1**, we observe that the fit is adequate. The reason is that the meteorological parameters considered in this study, Irradiation (X_1), Temperature (X_2), and Humidity (X_4), were able to explain that up to 94.88% of the solar power output was attributed to these variables while 5.12% was unexplained. The unexplained variables are due to other environmental conditions not considered. This implies that there are other factors such as cloud, the variation in the design temperature and operational temperature of the solar panels etc, which also influence solar power output. From the Analysis of Variance (ANOVA) **Table 3**, we observed that Wind speed (X_3) was not significant. In this case we accept the null hypothesis (H_0) and conclude that the effect of the wind speed to solar energy output is negligible in the first quarter, from January to March 2021 and by extension, in dry seasons. On the other hand, we observed from the analysis that; Irradiation (X_1), Temperature (X_2), and Humidity (X_4) are significant in solar power output in this quarter. In this case, we accept the alternative hypothesis (H_1) and conclude that these parameters (Irradiation, Temperature and Humidity) contribute significantly to the solar power output. Equation (11) is the fitted model or the trend line. This model can be used to forecast for the solar power output in the dry season provided the values of the independent variables are known.

Also, from the analysis in the data presented in **Table 2** that is, the second quarter of the year under consideration (April-June, 2021), we observe that the fit was very much adequate. The reason is that the meteorological parameters considered in this study, Irradiation (X_1), Temperature (X_2), and Humidity (X_4), were able to explain that up to 99.61% of the solar power output was attributed

Table 3. Analysis of variance.

Source	DF	Seq SS	Adj SS	ADJ MS	F	P
Regression	4	5395.98	5395.98	1349	351.809	0.0010
X_1	1	3660.51	2832.35	2832.35	738.657	0.010
X_2	1	310.18	191.77	191.77	50.012	0.0020
X_3	1	27.08	13.53	13.53	3.529	0.0640
X_4	1	1398.21	1398.21	1398.21	364.645	0.0060
Error	76	291.42	291.42	3.83		
Total	80	5687.4				

Table 4. Comparative analysis and results of variance.

Source	DF	Seq SS	Adj SS	ADJ MS	F	P
Regression	4	5116.61	5116.61	1279.15	5112.00	0.00010
X_1	1	3176.56	3176.04	3176.04	1269.80	0.0110
X_2	1	166.07	364.36	364.36	1456.10	0.0010
X_3	1	82.48	86.30	86.30	344.90	0.0120
X_4	1	1691.5	1691.50	1691.50	6759.90	0.0010
Error	76	19.02	19.020	0.250		
Total	80	5135.63				

to these variables while 0.39% unexplained variation was due to other environmental conditions not considered in this work. This implies that there are other negligible factors such as cloud, the variation in the design temperature and operational temperature of the solar panels etc, which also help to determine solar power output. From the Analysis of Variance (ANOVA) Table 4, we observed that all the parameters such as; Irradiation (X_1), Temperature (X_2), Wind speed (X_3) and Humidity (X_4) were all significant in solar power output in this quarter. In this case, we accept the alternative hypothesis (H_1) and conclude that these parameters (Irradiation, Temperature, Wind speed and Humidity) contribute significantly to the solar power output. We also observed that the second quarter have a better fit than the first quarter irrespective of the fact that it was rainy season. Equation (12) is the fitted model or the trend line for rainy season. This model can be used to forecast for the solar power output provided the values of the independent variables are known.

4.4. Comparative Analysis of the Results between Dry and Rainy Seasons

We observed that all three meteorological parameters were significant except the wind in the dry season, but in the rainy season, all four parameters including wind were significant. This means that rain does not have a negative effect on solar power output; rather, it enhances solar power production. We also observed that the independent variables explain the model better in the rainy season; thereby giving a better fit than in the dry season. So many factors such as the rain washing away the dusty surface of the panel allowing it to function optimally could account for better performance compared to the dry season when dust covers the surface of the solar panel. Again, lower temperature due to the rainy season could also account for better performance. The higher temperature of the dry season could affect solar power production negatively. But in all, solar power output was optimal in both seasons with the independent variables accounting for 94.88% and 99.61% of the variation in both dry and rainy seasons while leaving a negligible proportion of the variations 5.12% and 0.39% unexplained. These unexplained variations are due to some contributing factors that were not considered. Finally, south-facing panels at an angle of 5˚ (Tilt) produced optimal solar power output in all seasons.

5. Conclusion

In this paper, our concern was to model solar power output with respect to meteorological parameters. We did a pilot study with different directions (facing) of solar panels; such facing include north facing, south facing, east facing and west facing. We had pilot survey collected data on them and determined which of the facing produces better results. We discovered that south-facing panel produced better results than others; hence, in the main data collection, we concentrated on the south-facing panel and ignored others because our interest is to maximize the power output. We also considered the angle of inclination of the panel for effective solar radiation and other meteorological variables. The pilot study we carried out shows that a 5˚ angle (Tilt) produced a better result than other angles which ranges from 0˚ to 90˚. For this reason, we concentrated at a 5˚ angle (Tilt) of inclination so as to maximize power output. The variables of interest here are stated as follows: Irradiation (X_1), Temperature (X_2), Wind speed (X_3) and Humidity (X_4), while power output (Y_i) is the fifth variable considered in the work. We have an interest in what happens in the solar power output in both dry and rainy seasons. For this reason, we collected data for two seasons, the dry season covers January to March 2021 and the rainy seasons cover from April to June 2021 which is two quarters. We collected a sample of eighty-one sample data points covering the period of three months each. The data for each quarter was presented in **Table 1** and **Table 2** respectively. From the data obtained, we developed a power output model which follows a multiple linear regression model. We carried out a comparative analysis of the models in the two seasons and conclude that the system performs slightly better in the rainy season. But we observed that the system performs well in all seasons under the conditions considered in this research work. We can also use our developed and fitted model to forecast future power generation. The operational temperature should be increased to 40˚C for the panels that should be used in Nigeria so as to accommodate the temperature at which it operates in Nigeria for better and optimal performance of the system. Using the microgrid system, many of these panels can be connected in parallel to produce power that can be linked to a national grid for the purpose of supplying powers for both private and industrial use.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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