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OPTIMIZATION OF THE TILT-ANGLE AND CLIMATIC FACTORS OF A PHOTOVOLTAIC (PV) SOLAR SYSTEM THROUGH EXPERIMENTAL AND REGRESSION ANALYSIS MODELING

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ABSTRACT

The implications of climate change have swiftly become acknowledged as one of the most critical concerns of this century. No nation is free from the fast changes in climate; the greenhouse effect, global warming, and climatic forcing are all direct results of the usage of fossil fuels. Because of the economic significance and natural benefits, it offers, photovoltaic (PV) as a source of renewable energy has received an amazing degree of interest from manufacturers, academics, and world's leaders. The high levels of solar energy that are accessible in many places of the world present an exceptional opportunity for the installation of photovoltaic solar panels that have a high level of output. This study optimized photovoltaic solar energy. Three 250-watts photovoltaic solar panels were positioned at angle of 0, 6.8, and 16.8 degrees to the horizontal at the University of Nigeria, Nsukka's Engineering department for 90 days to find the panel's best tilt angle. Temperature reduces power output from -8.31% to -10.87% and open circuit voltage from -6.38% to -8.34%. The positive output current coefficient grew from 1.3% to 1.69%. Temperature, humidity, solar-radiation regression, and multiple-regression models demonstrated overall correlation coefficients of 0.73709, 0.69393, 0.99678, and 0.99891. The combined model predicted photovoltaic model output performance ratio (PR) better than the other three models.

Index Terms - data-logger, efficiency, humidity, model, optimization, performance ratio, photovoltaic, regression analysis, solar radiation, temperature, tilt-angle.

1. INTRODUCTION

Nigeria is located between the Tropic of Cancer and the Equator, with latitudes 4-14° N and longitudes 2-15° E. As of Friday, November 24, 2023, there are 225,918,579 people living in Nigeria, according to the World meter enhancement of the latest United Nations figures. Nigerians make up 2.64 percent of the world's population [1], [2]. The Nigerian economy is the largest in all sub-Saharan Africa, yet it faces pressure to develop because of its reliance on the oil industry. Nigeria possesses significant reserves of oil, gas, hydro, and solar power, which give it the capacity to produce 12,522 MW of energy with its current infrastructure. Nigeria holds the distinction of being the country with the highest population and the greatest economy in Africa [3]. As the population continues to rise at a fast pace, there is a rising need for energy, which plays a crucial role in driving economic development. Nigeria's electricity demand in 2022 amounted to 32.1 terawatt hours. Subsequently, there has been a consistent increase in this pattern since 2020. Nevertheless, a significant segment of the Nigerian population still lacks access to electricity [4]. By the year 2020, slightly more than 55 percent of the Nigerian population enjoyed the privilege of electricity, while the remaining 45 percent were deprived of this essential resource. One of the obstacles confronting the Nigerian government in achieving economic development is the need to tackle electricity grid issues in light of the country's constantly expanding population. The user's text is "[5]". The electrical grid in Nigeria is facing significant difficulties. The sector is now facing several impediments, such as inadequate transmission coverage, losses in the value chain, interruptions in supply, corruption, and theft. Natural gas is the primary source of electricity generation in Nigeria. Based on the Africa Energy Outlook 2022 [6], a significant 70.5 percent of the country's electricity was generated from natural gas.

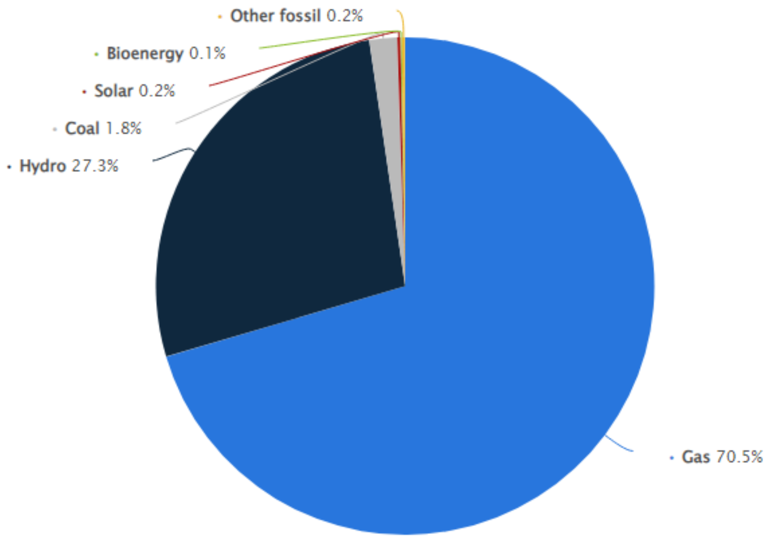

Figure 1: Distribution of electricity generation in Nigeria in 2022[3][5]

Hydroelectric power claimed the second position, contributing approximately 27. 3% to Nigeria's overall power production, while the remainder was attributed to other sources as renewable energy, coal, and other sources [6], [7] as shown in Figure 1. Considering the 4 GW added by USAID, the average solar PV installation volume is around about 44% of renewable sources [1]Aliyu et al. [8]noted that Nigeria, a premier nation in sub-Saharan Africa, may not continue in the traditional exploitation of fossil fuels as the principal energy source to ensure uninterrupted provision of electric power.

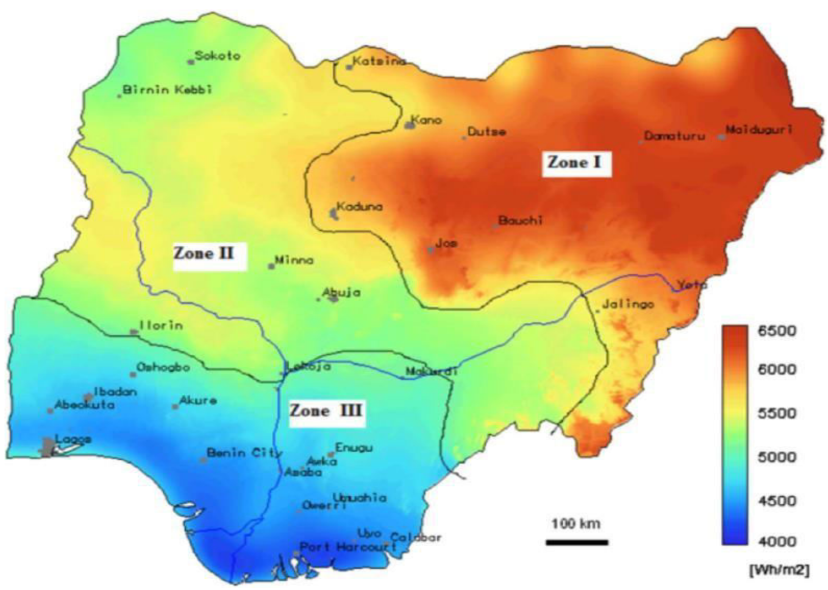

Figure 2: Map of annual direct plus diffuse solar radiation on a horizontal surface for Nigeria [7]

Figure 2 illustrates Nigeria's solar radiation distribution across three zones of Nigeria: Zone I, Zone II, and Zone III. Each zone necessitates distinct radiation levels for project sizing and selection [8]. Zone I encompass all North-Eastern states, benefitting from abundant sun irradiation incidents on planar surfaces, making these provinces ideal for large-scale solar PV, particularly in the semi-arid zone. Zone II, covering Nigeria's North-West, middle belts, and North-central regions, provides sufficient sun irradiation for major solar PV installations. Zone III, including coastal and southern Nigerian locales, experiences low annual worldwide sun irradiance, rendering it suitable for stand-alone solar photovoltaic (PV) systems. While Nigeria boasts substantial yearly global sun irradiation, its utilization remains primarily isolated and small-scale [8]. This study employs Nsukka as a reference, and its findings are extrapolated to other Zone III locales. Nsukka, a university town in Enugu State, is situated 488 meters above sea level at latitude 6.8°N and longitude 7.35°E. Known for cultivating cassava, yams, taro, pigeon peas, corn (maize), and palm nut, Nsukka is home to the University of Nigeria (established in 1960) [8]. The town experiences oppressive wet seasons and partly cloudy dry seasons, with an average annual temperature ranging from 61°F to 86°F [9]. Figure 2 indicates that the solar radiation in Zone III of Nsukka is below 5000Wh/m2 and roughly 1822KWh/m2/year [10]. A conventional solar collector can be installed at a right angle to the sun's rays. In their article titled "Determination of Optimal Tilt-Angle for Maximum Solar Insolation for Photovoltaic Systems in Enugu – Southern Nigeria," Udoakah and Okpura [9] showcased the energy generated by a photovoltaic (PV) module at various tilt angles in Enugu town. The study examines solar irradiance data obtained from sunlight hours and ambient temperatures in order to forecast the photovoltaic energy production at the location. The analysis determined that the most favourable inclination angle for generating photovoltaic energy is 60 degrees while the module is stationary, but it fluctuates when altered on a monthly basis. In their study titled "Implicit Meteorological Parameter-Based Empirical Models for Estimating Back Temperature Solar Modules Under Varying Tilt-Angles in Lagos, Nigeria," Umunnakwe et al. [10] observed the back temperature of solar PV modules tilted at angles of 0°, 6.70°, 16.80°, and 26.80°. They then developed models to calculate solar PV panels in Lagos, Nigeria, which is located at Latitude 6.6080oN and Longitude 3.6218oE. In his paper titled "The Global Solar Radiation on a Horizontal Surface in Akure, Nigeria," Adaramola [11] examined an empirical correlation to calculate the average daily global solar irradiance in Akure. The monthly clearness index calculations suggest that the prevalent weather conditions in Akure are characterised by partial cloudiness, which has the potential to intensify into heavy cloudiness from July to September [11]. Several other studies related to photovoltaic solar energy have been conducted in various cities and towns across Nigeria and globally [9]–[23]. Subsequent experimental studies on the optimization of photovoltaic solar panels are scheduled to take place at the University of Nigeria, Nsukka. These studies will incorporate a new correlation for the months of July to September (rainy season) and optimal tilt angles, precisely estimated for each month. Additionally, a regression analysis model that best describes the efficiency of photovoltaic solar panels installed at the prescribed tilt angle in the study location will be formulated. This model, applicable to locations with similar climatic conditions, will be developed with the assistance of MATLAB, SPSS software, and other available tools. For optimal performance ratio (PR), installing the collector on a two-pivot tracker that tracks the sun second-by-second and period-by-period is recommended while this approach is substantial and involves numerous mechanical and electrical components, this study introduces an enhanced method for generating output power from solar modules, tapping into the real potential for solar panel installations through advanced photovoltaic technology.

2. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup, data logging, monitoring, data gathering, and planning for data analysis were the resources and procedures that were utilized to measure the voltage, current, power, radiation, temperature, and humidity of the solar PV panels that were in a particular area in Nsukka. The initial step in this procedure involved assessing the functionality of the PV tilting platform. Three photovoltaic solar panels, each with a power of 0.25kwatts were positioned on the platform, which was then tilted from 0 to 40 degrees, as illustrated in Figure 3(a). The PV tilting platform demonstrated satisfactory stability, strength, ease of tilting, and overall performance. Subsequently, the specially designed data logger was affixed to a 0.25kwatt PV solar panel, accompanied by the SM206 secondary standard irradiance meter and the AT4208 multi-channel temperature meter. This setup persisted for a duration of 10 hours, during which global horizontal radiation and ambient temperature were measured and recorded, as depicted in Figure 3(b-f). Three solar panels were positioned to face south, adhering to the universal principle that dictates solar PV panels in the Northern hemisphere should be oriented towards the equator (south)[24].

Figure 3: Experimental set-up (a-b) 0 to 40 degrees tilted platform(c)Temperature and humidity measurement set-up (d) radiation meter (e) Panel A-C set-up (f) data logger

As shown in Figure 3(e), the tilting angles of 0°, 6.80° (based on the latitude of Nsukka, which is 6.80°), and 16.80°, panel A was set according to the models proposed by Udoakah and Okpura [9]for 0°, panel B was also set conferring to Lave and Kleissl model [22]using Nsukka's latitude and lastly, panel C was set according to Kern and Harris model [25] for 16.8°.Parametric data such as current, voltage, power, relative humidity, and ambient temperature were measured and logged daily at 20-second intervals for three months using a specifically designed automated data logger. The logger was programmed to record readings from three sets of loads, each consisting of 0.25kwatts car headlamps connected in parallel to create a total power of 0.25kwatts at a resistance of 4.0 Ω. These loads were connected across the terminals of each solar panel to dissipate the generated power through the low-resistance load system, allowing measurement of voltage drop and current. The DHT22 sensor was attached to each panel so that it can read variable temperatures and humidity around the solar panel, the DHT22 is a Temperature and Humidity Sensor. The operation is based on the exclusive digital-signal-acquisition method; and the humidity and temperature-recognizing technology. It ensures a great dependability and exceptional long-term permanence [26]. The data logger operated at 20-second intervals for 10 hours a day, starting from 7 am to 5 pm. Over a one-week period (from Sunday to Saturday) for each solar panel, a total of 1800 output data points for each of the five measured solar parameters (current, voltage, temperature, humidity, and solar radiation) were logged and saved into the memory card, accumulating a comprehensive dataset over the three-month period. During the experiment, the numerous solar and electrical parameters, including radiation, temperature, humidity, voltage, and current were tracked and measured with the assistance of the data recording system. The experiment lasted for a total of ninety days, which is equivalent to three months. The data were checked and recorded for ten hours each day, beginning at 7 am in the morning and continuing until 5 pm in the afternoon; this process began on the first of July and continued until the last day of September.

3. THE DATA VALIDATION

- The data were given as the initial set of data that had been acquired for ninety days on the irradiance, ambient temperature, relative humidity, back-module temperature, current, and voltage of the three PV solar modules. These measurements were taken over the course of the study. To have additional influence on the operable set-up, the raw data first needs to be changed and then maintained. If the proper safeguarding measures are not carried out to ensure the integrity of the datasets, it is possible that the datasets could be compromised. Human mistakes, data transfers, software faults, non-compliance with operational protocols, and physical compromise to devices are all common sources of data reliability inaccuracies [27], [28]. The maintenance of data integrity is a crucial component of the industry's accountability to guarantee the efficacy, safety, and value of their products. The integrity of the datasets acquired up to this point has been evaluated using the appropriate statistical normality test to ensure their accuracy. Normality tests are used in statistics to determine whether the datasets that have been gathered have a normally distributed distribution [29]. Because typical data are a fundamental assumption in parametric analysis, certain statistical tests require that you do an evaluation of the data to determine whether they are normally distributed. Numerical (or counting statistical) tests and graphical [30] evaluations are the two basic methods for determining whether a distribution is normal. A graphical translation offers the advantage of facilitating the decision-making capacity required to assess the level of normalcy present in delicate situations. Even though using graphical techniques for normality evaluation requires a great deal of experience to select an appropriate translation [30], there are numerous methods available to test the normality of a continuous data set, of these methods, the most mainstream techniques include the Kolmogorov–Smirnov test, the Shapiro–Wilk test, skewness, kurtosis, box plot, histogram, P–P Plot, mean, and standard deviation [31]. The significance of the normal distribution is self-evident, given that it serves as a foundational premise for many different approaches to measurement, including t-tests, linear analysis, analysis of variance (ANOVA), discriminant analysis, and regression analysis. When the normalcy hypothesis is disproved, the interpretation and the corollaries that follow from it may no longer be reliable or authoritative [15]. In this investigation, the skewness and kurtosis is used. A function's skewness can be thought of as a fractional representation of the asymmetry in its distribution [32]. A normal distribution has a skew valuation that is very close to being zero. The presence of a positive skew stem result indicates that the tail on the right side of the distribution is longer than the one on the left [32]. On the other hand, a skew stem with a negative angle shows that the tail on the left half of the distribution is longer than that on the right side. In contrast, the level of peak in a distribution is referred to as the kurtosis. The sample size should be comparable to that of the normal distribution [17]. A distribution is said to be leptokurtic if it has an ever-increasing top (for instance, if the peak of the distribution is ever-increasingly pointed). A mesocratic distribution is one that is less crested than others (for example, one whose pinnacle is not as sharp as others). The distribution's "tails" are the best place to look for anomalies [18]. They would unquestionably influence the kurtosis of the distribution; as a general matter, they would influence all the datasets. For univariate data Y1, Y2,.Yn, equations (1) and (2) present formulae for the skewness and kurtosis coefficient:

$$\text{skewness coefficient} = \frac{\sum_{i=1}^{N}(X_i-\bar{X})^3}{(N-1)S^3} \qquad (1)$$

$$\text{Kurtosis coefficient} = \frac{\sum_{i=1}^{N}(X_i-\bar{X})^4}{(N-1)S^4} \qquad (2)$$

According to *George D et al, a* normality test at the 95% confidence interval was successfully completed for each of the datasets that were gathered [33]. We thus confirm that the datasets that were obtained for this present work are legible, contemporaneous, original, accurate and complete.

4. **EXPERIMENTAL RESULTS AND ANALYSIS**

Over a period of ninety days (equivalent to thirteen weeks), the experimental parametric datasets for temperature, humidity, solar radiation, output current, and output voltage of each of the three PV solar panels, which were positioned at different tilt angles, were continuously monitored, measured, and recorded at intervals of twenty seconds. Following that, the primary datasets were subjected to an integrity test using a statistical normality test using the software packages IBM SPSS, Microsoft Excel, and MATLAB [33]. In addition, the power output (P) and the performance ratio (PR) are the two factors that are utilized most of the time when comparing the performance of one solar module to another. The power output (P) is the product of the voltage (V) and the current (I), and it is measured in watts (W). The performance ratio of a solar panel is a metric used to evaluate the efficiency and overall performance of a photovoltaic (PV) system. It is a ratio that compares the actual energy output of the solar panel or PV system to the theoretical or expected output under standard or optimal conditions [34]. The performance ratio is expressed as a percentage and the formula for calculating the performance ratio is given in equation (3):

$$PR\ (\%) = \frac{Actual\ Energy\ Output}{Expected\ Energy\ Output} \times 100 \quad (3)$$

$$PR\ (\%) = \frac{V * I * t}{250 * t} \times 100 \quad (4)$$

Where:

Actual Energy Output is the total amount of energy produced by the solar panel or PV system over a specific period. Expected Energy Output is the theoretical or expected energy output based on standard test conditions (STC) or other reference conditions.

A performance ratio close to 100% indicates that the solar panel or PV system is performing efficiently, close to its expected output. Factors that can affect the performance ratio include shading, soiling, temperature variations, and the overall health of the solar panels. By applying equations 3 and 4, we were able to determine the amount of electricity that was generated by each of the PV solar panels throughout the course of all thirteen weeks. The datasets were analyzed with descriptive statistics such as the mean, the maximum, the minimum, and the standard variations. The findings acquired from all the studies were presented. Figure 4 illustrates the thirteen-week average performance ratio of the three solar panels.

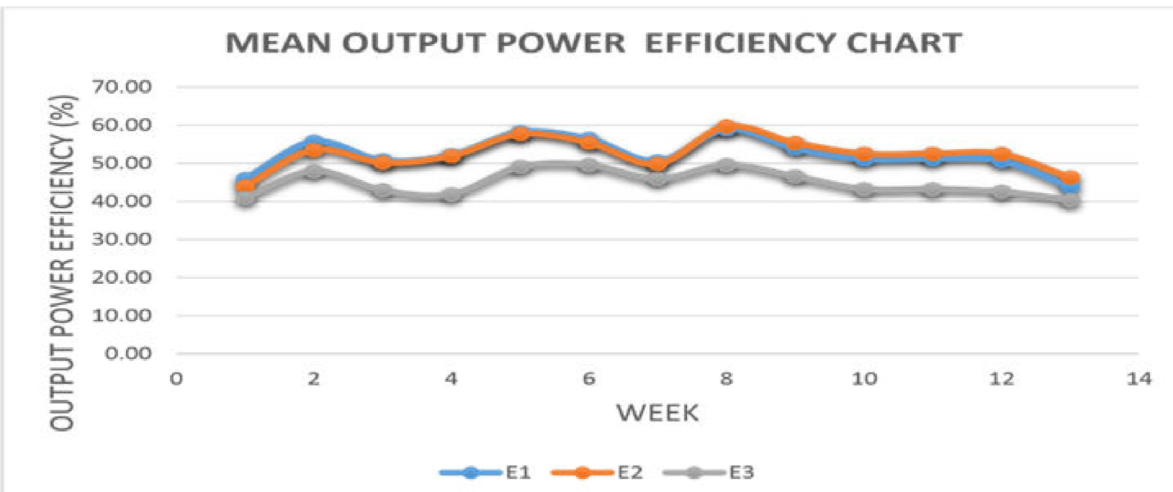

Figure 4 : Mean output power performance ratio chart

For all three PV solar panels, plotted for week 1 to 13, PV solar panel A, installed at a tilt-angle of 0 degrees to the horizontal axis, had the best average yield output performance ratio from week 1 to week 7 (July 1 to August 17, 2022), ranging from 45,85% to 58,16%. This finding supported Udoakah and Okpura [27] and resembled Bakirci [28], Skeiker [29], and Ulgen [30]. Second, solar panel B, installed at the tilt-angle corresponding to Nssuka's latitude (ϴ = 6.8 degree), has the closest average performance ratio to PV solar panel A, with an average value ranging from 44,00% to 57,70%. PV solar panel C, installed at 16.8 degree (ϴ+10), has the lowest average performance ratio, ranging from 40,92% to 49,56% for all seven weeks. As shown in Figure 5, panel B output performance ratio was reduced by 4.73% at week one and 0.01% at week seven compared to panel A. As demonstrated in Figure 6, panel C output performance ratio decreased by 19.73% at week four and 9.11% at week seven compared to panel A. However, the PV solar panel B, positioned at the tilt-angle corresponding to Nssuka's latitude (ϴ = 6.8 degree), produced the highest average output performance ratio from week 8 to week 13. This result supported Lave and Kleissl's [31] claim that the PV solar panel's output performance ratio is highest when installed at a tilt angle equal to the site's latitude, as well as Gunerhan and Hephasli [32], Benghanem and [33], and Rowland et al. [34]. PV solar panel A, installed at 0 degrees on the seventh week, had the highest performance ratio of 97.18%, as shown in Figure 6.

Figure 5: Percentage loss in the output performance ratio of panels A and C compared to panel A

The PV solar panel C, installed at 16.8 degrees (Θ +10), had the lowest performance ratio of 64.4% on the thirteenth week. The dataset also revealed that the maximum output performance ratio was recorded on August 21, as shown in Figure 9.

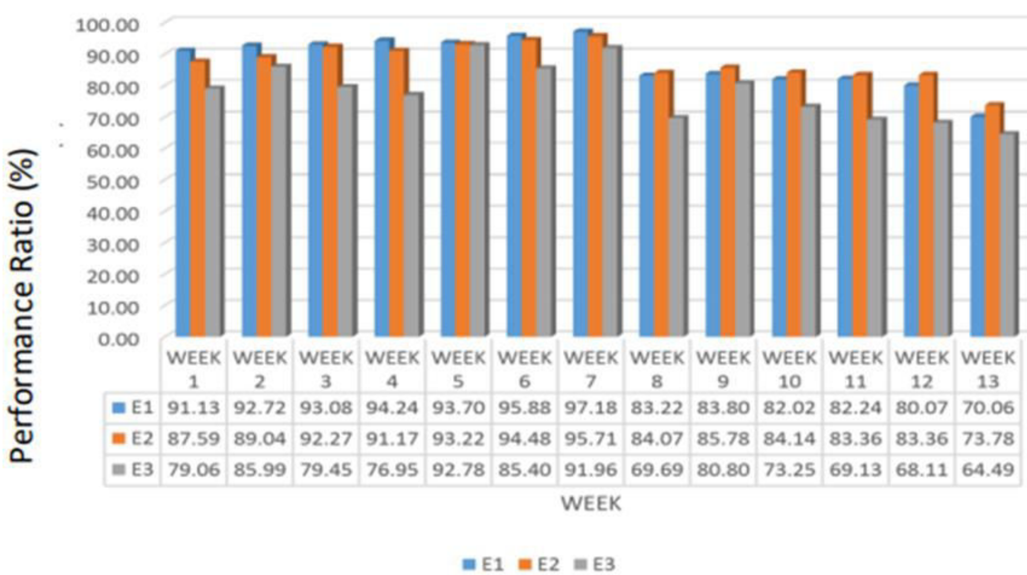

Figure 6: Maximum output power performance ratio chart

Solar radiation, ambient temperature, and relative humidity affect solar PV panel power and efficiency. Thus, temperature's effect on solar PV material's current, voltage, and output power efficiency must be assessed. Regularizing solar PV module power ratings using 1,000 W/m^2 irradiation at 25°C. On August 21, the operating temperature was 25^0C at 7am and 24^0C at 8:45am, It peaked at 49.5^0C at 1:15 pm and plummeted to 23^0C at 4:45pm. Temperature coefficients are used to determine photovoltaic solar panel temperature effects. Solar PV module technical manuals provide the temperature coefficients for open circuit voltage (Voc), maximum power (Pmax), and short circuit current (Isc) [35]. Each °C of cell temperature deviation from typical test circumstances causes a corresponding change in Isc, Voc, or Pmax. In Equation (5), the coefficient for Pmax determines the percentage power change of a PV cell owing to operational temperature [35]. Calculate the percentage change in a module's open voltage (Voc) and short circuit current (Isc) at operating temperature using equations 6 and 7.

$$\%\ change\ P_{max} = (T_C - T_{stc}) \times \left(\frac{Temp\ coeff\ P_{max}\%}{T_C}\right) \quad (5)$$

$$\%\ change\ V_{oc} = (T_C - T_{stc}) \times \left(\frac{Temp\ coeff\ V_{oc}\%}{T_C}\right) \quad (6)$$

$$\%\ change\ I_{sc} = (T_C - T_{stc}) \times \left(\frac{Temp\ coeff\ \ I_{sc}\%}{T_C}\right) \quad (7)$$

T_c = *Cell operating Temperature* (^oC)

T_{stc} = *Standard Test Conditions Temperature* (25^oC)

The V_{oc}, I_{sc}, and Pmax refers to parameters that may be readily calculated from the I-V characteristic of the solar cell. The normalised temperature coefficient of the reverse saturation current (Io) refers to the rate at which the reverse saturation current changes with temperature, taking into account any normalisation factors. can be calculated by using equations (5) to (7), and the temperature coefficients (T_C) have been determined in the datasheet, as shown in Figure 7.

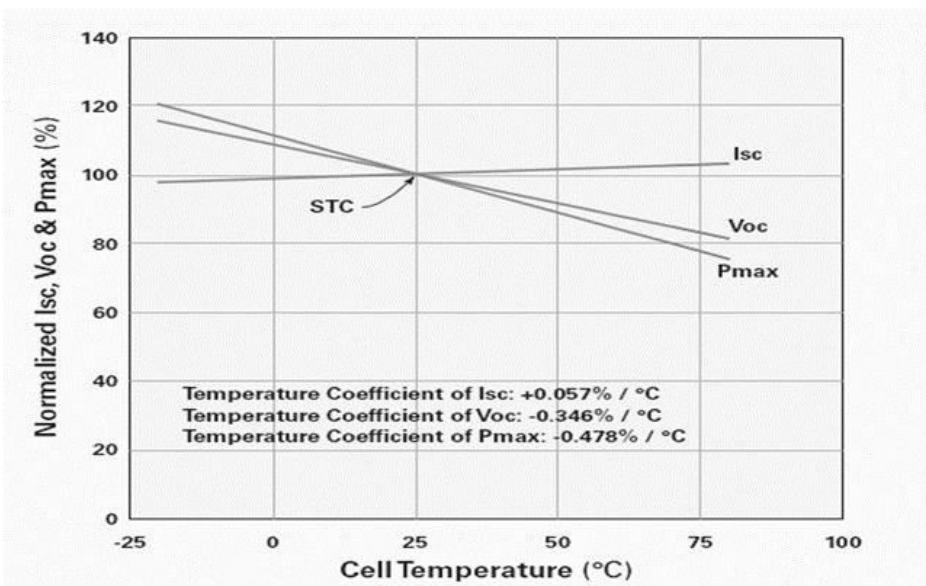

Figure 7: Effect of Temperature on PV Cell Using datasheet Coefficients [35]

To prevent relapse, the dataset for August 21 is used to study how changing the operational temperature affects power output, voltage output, and current output. Figure 7 shows the output power, voltage, and current change due to operational temperature increases using equations 5 to 7 and Figure . Any temperature increases over 25°C will impact the panel's output performance, since the module's tag specifies the rated output power at 25°C. The temperature has a negative coefficient of about on maximum output power and open circuit voltage, which reduces maximum power output by -8.31% to -10.87, -6.38% to – 8.34%, and a positive coefficient on output current, which increases by 1.3% to 1.69%. An erroneous or excessive slanted angle raises a solar panel's working temperature, reducing its power output efficiency. Humidity is atmospheric moisture. Two ways humidity might impact solar panel module performance. Water droplets on the solar panel module's surface reflect light and corrode the metallic parts, reducing the solar panel's output power and lifespan. Relative humidity is the ratio of water vapour in a volume of air at a certain temperature to the amount it might saturate [36]. Humidity directly affects output performance. When humidity decreases, current, voltage, power, and efficiency rise, and vice versa. Solar energy is transformed directly into electricity by the semi-conductors used in PV solar panels. Although, there have been countless developments in semi-conductor technique in contemporary years, module efficiency is still very low. The solar radiance level on the Photovoltaic (PV) panels diverges, depending on the location of the panel and the time intervals in a day. An increase in Photovoltaic (PV) cell temperature reduces the overall performance of the photovoltaic (PV) solar panel. The influences of solar radiation were studied on the overall performance of the photovoltaic (PV) and the outcome shows that there is a direct proportionality between solar radiance, output voltage, output current and output power, as well performance ratio.

5.0 REGRESSION ANALYSIS MODELLING

Regression analysis is a statistical system for assessing the association between functions, which are outcome-related. The most common models are univariate and multiple linear. Non-linear regression analysis is normally used for more complex data, which are independent; and the dependent variables demonstrate a non-linear relationship [36,37].

Simple linear regression evaluates the connection between an independent variable Y and dependent variables like X1,,, Xn. The dependent-independent linear equation is then formulated. The unadorned univariate regression model has one predictor, X. Equation (8) describes this popular model.

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \qquad (8)$$

The response variable, also known as the dependent variable, is the variable that you are attempting to forecast.

The predictor variable, also known as the independent variable, is utilised to forecast the response variable.

The β0 coefficient represents the value of Y when X is equal to 0, often known as the intercept.

β1 represents the slope or gradient of the line, indicating the amount of change in Y for a one-unit change in X.

The error term denotes the residual variation in Y that remains unexplained by the linear association with X.

The objective of simple linear regression is to estimate the values of β0 and β1 in a manner that minimises the total of the squared deviations between the actual values of Y and the values predicted by the model. Linear-regression analysis is based on six essential assumptions.

In basic linear regression, the objective is to determine the optimal straight line (defined by the intercept β0 and the slope β1) that minimises the sum of squared deviations between the observed and predicted values of the dependent variable. This is accomplished using the least squares technique.

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 x_1 \ldots \qquad (9)$$

$$\beta_1 = \frac{\sum_{i=1}^{n} y_i x_i - \{\sum_{i=1}^{n} y_i\}\frac{\{\Sigma_{i=1}^{n} x_i\}}{n}}{\sum_{i=1}^{n} {x_i}^2 - \frac{\{\Sigma_{i=1}^{n} x_i\}^2}{n}} \qquad (10)$$

Where, $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_1$ and $\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_1$ are the averages of X_1 and Y_1 respectively. Therefore, β_0 and β_1 are the least squares estimators of the intercept and the gradient. The residuals ε are the unexplained variation and the predicted values $\mathbf{y_i} - \hat{\mathbf{y}}$, i=1, 2, ..., n. The correlation coefficient R assesses the goodness of the appropriate data measured and the standard error measures, but S is computed. The correlation coefficient value can differ in the range +1 Furthermore, there is a negative correlation of -1 between the variables x and y. A linear correlation between the variables does not exist when the value is zero. The calculation of the correlation coefficient (R) and the standard error measures (S) are as follows [38]:

$$R = \frac{\sum_{i=1}^{n} y_i x_i - \{\sum_{i=1}^{n} y_i\}\frac{\{\Sigma_{i=1}^{n} x_i\}}{n}}{[\{\Sigma_{i=1}^{n} X_i^2\} - \{\sum_{i=1}^{n} X_i\}^2][\{\Sigma_{i=1}^{n} Y_i^2\} - \{\sum_{i=1}^{n} Y_i\}^2]} \qquad (11)$$

$$S = \frac{\Sigma_{i=1}^{n} Y_i^2 \beta_0 - \sum_{i=1}^{n} Y_i - e\beta_1 \sum_{i=1}^{n} y_i x_i}{n} \qquad (12)$$

The coefficient of determination, R^2 is given by

$$R^2 = \frac{\{\sum_{i=1}^{n} \hat{y}_i - \bar{y}_i\}^2}{\{\sum_{i=1}^{n} \hat{y}_i - \bar{y}_i\}^2} \qquad (13)$$

The coefficient of determination (R^2), measures the proportion of overall variation in Y that has been described by the regression. Temperature, output current, voltage, power, and efficiency are related. The IBM SPSS 26 linear regression of temperature approach is used to analyse

equations (9) to (13). βo is −53.94 and β1 is 2.9. The linear regression analysis model for temperature and output power performance ratio is:

$$PR = -53.94 + 2.97T \qquad (14)$$

The model value of correlation coefficient (R) is 0.698 for the dependent output power performance ratio variable against the temperature as an independent variable, showing a moderate positive correlation between temperature and output-power efficiency. Further, the value of the coefficient of determination (r^2) = 0.487 for the output power performance ratio, which indicates that 48.7% of the total variation in the output power efficiency can be explained by the linear relationship between air temperature and the output power performance ratio, as described by the regression equation 14. Also, the general layout of the regression chart shows a direct proportionality between the two variables, as shown in Figure 8.

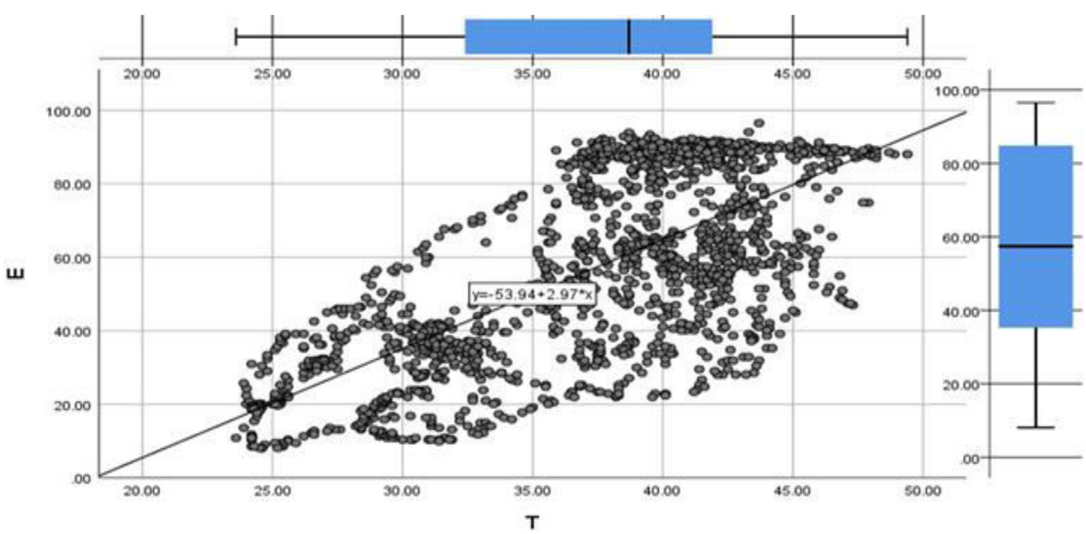

Figure 8: The scatter plot with the fitted line of Output Power performance ratio versus air temperature

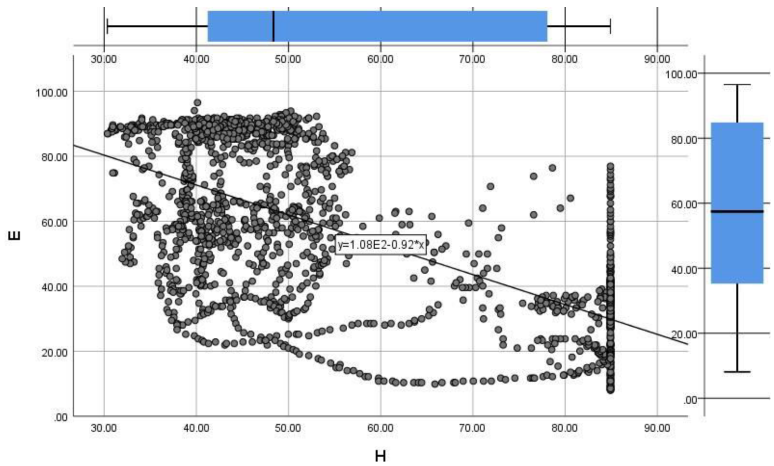

Figure 9: The scatter plot with the fitted line of Output Power performance ratio versus air Humidity

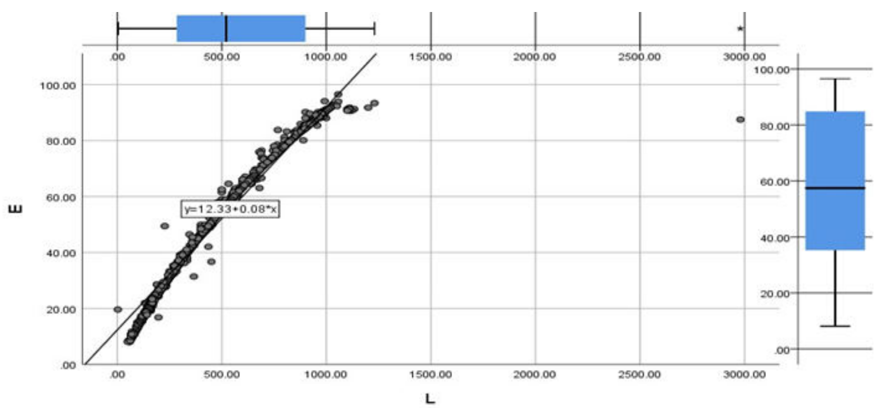

Figure 10: The scatter plot with the fitted line of Output Power performance ratio versus solar radiation The values of βo and β1 are 107.896 and -0.92, respectively. The regression equation obtained from the analysis is given as:

$$PR = \mathbf{107.896 - 0.92}\boldsymbol{H} \quad (15)$$

Where, H represents the independent variable humidity and η indicates the dependent variable PV module output power performance ratio. The analysis displays 0.662 as the value for the correlation *coefficient (R), which proves that a good* positive correlation exists between humidity and efficiency. More also, the value of the coefficient of determination (R^2) becomes 0.438. From the value, more than 50% of the variation in humidity cannot be explained by the linear relationship, as described by the regression equation. Figure 9 shows that the output power performance ratio of the photovoltaic module decreases with an increase in humidity, and vice versa. The values of βo and β1 are 12.334 and 0.08, respectively. The least-squares fit to the solar radiation data is given as:

$$PR = 12.334 + 0.08L \quad (16)$$

The estimated value of the output power performance ratio corresponding to the solar radiation of (L) is denoted by (η). The equation that has been adjusted to fit the data is graphed in Figure 10. The value of the linear correlation coefficient (R) in this situation is 0.981. There is a clear and direct correlation between the efficiency of the output power and the amount of solar radiation received by the photovoltaic solar panel. This implies that there is a direct correlation between solar radiation and the output power performance ratio. As the sun radiation intensifies, the output power also increases. The model's analysis of variance (R2) is 0.962, indicating that approximately 96.2% of the variation in solar radiation can be explained by the linear relationship with the output power performance ratio.

Multiple regression analysis is a widely utilised statistical tool for investigating and illustrating the relationship between variables [39].

$\beta 0$, = -14.352 , βT = 0.648, βH = 0.093 and βL = 0.075

PR = -14.352 + 0.648**XT** + 0.093**XH** + 0.075**XL** (17)

In his publication titled 'Interpreting the Basic Outputs (SPSS) of Multiple Linear Regression', Dhaka [35] states that the dataset should include values for all predictors that were close to zero. The predicted value for the dependent variable in this study is -14.352, which represents the output power efficiency when all independent variables (ambient temperature, ambient humidity, and solar irradiance) are set to zero. The unstandardized coefficient measures the extent to which the dependent variable changes in response to a change in one independent variable, while holding all other independent variables constant. The regression coefficient quantifies the amount of predictable change in the dependent variable (the output power efficiency) that occurs with a one-unit increase in the independent variable. The unstandardized coefficient for ambient temperature in Table 4 is 0.648. For each incremental rise of one degree Celsius in the surrounding temperature, the output power efficiency increases by 0.648%. Moreover, the standardised coefficient is referred to as the beta weight, which is provided in the beta column. These metrics rate the predictor variables based on their involvement, regardless of sign, in explaining the impact of solar radiation on the highest contributing value of 0.922. Ambient humidity has the lowest contributing value of 0.067 as a predictor. to explain output power efficiency. In order to check the accuracy of the predictable models in this present study, the four models (Temperature model, humidity model, solar radiation model and Temp-Hum-rad combined model) were used to predict the output power efficiency datasets by using the Microsoft excel software package. The predicted output power efficiency datasets of each model were then trained on the Levenberg-Marquardt algorithm machine learning with the aid of MATLAB-2017b software package to about 70% (1222) of the total (1746) datasets with the original output power efficiency for about 1000 iterations for the period of 7 seconds for each iteration.

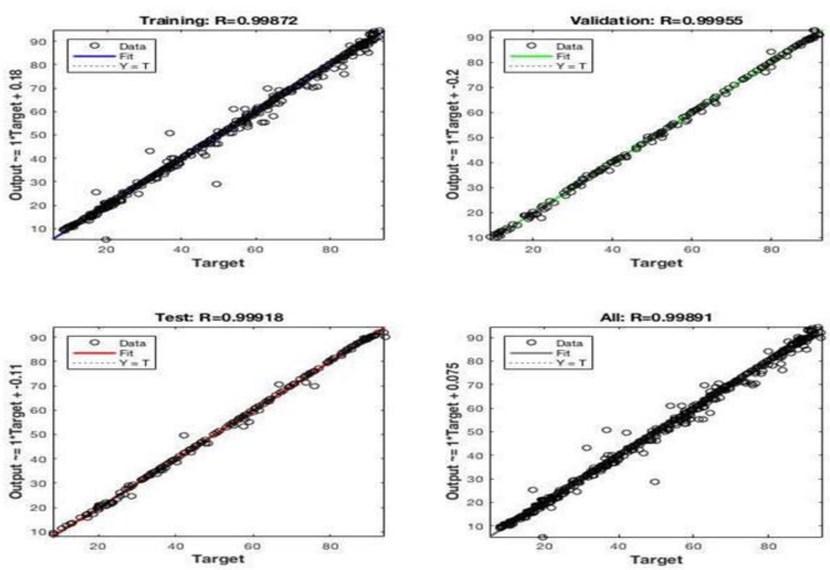

Figure 11: The scatter plots (a) Training (b) Testing (c) Validation (d) Combination of the multiple regressions of Temperature, humidity and solar radiation model trained on Levenberg-Marquardt algorithm.

The overall correlation coefficient of temperature model, humidity model, solar radiation regression model and multiple regression model of temperature, humidity and solar radiation were 0.73709, 0.69393, 0.99678 and

0.99891, respectively. Figure 11 show a virtually perfect straight-line correlation of +1, indicating a positive association between the two variables [36]

6. CONCLUSIONS

Based on comprehensive investigations and considering the results of practical experiments conducted on three similar samples of 250-watt photovoltaic solar panels installed at three different tilt-angles of 0, 6.8 and 16.8 degrees to the horizontal at the faculty of Engineering at the University of Nigeria, Nsukka for 90 days, the optimal tilt angle for the photovoltaic solar panel at the present location was determined. The experiments showed that: The optimum tilt-angle of a fixed photovoltaic solar panel is crucial during installation to maximise the panel's output power efficiency. A panel installed at a fixed angle for a year loses 19.73% of its output power efficiency each month. The best fixed tilt-angle is established weekly because photovoltaic solar panels should be tilted monthly or seasonally to maximise output power efficiency. Table 5 rates this study's regression models. From the tabulated findings, the humidity model had the lowest correlation coefficient, while the combination model had the highest. To improve photovoltaic solar-panel module performance, this study examined temperature, sun radiation, and relative humidity. The Temperature model can only predict energy lost in the photovoltaic solar panel, not output power efficiency, because it was proven early that any increase in temperature beyond 25^0C would decrease the solar panel's output power and efficiency. The solar-radiation model alone has a strong correlation coefficient of 0.99678, indicating that solar radiation is more important to photovoltaic solar panel performance than other climatic parameters like temperature and relative humidity. However, without adding temperature and relative humidity, the solar radiation model may not forecast correct numbers for output power efficiency. Based on the preceding explanation and a specific evaluation of the combination model, which considered all three factors, the correlation coefficient is 0.99891. This model is closer to 1.0000 than the other three. The combined model predicts photovoltaic module output power efficiency better than the other three models.

For the highest output power efficiency of photovoltaic solar panels in Nsukka and its surrounds, Nigeria, the ideal tilt-angle is 0 degrees in July and August. Photovoltaic solar panels erected at tilt-angles greater than 0 degrees to the horizontal in July and August in Nsukka, Nigeria, will lower the output power efficiency by 9.11 to 19.73%. For optimal output power efficiency, photovoltaic solar panels should be installed at Nsukka, Nigeria at 6.8 (angle of latitude) degrees to the horizontal in September. In September in Nsukka, Nigeria, photovoltaic solar panels positioned below 6.8 degrees to the horizontal will decrease electricity efficiency by 5.4%.Photovoltaic solar panels erected at a tilt-angle over 6.8 degrees to the horizontal in September at Nsukka, Nigeria, will decrease output power efficiency by 19.01 %. In Nsukka, Nigeria, photovoltaic solar panels installed at a tilt-angle between 0 and 6.8 degrees to the horizontal in July to September have a maximum output power efficiency of 96.17% when the solar radiance is 1222 W/m2, the average operating temperature is 32 degrees, and the relative humidity is 47%. The negative coefficient of temperature on open-circuit voltage reduces it by 6.38% to 8.34%. Temperature increases output current by 1.3% to 1.69%, Temperature decreases power production by -8.31% to -10.87%. Relative humidity indirectly affects photovoltaic solar panel output power efficiency. Photovoltaic solar panels lose output power efficiency when relative humidity rises.If the humidity is above 50%, efficiency may drop to 15%–30%, affecting system performance. Solar radiation increases output current, which boosts photovoltaic solar panel power efficiency. Power values are optimum at low temperature, low relative humidity, and high sun radiation. $\eta = -14.352 + 0.648XT + 0.093XH + 0.075XL$ regression model can estimate the output power efficiency of photovoltaic solar panels erected at 0 to 6.8 degrees to the horizontal in Nsukka, Nigeria. This study's correlations may be relevant in climates like Nsukka's.

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