Abstract—This study presents second-order polynomial, exponential, and power models for estimating diffuse solar radiation in Lagos, Nigeria. The estimation was based on a correlation between clearness index (KT) and diffuse fraction (Kd). The models were compared with the widely applicable models. The accuracy of estimation of these models is tested by calculating the mean percentage error (MPE), mean bias error (MBE), and root mean square errors (RMSE). Statistical indices show that all models produce reasonably good estimates of diffuse solar radiation. The lowest values of -0.010%, 0.048kWh/m²/day, and -0.001 kWh/m²/day for MPE, RMSE, and MBE respectively are obtained for the second-order quadratic model. The study found that the developed model produced the best estimates of diffuse solar radiation.

Keywords—Diffuse solar radiation, clearness index, diffuse fraction, solar radiation, Lagos.

I. INTRODUCTION

The utilization of renewable energy resources has increased largely in the last years owing to the ever increasing need for electrical energy, the limited fossil fuel resources needed for generation of conventional electrical power, and the global environmental concerns over the use of fossil fuels. Solar energy is one of the most promising renewable sources. It is environmentally friendly, plentiful and easy to utilize. A detailed and accurate knowledge of the local solar radiation is essential for the optimum design and study of solar energy conversion system.

The global solar radiation can be divided into two components: diffuse solar radiation, which results from scattering caused by gases in the Earth’s atmosphere, dispersed water droplets and particulates; and direct solar radiation, which have not been scattered. Global solar radiation is the algebraic sum of the two components.

[3] proposed a correlation given by;

\[ \frac{H_d}{H} = 1.390 - 0.027K_T + 5.53K_T^2 - 3.108K_T^3 \]

where \( H_d \) is the diffuse solar radiation (kWh/m²/day), \( H \) is the global solar radiation (kWh/m²/day), and \( K_T \) is the clearness index. \( K_T \) is calculated as [1]

\[ K_T = \frac{H}{H_0} \]

where \( H_0 \) is the extraterrestrial solar radiation on a horizontal surface (MJ/m²/day). The extraterrestrial solar radiation is the solar radiation outside the atmosphere incident on a horizontal surface, and is given by the following expression [7].

\[ H_0 = \frac{24 \times 3.6 \times 10^{-3} \times I_{sc}}{\pi} \left( 1 + 0.033 \cos \frac{360}{365} \cos \delta \cos \omega + \omega \sin \delta \right) \]

where \( I_{sc} \) is the solar constant (1367W/m²), \( J \) is the Julian day number, \( \delta \) is the latitude of the location, \( \delta \) is the solar declination angle given as

\[ \delta = 23.45 \sin \left( \frac{360 \times 248 + J}{365} \right) \]

and \( \omega \) is the sunset hour angle given as

\[ \omega = \cos^{-1} \left( -\tan \delta \tan \delta \right) \]
The following models were proposed for the study area, besides the established models in order to get the best model for the study area.

A second-order polynomial model is given as:

$$K_d = a + bK_T + cK_T^2$$  \hspace{1cm} (7)

The exponential model is of the form:

$$K_d = e^{K_T}$$ \hspace{1cm} (8)

The power model is expressed as

$$K_d = e^{K_T^f}$$ \hspace{1cm} (9)

where a, b, c, d, e, and f are empirical constants.

### III. Evaluation Parameters

The performance of each of the models was tested statistically by calculating the mean bias error (MBE), root mean square (RMSE) and the mean percentage (MPE) errors and other statistical concepts. These indicators are defined respectively as:

$$MBE = \frac{\sum (H_{d_{cal}} - H_{d_{meas}})}{n}$$ \hspace{1cm} (10)

$$RMSE = \sqrt{\frac{\sum (H_{d_{cal}} - H_{d_{meas}})^2}{n}}$$ \hspace{1cm} (11)

$$MPE = \frac{\sum \left(\frac{H_{d_{meas}} - H_{d_{cal}}}{H_{d_{meas}}} \times 100\right)}{n}$$ \hspace{1cm} (12)

where $H_{d_{cal}}$ and $H_{d_{meas}}$ are the respective $i^{th}$ estimated and the observed mean values of diffuse solar radiation, and $n$ is the total number of observations.

In general a low RMSE and MBE are desirable while positive MBE indicates overestimation. The MPE test gives long term performance of the examined regression equations, a positive MPE values provide the averages amount of overestimation in the calculated values, while the negative values gives underestimation.

### IV. Results And Discussion

The Figure 1 shows the behavior of clearness index ($K_T$) and the ratio of diffuse to global solar radiation ($K_d$). The dip in the value of $K_T$ in the months of June to September is in accordance with the high value of $K_d$ for the same months. During these periods the location is under heavy rainfall. In rainy season, more clouds cover the sky, which in turn reduce the intensity of solar radiation reaching the earth’s surface. From the observation of clearness index and ratio of diffuse to global solar radiation, the maximum values of clearness index occurred during dry season. This is the favorable condition for solar energy utilization. High values of clearness index indicate great availability of solar radiation during dry season.

The diffuse solar radiation was determined from measured horizontal data using five models and compared with the observed data. The results of the regression analysis of equations 7, 8, and 9 are illustrated in equations 13 – 15 as follows:

#### Second-order Polynomial Model

$$K_d = 0.9676 - 1.2654K_T + 0.3199K_T^2$$ \hspace{1cm} (13)

#### Exponential Model

$$K_d = 1.2313e^{ -2.2K_T}$$ \hspace{1cm} (14)

#### Power Model

$$K_d = 0.2X_T^{-1.412}$$ \hspace{1cm} (15)

Figures 2 – 6 shows the correlation between the estimated and observed values of the diffuse solar radiation. Figure 7 shows a comparison of the estimated values of monthly mean diffuse solar radiation obtained using (13) – (15) with those from existing models.

For the Page model, the correlation of coefficient of 0.991 exists between the diffuse fraction, clearness index. The coefficient of determination of 0.982 implies 98.2% of diffuse fraction can be accounted by clearness index. The MPE, RMSE, and MBE values of -4.800%, 0.129kWh/m²/day, and 0.104kWh/m²/day respectively were observed for the Page model. The coefficient of determination of 0.978 implies 97.8% of diffuse fraction can be accounted for in Liu and Jordan model. The model gave values of 9.336%, 0.201kWh/m²/day, and -0.194 kWh/m²/day for the MSE, RMSE, and MBE respectively. For the second-order polynomial model, the coefficient of determination of 0.982 implies 98.2% of diffuse fraction can be accounted for using the model. The MPE, RMSE, and MBE values of -0.010%, 0.048kWh/m²/day, and 0.012kWh/m²/day respectively were observed for the second-order polynomial model. The exponential model gave the coefficient of determination of 0.980 which implies 98% of diffuse fraction can be accounted for using the model. The MPE, RMSE, and MBE values of 0.012%, 0.051kWh/m²/day, and -0.001kWh/m²/day respectively were observed for the exponential model. The coefficient of determination of 0.971 implies 97.1% of diffuse fraction can be accounted for using power model. The Table 1 shows the statistical results of the five models. It can be observed from the Table 1 that lowest values of -0.010%, 0.048kWh/m²/day, and -0.001 kWh/m²/day for MSE, RMSE, and MBE respectively are obtained for the second-order quadratic model. The results were in agreement with the results of [4].

The test of MBE provides information on the long-term performance of the proposed models. It was observed that the second-order polynomial and exponential models have the lowest MBE which implied that the models have a good long term performance. The test of MPE also gives long term performance of the examined models. The lowest MPE value was observed for second-order polynomial model while the maximum MPE values was obtained from the Liu and Jordan estimates. The test of RMSE provides information on the short-term performance of the proposed models. Low RMSE values are desirable [2]. The second-order polynomial model has the lowest RMSE value while Liu and Jordan model has the highest RMSE value. This indicates that the second-order...
polynomial model has the best short-term performance for the study location. The result of this comparison is illustrated in Figure 7.

Fig. 1 The behaviour of the Kt and Kd for Lagos

Fig. 2 Comparison of the predicted and observed monthly average of diffuse fraction of global solar radiation using Page model

Fig. 3 Comparison of the predicted and observed monthly average of diffuse fraction of global solar radiation using Liu and Jordan model

Fig. 4 Comparison of the predicted and observed monthly average of diffuse fraction of global solar radiation using second-order polynomial model

Fig. 5 Comparison of the predicted and observed monthly average of diffuse fraction of global solar radiation using exponential model

Fig. 6 Comparison of the predicted and observed monthly average of diffuse fraction of global solar radiation using power model
**V. CONCLUSION**

The study evaluated the diffuse solar radiation models by Liu and Jordan, Page, and Falayi et al. A second-order polynomial and exponential models were also developed for the study location. The performances for the models have been done in terms of widely used statistical indicators, Mean Percentage Error (MPE), Mean Bias Error (MBE), and Root Mean Square Error (RMSE). It was observed from statistical indicators that second-order quadratic model provided reasonably high degree of precision in the forecast of monthly average of diffuse solar radiation on the horizontal surfaces. The results were in agreement with the results of [4s]. This work will set a very strong platform for the energy planners to utilize the solar energy potential for Lagos.

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