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Optimal sizing of Distribution Transformer using Improved Consumer Load Forecasting

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ABSTRACT: *The study investigated the sizes and load percentage of distribution transformers inElekahia, Stadium Road and Rumukalagbor zones all in Port Harcourt city metropolis of Nigeria. The optimal sizing of the distribution transformers was demonstrated with the different loading conditions: under loading, optimal loading and overloading.The study reveals that not too many distribution transformers are overloaded in the selected zones. A total of two transformers were found to be overloaded, eleven transformers were found to be under loaded and nineteen transformers were found to have optimal loading. Furthermore, the study recommends installation of more transformer units in the distribution network where load consumption is very high in order to avoid overloading the existing distribution transformers. In addition, the Fourier series model was adopted for forecasting long-term future load consumption on the distribution transformers. The simulation was carried out on Matrix Laboratory software (MatLab) platform. The Root Mean Square Error (RMSE) parameter was used in the analysis to study the model performance and forecasting precision. The model was tested and found useful for forecasting the electric load consumption from 2018 to 2030. The validation of the model results in high degree of accuracy and dependability as the original data collected from the Port Harcourt Electricity Distribution Company (PHEDC) was compared with the forecasted values. The RMSE result for the different zones reveals that Stadium Road zone (0.002193) has the lowest error, followed by Elekahia zone (0.03427) and then, Rumukalagbor (0.1666)zone. The result of this work would help the PHEDC to provide more reliable services to consumers and make adequate planning for the future load consumption.*

KEYWORDS:*Distribution Transformer; Overload,Load Forecasting; Fourier series;*

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I. INTRODUCTION

The distribution transformer is one of the major power equipment which connects the power supply to the consumer. The rapid growth in electric energy consumption due to increase in the use of electric appliances or machines has become a major concern in the distribution network as this has resulted in overloadingsome distribution transformers. Over time, among other factors, transformer failure in the distribution network has been majorly attributed to overload of the transformer. The failure which occurs when the capacity of the transformer is eventually exceeded with load and this has proven that the loading of distribution transformers has not been given proper attention and it is quite difficult to tell how consumption rate will rise to in the nearest future. To this end, distribution transformers in Elekahia, Stadium Road and Rumukalagbor zones within the city of Port Harcourt would be studied with much interest in the optimal sizing of the distribution transformers as the consumer load varies with time and the transformer load record would be used to forecast the future load consumptions.

II. LITERATURE REVIEW

The distribution transformer capacity is rated in kilovolt-amp kVA. It is expected that the load connected to the transformer shouldn't exceed the rated value so as to avoid overloading. Short, (2003) utility has found it more economical to overload an existing transformer than to install a new one. Hameedullah (2014), Distribution Transformers are generally not recommended for continuous overloading. Hachimenum, et al (2016) published that while load on transformers grows continuously, the installation of new transformers keeps declining.

Chakrabarti and Halder, (2008) defined load forecasting as a method of estimating the load to the future from the available past data. Ravi, (2011) in a like manner states that load forecasting is a systematic way of projecting a future event using a past data. Feinberg, et al (2003) presented that in the operation and planning of any utility company, choosing an adequate model for electric load forecasting is essential. Eugene, (2012) states that load forecasting is important in estimating the consumer energy consumption as it affects the performance of the transformer. Stating the advantages, Steven (2016), added that load forecast enables the utility company to make adequate plans for the future consumption.

There are several available forecasting techniques being used for different purposes. Artificial neural networks (ANNs) have been applied in numerous power system to solve problems in areas like protection, planning, control, analysis, load forecasting, fault diagnosis and so on. In a study carried out by Uhunmwangho and Omorogiuwa (2015) to develop ANN based technique for diagnosing and predicting internal fault conditions of oil filled distribution transformers, ANN was found useful.

The usual autoregressive integrated moving average (ARIMA) models developed by Box and Jenkins (1970) has been extensively used in modelling.According to a study by Hongzhan et al, (2012)**,** theAutoregressive Integrated Moving Average (ARIMA) is only suited for the linear part of the load data.

Maged and Elsayed (2017) examined the adaptive Fourier series in enhancing the prediction accuracy of ARIMA and ANN models. The experimental results show that the adaptive Fourier series enhances the prediction power of the ARIMA and ANN models. Tolstov and Silverman (2014)stated that Fourier series model was originally developed to solve the heat equation problems. However, it has found different applications in other fields of study in problem solving. Ejiko and Oladebeye (2015) in predicting the sales volume of a manufacturing firm; applied the Fourier series forecasting model which was developed, tested and validated with the actual sales data and the result had high correlation with the actual data which confirms accuracy, reliability and dependability. For this reason, the Fourier model was proposed for products with seasonal fluctuations.

III. MATERIALS AND METHODS

The study employed the curve fitting method using Fourier series to model and analyse the historical load (the distribution transformer readings) data which were obtained from the Port Harcourt Electricity Distribution Company PHEDC substation, Rumuola, Port Harcourt as shown in Table 3.1. The method mathematically constructs a function and describes a curve that has the best fit for a given dataset**.**

Table 3.1: Historical Load Data

	ELEKAHIA	STADIUM ROAD	RUMUKALAGBOR
YEAR	LOAD CONSUMPTION (KW)	LOAD CONSUMPTION (KW)	LOAD CONSUMPTION (KW)
2008	1291.33	3483.00	2303.67
2009	1301.33	3696.00	2151.67
2010	1520.67	4029.33	2435.33
2011	1769.67	4015.00	2926.67
2012	1740.00	4506.33	2635.67
2013	1666.67	4332.67	3166.00
2014	1714.00	4426.67	3015.00
2015	1880.33	4955.00	3265.00
2016	1761.67	4273.67	3228.67
2017	1479.00	4533.67	3427.00

Curve fitting is conducted using the historical data for each of the three zones onMatLab platform and same was used in the development of the algorithm to call up the Fourier model in order to forecast the future load consumption from 2018 to 2030. The load data from 2015 to 2017 were used to validate the forecasting result accuracy.

Mathematically, the Fourier series model is given as;

$$f(x) = a_0 + \sum_{n=1}^{\infty} (a_n \cos xw + b_n \sin xw) \quad (1)$$

Where;
f(x): Dependent variable (transformer load consumption in KW)
x : Independent variable (Time in Years)
w : Periodicity and,
a_0, a_n and b_n are the Fourier coefficients of the model.

3.1. Performance metric

The choice of using a particular metric will depend on the nature of data. For very large variation in data, the Mean Absolute Percentage Error (MAPE) metric is recommended otherwise the Root-Mean Squared Error (RMSE) metric is just sufficient. The Root Mean Squared Error (RMSE) is a common metric used to measure accuracy for continuous variables. RMSE tells how concentrated the data is around the line of best fit or how spread out from the regression line data points are. A lower value of RMSE indicates a better fit. Mathematically, it is given as

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} = \sqrt{MSE} \qquad (2)$$

$\hat{y}_i$ is the predicted value from the fit
y_i is the observed data value
n is the sample size

3.2. The Optimal Sizing of Distribution Transformers

First, the sizes and the percentage of load connected to each of the distribution transformers in the selected zones are investigated. With this investigation, it is easy to know whether a particular transformer of any size is either under loaded or overloaded.

The optimal transformer sizing is achieved by matching the proper transformer capacity with the amount of load connected to that transformer. To realize this, the following steps are carried out.

$$\mathbf{Average transformer reading} = \frac{\text{Red phase} + \text{Yellow phase} + \text{Blue phase}}{3} \quad (3)$$

$$\mathbf{Current} = \frac{\text{Power(KVA)}}{0.415\text{x}\sqrt{3}} \quad (4)$$

$$\mathbf{Load} = \frac{\text{Average transformer reading}}{\text{Current}} \text{x } 100\% \qquad (5)$$

Status: under loading (0-40%), optimal loading (41-79%) or overloading (80% and above).

IV. RESULTS AND DISCUSSION

4.1. Distribution Transformers Optimal Sizing Result

The optimal sizing of the distribution transformers was realized by carefully matching the calculated percentage load of the transformers to the different loading conditions: under loading (0-40%), optimal Loading (41-79%) and overloading (80% and above). This is demonstrated for just the recent year (2017).

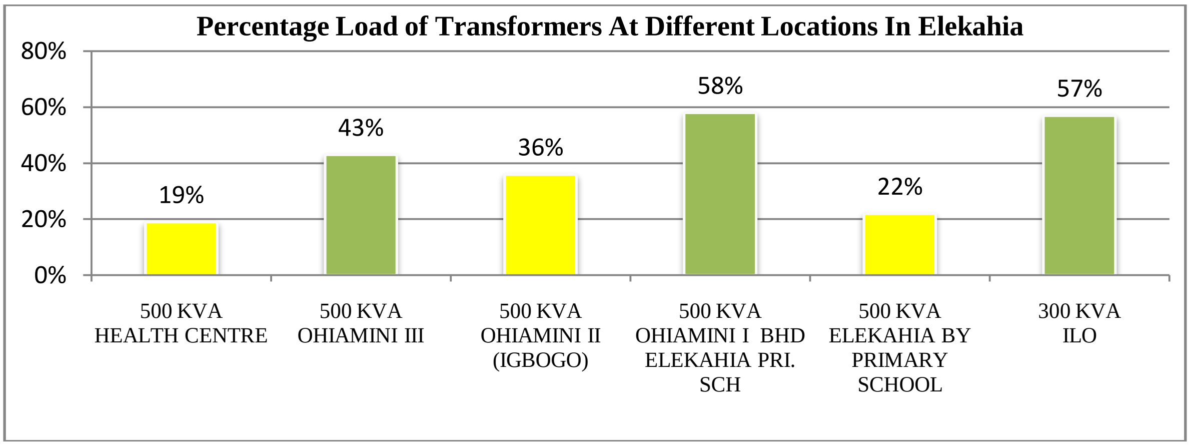

Figure 4.1: Percentage load of transformers at different locations in Elekahia Zone

The optimal sizing result for Elekahia zone shows that out of six distribution transformers in operation, three are under loaded, three are optimally loaded and no one is overloaded.

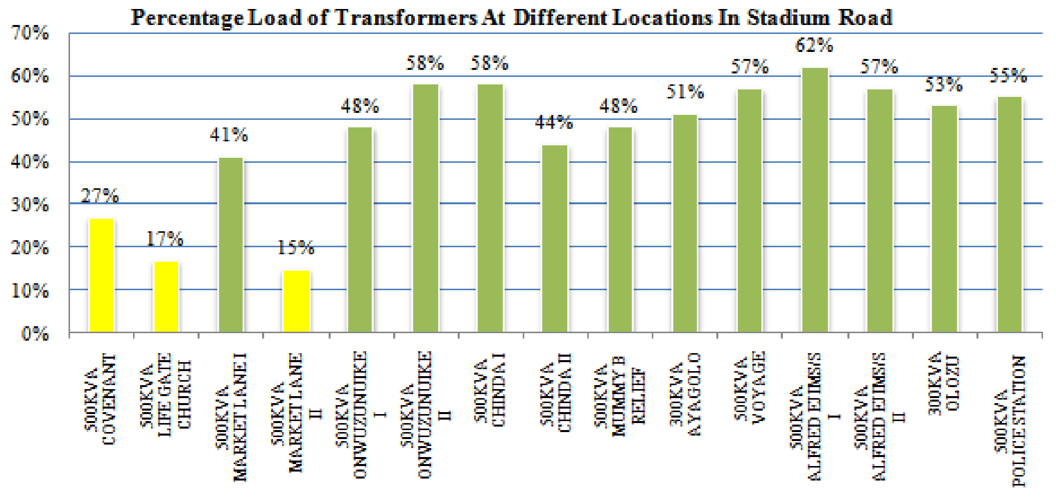

Figure 4.2: Percentage load of transformers at different locations in Stadium Road

It was observed that fifteen distribution transformers are in operation in Stadium Roadzone, three are under loaded, twelve are optimally loaded and no one is overloaded.

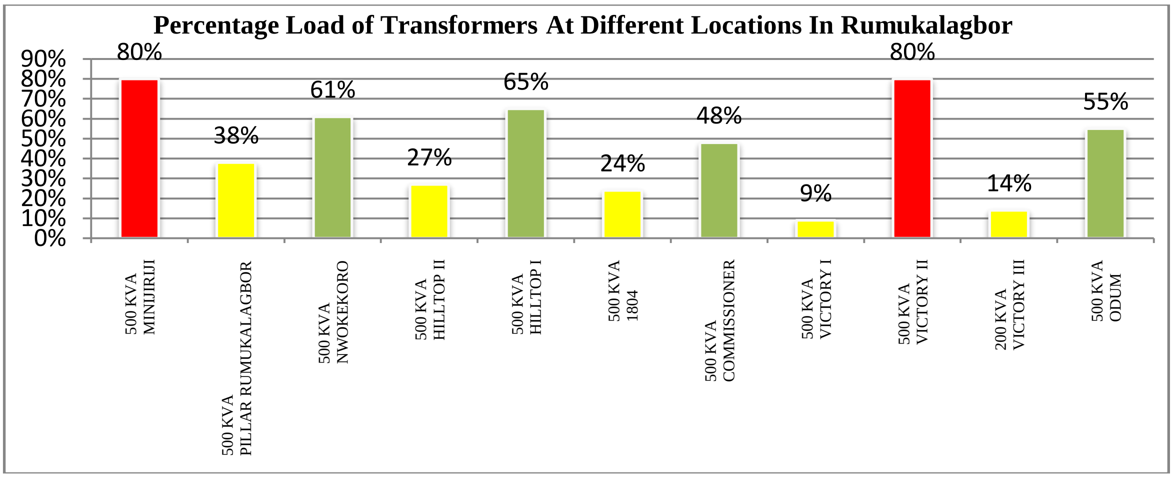

Figure 4.3: Percentage load of transformers at different locations in Rumukalagbor Zone

It was observed that out of eleven operational transformers in Rumukalagbor zone, five distribution transformers are under loaded, four are optimally loaded and two are overloaded.

From the range of conditions given, underutilized or under loaded transformers can be optimally sized as follows:

i. Adding or connecting more load to the under loaded transformer
ii. Replace a smaller capacity with an adequate capacity
iii. Integrate two or more feeders to a transformer

While over utilized or overloaded transformers can be optimally sizedas follows:

i. Reduce Load
ii. Introduce/install a relief transformer
iii. Replace transformer with a larger capacity

Carrying out the optimal sizing processes above, a distribution transformer can actually and regularly be sized to the demanded load.

4.2. Graphical Performance of the Forecasted Load

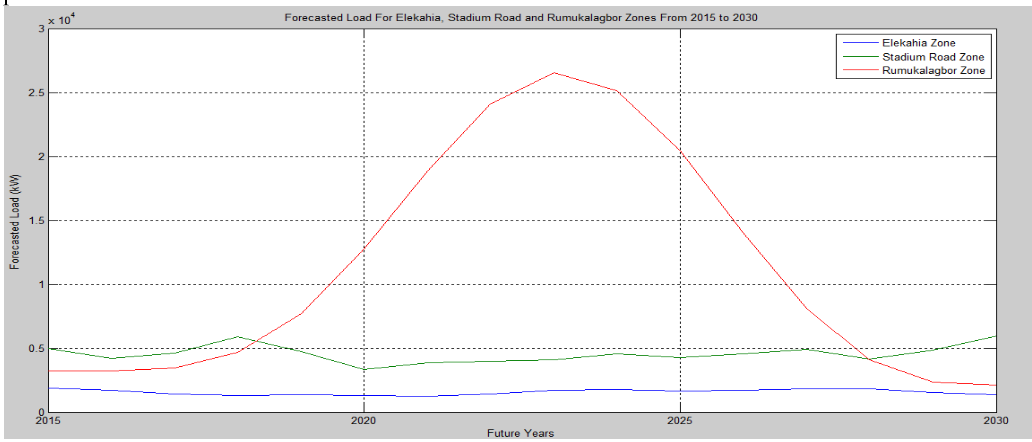

Figure 4.4: Forecasting performance with Fourier series for the three zones

It was observed in Elekahia zone that there will be no much rise in load consumption which implies that the transformers operating within this zone will likely be operating optimally for the period of consideration. For Stadium Road zone, consumption will greatly drop from 2018 to 2020. Again, there will be a drastic rise in consumption up to 2030. There is the likelihood that some transformers within this zone will experience overloading especially, in 2018 and 2030 respectively. Also for Rumukalagbor zone, there will be a gradual rise in load consumption up to 2023 then continuous drop in consumption down to 2030. As a result, a number of distribution transformers operating within this zone would likely be overloaded for this period of time.

4.3. Evaluating the Goodness of Fit of the Forecasted Results

The values of RMSE reveals by comparison that, Stadium Road (0.002193) has the lowest error value, followed by Elekahia Zone with (0.03427) and finally Rumukalagor Zone (0.1666) which means that the load forecasting gives minimal error values which indicates a very high level of accuracy.

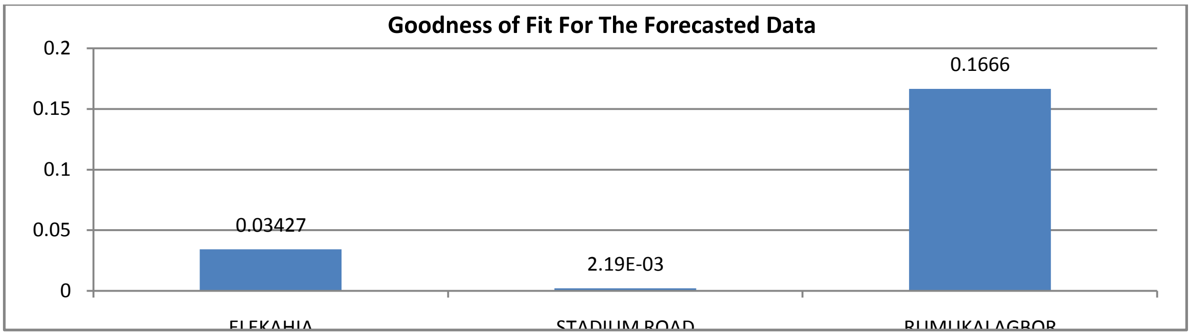

Figure 4.5: Forecast accuracy in terms of RMSE value

4.4. Error Analysis and Validation

The forecasted result was validated for the years 2015, 2016 and 2017 since the data for these years are already available as presented in Table 3.1.

Table 4.1: Model Error Analysis

	Elekahia Zone			**Stadium Road Zone**			**Rumukalagor Zone**		
Years	**Actual Values**	**Forecasted Values**	**Error**	**Actual Values**	**Forecasted Values**	**Error**	**Actual Values**	**Forecasted Values**	**Error**
2015	1880.33	1874.40	5.93	4955.00	4946.60	8.40	3265.00	3235.30	29.70
2016	1761.67	1738.70	22.97	4273.67	4224.10	49.57	3228.67	3224.20	4.47
2017	1479.00	1449.50	29.50	4533.67	4630.70	-97.03	3427.00	3434.60	-7.60

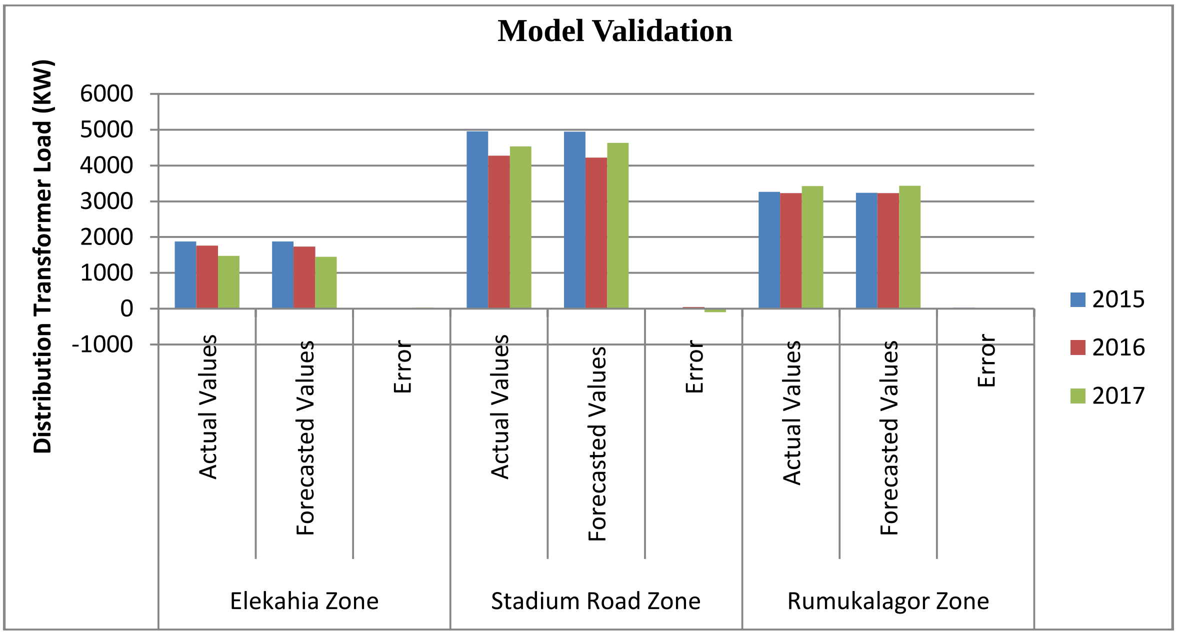

Figure 4.6: Model Error Analysis

By comparison, it can be observed that there is no significant difference between the actual and forecasted load. This signifies that a small error was recorded in the forecasting model which by implication, a high level of accuracy has been achieved. It can be deduced that the future load consumption as forecasted would follow a similar pattern based on the model used.

V. CONCLUSION AND RECOMMENDATIONS

This study investigated the sizes and loading capabilities of the distribution transformers in Elekahia, Stadium Road and Rumukalagbor zones all in the city of Port Harcourt and also demonstrated steps or processes in which a distribution transformer can actually and regularly be sized to the demanded load. The optimal sizing of the transformer result shows that a total of two transformers were found to be overloaded, eleven transformers were found to be under loaded and nineteen transformers were found to have optimal loading. Nonetheless, the study recommends installation of additional transformer units in order to reduce the loads on the existing overloaded transformer units within the network in order to improve the distribution transformers expectant service life and efficiency.

The forecast result returned a significantly reduced error which indicates that a precise, effective and reliable forecast has been done. As a result, the forecasted result obtained would serve as a guide and practical tool for policy makers and the utility company (PHEDC) to properly plan ahead on the capacity of the distribution transformers and the network expansion so as to adequately supply consumers with the required energy since there is now an understanding of the future load consumption or load demand.

Statement of Competing Interests

The authors declare that no conflicting interests exist.

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