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Numerical Technique Based Model Approach to Electricity Growth Forecasting: Ilorin PHCN District as Sample

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Abstract - **Many researchers have expressed some concerns in the past about possible development of forecasting model for accurate prediction of electricity growth in Nigeria. This paper has employed numerical technique and a set of mathematical rules which are used as building blocks for the purpose of predicting the growth of electricity. Power Holding Company of Nigeria has problems with generation, with distribution and even with billing. Over the years, electricity supply had been deficient in quality, quantity, accessibility and reliability. The focus therefore, is to discuss and highlight the concept of mathematical modeling and applying this model to solve the problem connected with inaccurate power data. The paper aims in using Dos-based software package to simulate model of electricity growth in Nigeria, Although two models of forecast were used but a modified linear regression method gave better and more accurate result. In this case data from Ilorin PHCN district was used to demonstrate the effectiveness of the model. The evaluation of the data gave a confidence level of 98% for omuaran. Correlation of data obtained from 'old' method with the "actual" produced figures of 64% and 94% respectively. Evidently accurate power forecasting will lead to sound energy management, capital and operational expenses.**

Keywords – **Electricity Growth, Energy, Forecasting, Load Demand, Power Consumption.**

I. Introduction

Electrical energy occupies a place of central importance in terms of its relative contribution to the national socioeconomic goal of raising productivity and therefore, higher living standards for the citizen [7,16]. It is one of nature's formidable and most productive forms of energy. However, many electric utilities are finding it difficult to keep pace with the ever-increasing energy needs. This is very so in Nigeria where electricity demand has always outstripped the supply [10, 11, 12]. It has not been possible to meet up with even the domestic need for many decades. There is energy crisis in Nigeria.

Study has shown that there appears to be no near accurate and reliable forecast of power consumption and demand in Nigeria. In view of this state of uncertainty, it has become expedient that a more reliable forecast of energy demand for the near and distant future be established so that it can guide the energy policy makers in undertaking aggregate planning.

A research into future demand for electricity in Nigeria [6] predicted that electricity demand in Nigeria in 2030 would be 160,000 MW (subject to Nigeria meeting Millennium Development Goals [MDG]) against current demand of 4,000 MW. Their estimate appears some how dilated.

Also, Box-Jenkins oriented forecasting models have been widely used successful in different context by researcher to forecast certain phenomenon of interest. For example, Sahu reported the successful forecast of yield behaviour of potato, rice, mustard and wheat under immigrating [14]. Wrong et al applied Box-Jenkins forecasting model to estimate cost of capital [15]. Furthermore, Badri et. al applied Box-Jenkins among other decision support system for electricity peak load forecasting [4]. Also, Abdul and Ringwood et al applied Box-Jenkins Model to forecast monthly energy electricity consumption in Eastern, Saudi Arabia and Ireland respectively [1, 13]. It is evident from this foregoing literature that Box-Jenkins time series model is widely used in load forecasting.

The aim of this paper is to use a DOS-based software package to simulate the model of electricity growth in Nigeria for both short term and long term forecasting [2, 11]. The goal has become very significant in view of the energy crisis that Nigeria has found herself entangled in. With a reliable prediction of future power demand, budgeting for upgrading and establishment of new generation facilities, the intractable electricity supply problems would be solved permanently.

II. Mathematics of the Modified Linear Regression

A statistical model is a mathematical model which relates one variable with one or more variables in the form of assumptions and hypotheses. All the variables concerned have well-defined statistical properties.

Mathematical modeling and solutions on digital computers constitute an extremely viable approach to system analysis and planning studies for a modern day power system with its large size, its complex and integrated nature [5, 11].

The mathematical concept of a straight line establishes the statistical technique for linear regression method.

A straight line equation is normally given as

$$y = a_0 + a_1 x \qquad \text{………..} (1.1)$$

In order to determine a curve which fit the equation, the number of points required is equal to the number of constants in the equation.

For example a parabola

$$y = a_2 x^2 + a_1 x + a_0 \qquad \text{………}(1.2)$$

is determined by three points.

In particular, given any two points, one can find exactly one straight line passing through the two points for (1.1).

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Similarly given any three points, there is a desired parabola as in (1.2). We may however want a straight line ‘approximately’ through three points, or a parabola “approximately” through four points. Equation (1.1) belongs to linear regression method while (1.2) is the non-linear regression method [8].

There are several ways to carry out the construction which approximates given data, a process called ‘curve fitting’. Assume that we have a set of n numbers say (x1,x2 …xn) to be replaced by a single number x , we first form the differences
between the single number x , and each of the set numbers; i.e.

$$(\bar{x}-x_i) \quad \text{for } i=1,2,......n \qquad .... (1.3)$$

Let the sum of the square of the differences be

$$S=\sum_{i=1}^{n}(\bar{x}-x_i)^2 \qquad .... (1.4)$$

i.e. $$S=n\bar{x}^2-\left(2\sum_{i=1}^{n}x_i\right)\bar{x}+\sum_{i=1}^{n}x_i^2 \qquad ...... (1.5)$$

To minimise S, and since S is a function of a single variable $\bar{x}$ we can find the minimum by making $\frac{\partial S}{\partial x}=0$

i.e. $$\frac{\partial S}{\partial \bar{x}}=2n\bar{x}-2\sum_{i=1}^{n}x_i=0 \qquad .... (1.6)$$

and $$\frac{d^2S}{\partial \bar{x}^2}=2n\succ 0$$

Represents a minimum

Thus $\bar{x}=\frac{\sum_{i=1}^{n}x_i}{n}$ is the desired value of $\bar{x}$.

It can be observed that the arithmetic average of x_i minimizes S. We say that $\bar{x}$ is the *best fit to the data in the sense of least squares.* It is now possible to use the method of least square to determine the constants a0, a1, and a2 in equations 1.1 and 1.2.

2.1 Old Linear Method

If we have a set of data (x1,y1) ……… (xn,yn) where y1 may represent the observed peak power at the times t, we now want to find the linear curve of the form

$$y=ax+b \qquad .... (1.7)$$

which best (in the sense of least squares) approximates this data. Such a line is the linear regression [8, 11].

For a given xi we have an estimate of y from the equation of the line $y=ax_i+b$.

Then we seek for a and b so that as to minimises,

$$S=\sum_{i=1}^{n}(b+ax_i-y_i)^2 \qquad .... (1.8)$$

Necessary conditions are:

$$\frac{\partial S}{\partial a}=0=\frac{\partial S}{\partial b} \qquad .... (1.9)$$

which leads to

$$2\sum_{i=1}^{n}(b+ax_i-y_i)=0........................(1.10)$$

and

$$2\sum_{i=1}^{n}(b+ax_i-y_i)x_i=0...........(1.11)$$

We can re -write these as

$$\left(\sum_{i=1}^{n}x_i\right)a+nb=\sum_{i=1}^{n}y_i..............(1.12)$$

$$and \quad \left(\sum_{i=1}^{n}x_i^2\right)a+\left(\sum_{i=1}^{n}x_i\right)b=\sum_{i=1}^{n}x_iy_i...(1.13)$$

Ho

$$a=\frac{n\Sigma x_iy_i-\Sigma x_i\Sigma y_1}{n\Sigma x_i^2-(\Sigma x_i)^2}..........................(1.14)$$

$$b=\frac{\Sigma x_i^2\Sigma y_i-\Sigma x_iy_i\Sigma x_i}{n\Sigma x_i^2-(\Sigma x_i)^2}......................(1.15)$$

The constants *a* and *b* can be evaluated from energy data obtained from previous years (or historical data) in each of the service areas under investigation.

2.2 Modified Linear Regression Method

In order to develop a more efficient method in building a model for load forecasting, let us consider a system of any finite number of linear equation in any finite number of variables.

Specifically we shall take a linear equation in 2 variables of the form

$$Y=a+a,x+a_2,x_2 \qquad .... (1.16)$$

where a_0, a_1 and a_2 are real numbers and x_1 and x_2 are two variables. Evidently equation (1.16) is more complete than equation (1.1) since equation (1.16) has an addition variable in form of

$$y=a_2x_2 \qquad .... (1.17)$$

For a sequence $f_n(x)$, i.e. a multi-linear function of the form

$$f_n(x)=a_0+a_1x_1+a_2x_2++a_3x_3+....a_nx_n \quad .. (1.18)$$

We expect the approximation to improve as n increases. In general we want a polynomial of degree which has its first derivatives equal to the first n-derivation of

$$y=f(x) \qquad .... (1.19)$$

Since equation (1.16) is an approximation of equation (1.18), we can therefore here build a forecast model on equation (1.16) which should be better and more accurate. Therefore the forecast model built on equation (1.16) is better than one built on equation (1.1). In this modified linear regression model of equation (1.16), y might represents the system peak demand in MW. [11]

2.3 Modified Multi-Regression Algorithm

Now to the modified multi-regression algorithm, recall the multi-linear equation (1.16) such as to minimize it. The principle involved is the same; computation of differences, differentiation of the sum of the squares of these differences, and calculation of the constants from the system of equations produced by setting the partial derivatives equal to zero.

Thus:

$$S = \sum_{i=1}^{n} \left(a_0 + a_1 x_{1i} + a_2 x_{2i} - y_i\right)^2 \quad \ldots\ldots\ldots\ldots\ldots (1.20)$$

The necessary conditions for minimum are

$$S = \left(\sum a_0 + a_1 x_{1i} + a_2 x_{2i} - y_i\right)^2$$

$$\frac{\partial S}{\partial a_0} = \frac{\partial S}{\partial a_1} = \frac{\partial S}{\partial a_2} = 0 \quad \ldots\ldots\ldots\ldots\ldots (1.21)$$

No ambiguity arises since the critical value obtained from these conditions can only be a minimum.

Now the sum of the square of differences of the form in the modified multi - linear equation of

$$y = a_0 + a_1 x_1 + a_2 x_2$$

$$\frac{\partial S}{\partial a_0} = 2\sum_{i=1}^{n} \left(a_0 + a_1 x_{1i} + a_2 x_{2i} - y_i\right) = 0 \ldots\ldots\ldots (1.23)$$

$$\frac{\partial S}{\partial a_1} = 2\sum_{i=1}^{n} \left(a_0 + a_1 x_{1i} + a_2 x_{2i} - y_i\right) x_{1i} = 0 \ldots\ldots (1.24)$$

$$\frac{\partial S}{\partial a_2} = 2\sum_{i=1}^{n} \left(a_0 + a_1 x_{1i} + a_2 x_{2i} - y_i\right) x_{2i} = 0 \ldots\ldots (1.25)$$

We can re - write these as

$$a_1\left(\sum_{i=1}^{n} x_{1i}\right) + a_2\left(\sum_{i=1}^{n} x_{2i}\right) + n a_0 = \sum_{i=1}^{n} y_i \quad \ldots\ldots (1.26)$$

$$a_0\left(\sum_{i=1}^{n} x_{1i}\right) + a_1\left(\sum_{i=1}^{n} x_{1i}^2\right) + a_2\left(\sum_{i=1}^{n} x_{1i} x_{2i}\right) = \sum_{i=1}^{n} x_{1i} y_i \ldots\ldots (1.27)$$

$$a_0\left(\sum_{i=1}^{n} x_{2i}\right) + a_1\left(\sum_{i=1}^{n} x_{1i} x_{2i}\right) + a_2\left(\sum_{i=1}^{n} x_{2i}^2\right) = \sum_{i=1}^{n} x_{2i} y_i \ldots\ldots (1.28)$$

Using the above equations as algorithms, we can now re - write the appropriate equations in the form of algorithm to find the line of best fit [9].

$$n a_0 + a_1 \sum_{i=1}^{n} x_{1i} + a_2 \sum_{i=1}^{n} x_{2i} = \sum_{i=1}^{n} y_i \quad \ldots\ldots\ldots (1.29)$$

$$a_0 \sum_{i=1}^{n} x_{1i} + a_1 \sum_{i=1}^{n} x_{1i}^2 + a_2 \sum_{i=1}^{n} x_{1i} x_{2i} = \sum_{i=1}^{n} x_{1i} y_i \ \ldots (1.30)$$

$$a_0 \sum_{i=1}^{n} x_{2i} + a_1 \sum_{i=1}^{n} x_{1i} x_{2i} + a_2 \sum_{i=1}^{n} x_{2i}^2 = \sum_{i=1}^{n} x_{2i} y_i \ \ldots (1.31)$$

Relating the above equations to the data collected from the various networks under investigation:

n = number of years under consideration
x_1 = successive year 1, 2. 3., …
y = yearly peak value of power of demand
x_2= yearly growth rate

III. Building the Model

It is possible to linearise the above three equations by assigning appropriate variables thus:

$$n a_0 + a_1 x + a_2 z = y \ \ldots\ldots\ldots\ldots (1.32)$$

$$a_0 x + a_1 xx + a_2 xz = xy \ \ldots\ldots (1.33)$$

$$a_0 z + a_1 xz + a_2 zz = zy \ \ldots\ldots (1.34)$$

where x, y, z, xx, xz, xy, zz and zy are the appropriate summations of the energy parameters in equations 1.29 to 1.31.

We can obtain a general solution to these equations by evaluating for the constants a_0, a_1 and a_2. Thus in (1.35)

$$a_0 = \frac{xy - a_1 xx - a_2 xz}{x} \quad \ldots\ldots\ldots\ldots (1.35)$$

and when this is substituted in equation (1.32) we arrive at

$$n\left(\frac{xy - a_1 xx - a_2 xz}{x}\right) + a_1 x + a_2 = y \quad \ldots (1.36)$$

From equations 1.35 and 1.36 we can make appropriate substitutions to get

$$a_0 x.z + a_1 xx.z + a_2 xz.z = xy.z$$

$$a_0 x.z + a_1 xz.x + a_2 zz.x = xy.z$$

$$a_1\left(xx.z - xz.x\right) + a_2\left(xz.z - zz.x\right) = xy.z - zy.x$$

$$a_1 = \frac{xy.z - zy.x - a_2\left(xz.z - zz.x\right)}{\left(xx.z - xz.x\right)} \quad (1.37)$$

From (1.29) and (1.31)

$$n a_0 x + a_1 x.x + a_2 z.x = y.x$$

$$n a_0 x + n a_1 xx + n a_2 xz = nyx$$

$$a_1\left(x.x - nxx\right) + a_2\left(z.x - nxz\right) = y.x - nxy$$

$$a_1 = \frac{y.x - nxy - a_2\left(z.x - nxz\right)}{\left(x.x - nxx\right)} \quad \ldots\ldots\ldots (1.38)$$

If we resolve the last two equations and isolate a_2 , we obtain

$$\frac{xy.z - zy.x - a_2\left(xz.z - zz.x\right)}{xx.z - xz.x} = \frac{y.x - nxy - a_2\left(z.x - nxz\right)}{x.x - nxx}$$

$$\left(xy.z - zy.x\right) - \left(xx.z - xz.x\right)\left(y.x - nxy\right)$$

$$= a\ \left(x.x - nxx\right)\left(xz.z - zz.x\right) - a_2\left(xx.z - xz.x\right)\left(z.x - nxy\right)$$

$$a_2 = \frac{\left(x.x - nxx\right)\left(xy.z - zy.x\right) - \left(xx.z - xz.x\right)\left(y.x - nxy\right)}{\left(x.x - nxx\right)\left(xz.z - zz.x\right) - \left(xx.z - xz.z\right)\left(z.x - nxz\right)} \quad \ldots\ldots (1.39)$$

Similarly $a_1 = \dfrac{xy.z - zy.x - a_2\left(xz. - zz.x\right)}{\left(xx.z - xz.x\right)}$ ….. (1.40)

and

$$a_0 = \frac{y - a_1 x - a_2 z}{n} \quad \ldots\ldots (1.41)$$

Having found means of assigning values to these coefficients, a good forecast model can now be built by the use of the above algorithms. Appropriate flowchart was drawn for developing the computer programme as shown in fig. 2

The values for a_0, a_1 and $a_2$is then computed using old load data with the aid of computer solution based on the above algorithms. The values of these coefficients will vary depending on the distribution network [5].

Therefore consumer load demand can be deduced (forecasted) using Multi- Regression method outlined above in the form of:

$$P_d = a_0 + a_1 x_1 + a_2 x_2 \quad \ldots\ldots (1.42)$$

Where P_d = system peak demand in MW
a_0 = independent constant coefficient (residual or error)
a_1 = constant coefficient representing power growth rate due to population.
x_1 = t = time frame in year
a_2 = constant coefficient representing level of industrialisation and other socio-economic factors or uncertainty factor.
x_2 = relates to existing system loading.

IV. Testing the Model

The developed model was tested using data from the distribution network of Ilorin PHCN District is used as a case study.

A DOS-based software package written to simulate the model is suitable for short-term and medium or long-term forecasting [3,9]. The software provided a quick way to visualize data on different information format in form of printed data and the graphical form. The model developed also recognizes and accommodates any scheduled changes in parameter e.g. growth rate. It is structured to predict total load demand by location.

For example, the performance level of the new algorithm was tested by employing the load data collected from the service areas for a period of 5 years (2005 to 2006) on Tables 1 to build two models. From the models, various but different values were obtained for the coefficients a and b in equation (1.7), and a0, a1, and a2 in equation (1.42).

Table 1: Monthly Peak Load (in MW) on 33KV Omuaran Feeder

Year	2005	2006	2007	2008	2009
Peak value	6.8	11.0	11.0	10.3	10.5

Specifically, load data for **Omuaran** PHCN Undertaking were used to build the old model and the new. For the algorithm built on equation 1.7, i.e

$$y = ax + b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.7)$$

According to equations 1.14 and 1.15, a = 0.63 and b =4.38 But for the new model, 0 a = 6.105, 1 a = 0394 and 2 a =
6.997. Subsequently forecast figures were obtained for year 2010 to 2014. The results are shown on Table 2.

Table 2: Comparison of Actual and Forecast Demand (Omuaran)

Year	2010	2011	2012	2013	2014
Actual Demand (Extrapolated)	9.00	11.00	12.00	14.00	16.00
Old Model (MW)	9.24	9.93	10.68	11.24	12.15
New Model (MW)	9.70	10.90	12.21	13.50	14.90

By employing equation (1.45) we can test the goodness or confidence level of the new model by correlating forecast figures of the two models with the actual data collected from the locations. From the above Table 2, xi stands for actual peak power, while yi is the forecasted values using the new model.

By substituting appropriately, we obtain the following.

$$R = \frac{\sum (x_i - x)(y_i - \tilde{y})}{\sqrt{\sum (x_i - x)^2 (y_i - \tilde{y})^2}} = \frac{22.12}{\sqrt{(29.4)(16.95)}} = 0.9836$$

The forecasted data obtained from the model for Omuaran correlates with actual figure with about 98 percent confidence level.

The figures obtained from testing the model revealed a very high confidence level of about 98 percent.

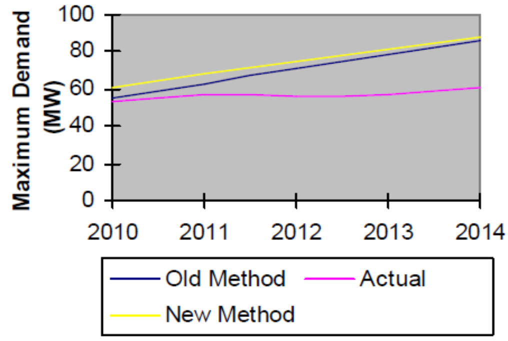

Fig. 1 Comparison of Actual and Forecast Demand Omuaran Start

Input linear regression
Algorithm to create model

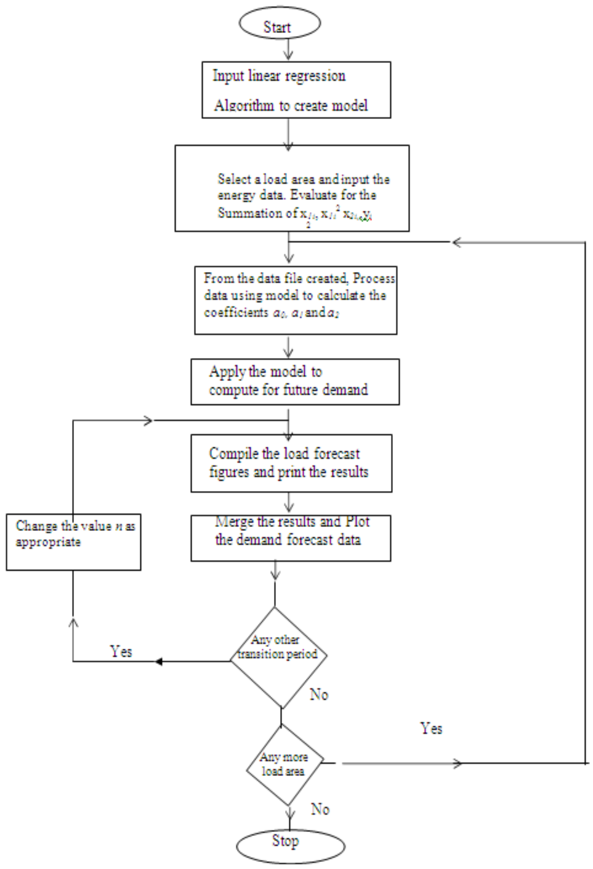

Fig.2. Forecast Flowchart

V. Discussion

The above Numerical Technique for electricity growth forecast model which relies on past observations has been used to predict electric consumption of Ilorin PHCN (Omuaran Supply Network distribution district for the next five years. These prediction do not take cognizance of any major shift in infrastructural development. But it is believed that electricity consumption will grow concomitantly with infrastructural development and population growth, as had been the trend in the past. The work Ibitoye and Adenikinju predicted that electricity consumption for the next 22 years which is about 2030 will be 160GW which 160,0000MW. They arrive at this estimate by using economic and demographic trends as well as GDP trends. Our own prediction appears to follow the science of time series forecast. Although two models of forecast were used. A common but older method used ordinary linear regression and loading data from the supply or generation end to build a forecast model. A modified linear regression model gave better and more accurate result.

VI. Conclusion

Linear equations are used to describe an electrical supply system. Specially, a set of linear equations are used as building blocks for the purpose of predicting the growth of electricity. With the method of 'least squares' appropriate equations were derived in form of algorithms to find the line of 'best fit' for the linear equation. A generalized demand model is presented based on modified multi – regression algorithm method as a first step in electric power distribution planning. The forecast Model thus development was tested using data derived from Ilorin Power Holding Company of Nigeria (Omuaran Supply network) Distribution district, a territory used as a case study. A common but older method used ordinary linear regression and loading data from the supply or generation end to build a forecast model. Data from Ilorin PHCN (former NEPA) District was used to develop and demonstrate the effectiveness of the model. The model was tested when results obtained from it were correlated with actual loading data. The evaluation gave a Confidence level of 98% for Omuaran. Correlation of data obtained from 'Old' method with the 'actual' produced figures of 64% and 94% respectively.

The model was then applied to predict future loads demand for each area of the specified territory for upward of ten years period. Results for Omu-aran distribution area indicate a steep rise of 17.33 MW to 29.0 MW between 2005 and 2009, and a steady increase of 31.78 MW to 42.3 MW thereafter till 2014.

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