Load Forecasting using Quadratic Regression Model for Energy Management in Distribution Networks

Igbogidi, O. N.[1], Dahunsi, A. A.[2]

[1]*Lecturer, Dept. of Electrical Engineering, Rivers State University, Port Harcourt, Nigeria*
[2]*PhD Student, Dept. of Electrical and Electronics Engineering, University of Port Harcourt, Nigeria*

Abstract: *Load forecasting is the predicting of electrical power desired to meet the short term, medium term or long term demand. This study was a detailed pragmatic method of load forecasting good enough for industrial purposes. Quadratic regression model was used to accomplish and proffer solution to the problem of load forecast in electricity distribution networks in Port Harcourt, Nigeria. Relevant data such as station installed capacity, feeder installed capacity, feeder route length, conductor size, feeder availability, feeder daily load, feeder monthly load, feeder yearly load, customer population on each feeder and population not connected to the network were collected from Port Harcourt Electricity Distribution Company (PHEDC). The historical data collected were analyzed and the average and maximum loads were determined with the rest data fed into excel software for statistical analysis. The regression model provided a non-linear relationship between the forecast values of maximum annual load consumed on each 33kV feeder. The annual growth rate for forecast loads for the years 2019-2020, 2020-2021 and 2021-2022 respectively indicated -2.8%, 1.78% and 1.9% for Greater PH 33kV feeder, 0.02%, 7.56% and 8.6% for NTA 33kV feeder, -8.26%, 10.44% and 8.16% for UPTH 33kV feeder and -0.14%, 1.04% and 8.66% for Rukpokwu 33kV feeder. The result showed a 3-year load forecast that can provide room for power system planning particularly in distribution networks.*

Key words*: Load forecasting, Quadratic Regression Model, Distribution Network, Feeder, Time Series.*

1. INTRODUCTION

In developed countries it is not uncommon for a utility to spend a very huge amount of money annually in developing and updating load forecasts. Some of the difference in forecasting expenditure among different utilities can be explained by the supply constrained nature of load growth in many developing countries. Generally, systems still engaged in substantial rural electrification face excess demand for power as they sell more power than they can generate. The utility essentially determines how much demand will grow by how much capacity it adds. The challenge faced by the utility is how to maximize service with limited amounts of capital available for plant and equipment. Accurate models meant for electric power load forecasting are very important for planning and operation of every utility company [1].

Many system managers and planners appear to undervalue forecast accuracy as they commit too few resources to this activity. The stakes are high and that, despite the speculation often surrounding load forecasting, there is the dear need to do it properly. Load forecasting is very necessary as it makes the power distribution company have smooth operation and effective management of the power supply to the customers. Load forecasting helps as it increases the power supply chain efficiency and revenues. With this, the utility is made to do proper load planning to satisfy customers with the needed energy. Electric load forecasting is very imperative for planning in advance to meet the continuous power supply demand [2].

Based on the above developments, it is necessary to develop a load forecast model that is pragmatic in nature capable of proffering solution to the problem of load forecasting especially in distribution networks. The reason is that load forecasting is very imperative as planning and expansion of the system depend largely and accurately on it.

2. RELATED WORKS

Load forecasting can be viewed as the predicting of electrical power desired to meet the short term, medium term or long term demand. Load forecasting may be seen as the problem of ascertaining the future values of system load depending on the past and the current data available [3]. The importance of past data cannot be ignored in load forecasting [4]. According to Gupta & Pal [5], load forecasting has to do with the estimation of future consumptions which depends on several available data and information in relation to consumer behavior. Electric load forecasting is a very vital process in the planning of the electric utility industry and plays a very important role in electric power systems capacity scheduling and management [6]. It is also worthy to note that forecasting provides well informed and efficient responses for electric power demand [7].

The short term load forecasting is aimed at estimating the load for the next half hour up to the next two weeks while the medium term load forecasting deals with a time span of up to one year ahead which is primarily concerned with outage and maintenance planning coupled with load switching operation. Usually, long term load forecasting refers to forecasting horizon of say one year to ten years, and at times up to several decades. The long term load forecasting makes available weekly or monthly forecasts for both peak and valley loads which are necessary for the planning and expansion of the generation, transmission and distribution systems. According to Abu-Shikhah et al. [8], medium term load forecasting runs through a time span of one month to twelve months, which depends solely on growth factors. According to Atla [9], from 1-10years which is a long-term time span, the load forecast can serve for power system planning.

Apart from the guiding principles in forecasting, the choice of a method may depend more on the background and time available from the planning engineer than on the technical merits of the method. Therefore, there is the need to identify the data, computational and planning engineer resources associated with each method involved. There are plenty methods for modelling and forecasting load requirements and generally electrical energy. Each analyst and organization is apt to characterize its computational approach in a different way. According to Huifang et al. [10], different methods and models have been proposed for electric load forecasting. The various ways of classifying models depict the various ways in which analytical methods treat customer choice and behavior. The models may include: Time series model, Econometric model, End-use model, Similar look up model, Regression based model, Artificial neural networks (ANN), Expert systems, Fuzzy logic, Support vector machines, etc.

Abu-Shikhah et al. [8] maintained that time series forecasting methods identify and explore structure such as autocorrelation, trend, or seasonal variation. According to Deb et al. [11], Time series forecasting is practically integral to building and enabling performance optimization. In the same way, Nepal et al. [12] maintained that Time series forecasting has optimally been used as well as gained popularity among researchers over some decades ago. Based on ease of development and interpretation, regression model has become the most commonly used method for building load forecasting [13]. In furtherance of this, Dahunsi et al. [14] stated that a major merit of forecasting load using regression analysis is that it is a lot easier to understand the input and output variables with regards to their relationship.

3. MATERIALS AND METHOD

3.1 Research Materials

The required data to carry out a comprehensive analysis and investigation of the study areas were collected from the Port Harcourt Electricity Distribution Company (PHEDC). The method and procedure adopted in this research are described as indicated.

3.2 Method of Analysis

A study was conducted on Port Harcourt distribution network, based on previous and present loads, weather and event data. The load forecasting was demonstrated on four 33kV feeders covering very vast areas in Port Harcourt, Nigeria as a case study. The feeders include Greater Port Harcourt (Greater PH), Nigerian Television Authority (NTA), University of Port Harcourt Teaching Hospital (UPTH) and Rukpokwu all feeding from Rumuosi transmission substation. The areas under consideration are:

1. Airport complex connected to Greater PH 33kV feeder.
2. NTA, Ohakwe, Ozuoba, Mbguoba, Odarawere, Obiri Ikwerre Junction, Location Road, Ada George, Farm Road, Egbelu and Ogbogoro all connected to NTA 33kV feeder though with some connected to 11kV feeders radiating from it.
3. Rumuekini, Alakahia, Mgbodo, Aluu, Choba, Rumuokparali, Rumualogu and University of Port Harcourt all connected to UPTH 33kV feeder though with some connected to 11kV feeders radiating from it.
4. Rukpokwu Town connected to Rukpokwu 33kV feeder with some 11kV feeders radiating from it to feed ADP, Market Road, SARS Road, OPM, Shell Estate, and Pipeline.

The study was carried out on the four feeders to ascertain their performance under different loading conditions involving the determination of feeder performance under present load and at the same time the forecasted load. Quadratic regression model, a hybrid model comprising of a time series and time trend approach coupled with regression analysis was used to forecast loads for a period of 3-years. After meticulously analyzing the historical data from 2015 to 2019, a quadratic regression model was used.

The quadratic regression model here is a hybrid model that uses a time series and time trend modelling approach coupled with regression analysis for a 3-year load forecast dwelling on historical data from 2015 to 2019. All the historical data collected were analyzed and the average and maximum loads were obtained. Also, station installed capacity, feeder installed capacity, feeder route length, conductor size, feeder availability were fed into excel software tool for statistical analysis. Other relevant data with regard to the analysis were feeder daily load, feeder monthly load, feeder yearly load, customer population on each feeder, population not connected to the network, etc. Table 3.1 has some of the relevant data used for the load forecasting.

Table 3.1: Relevant Data for Analysis

S/No	Parameter	Unit/Dimension
1	Greater PH 33kV feeder route length	18.3km
2	NTA 33kV feeder route length	5.42km
3	UPTH 33kV feeder route length	23.55km
4	Rukpokwu 33kV feeder route length	4.38km

5	Conductor size for each 33kV line	150mm^2
6	Rumuosi transmission station installed capacity	180MVA
7	Customer population	67,422
8	Estimated population not connected	45,324
9	Greater PH 33kV feeder average availability	24hrs
10	NTA 33kV feeder average availability	8hrs
11	UPTH 33kV feeder average availability	8hrs
12	Rukpokwu 33kV feeder average availability	24hrs
13	Greater PH 33kV feeder installed capacity	8.5MW
14	NTA 33kV feeder installed capacity	17.9MW
15	UPTH 33kV feeder installed capacity	14.6MW
16	Rukpokwu 33kV feeder installed capacity	150MW

3.3 Load Forecast Modelling Process Flow

This represents the whole research process flow for this study which is actually a multiple step process with steps interlinking for a continuous flow to achieve the desired result of this study. Chart 3.1 represents the step-by-step research process flow.

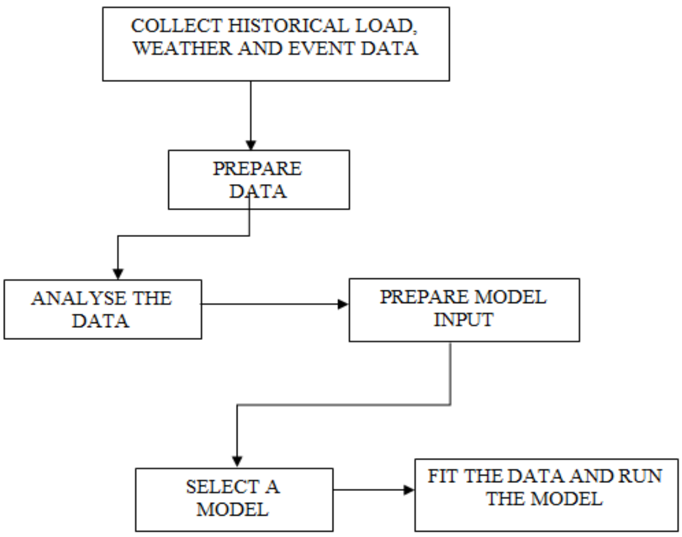


Chart 3.1: Load Forecast Process Chart

3.4 Load Forecasting Using Quadratic Regression Model

It is common to model energy use than peak use. Given an energy forecast, we obtain a peak load forecast by using the simple identity:

$$Peak\ load = \frac{Energy}{Load\ factor\ X\ Period\ of\ time} \qquad (3.1)$$

Where

Load factor is defined as the ratio of average demand to peak demand for the period of time under consideration.

Moving the simple load factor identity a bit further, it can be used to regress peak demand against base energy with the addition of a weather variable:

$$Peak\ load = a + b\ Xbase\ energy + weather \qquad (3.2)$$

Where

Base energy is the non-weather-sensitive portion of the load.

The regression model here is a hybrid model possessing a combination of time series and time trend coupled with regression analysis. The model provides a non-linear relationship between the forecast values of maximum annual load consumed, $P(j)$ of a given year, w_j in the equation referred to as,

$$P(j) = a_1 + a_2 w_j + a_3 w_j^2 \qquad (3.3)$$

Where

$P(j)$ = the maximum annual load consumption forecasted for a given year ahead in Megawatts

w_j = any given year as desired where the load consumption may be forecasted with integral values of j = 1, 2, 3, - - - k, (k+1), (k+2), (k+3)… (k+n).

a_1 = a constant of the model which represents the average network base load.

Finally, a_2 and a_3 are coefficients of change representing maximum annual electric load consumed.

The regression model, $P(j) = a_1 + a_2 w_j + a_3 w_j^2$ is generated by using a set of time series data of annual maximum load consumption for a given k number of consecutive years of annual maximum load consumption and thereafter harnessed by applying a statistical approach referred to as regression analysis which gives rise to:

$$a_1 k + a_2 \sum_{j=1}^{k} w_j + a_3 \sum_{j=1}^{k} w_j^2 = \sum_{j=1}^{k} p_j \qquad (3.4)$$

$$a_1 \sum_{j=1}^{k} w_j + a_2 \sum_{j=1}^{k} w_j^2 + a_3 \sum_{j=1}^{k} w_j^3 = \sum_{j=1}^{k} w_j p_j \qquad (3.5)$$

$$a_1 \sum_{j=1}^{k} w_j^2 + a_2 \sum_{j=1}^{k} w_j^3 + a_3 \sum_{j=1}^{k} w_j^4 = \sum_{j=1}^{k} w_j^2 p_j \quad (3.6)$$

The actual values of a_1, a_2 and a_3 are obtained by analytically resolving equations (3.4), (3.5) and (3.6) respectively.

Table 3.2: Historical Maximum Load on the Feeders in MW

Feeder	2015	2016	2017	2018	2019
Greater PH	2.6	4.9	5.1	6.0	7.5
NTA	9.6	13.8	15.5	16.5	17.4
UPTH	7.6	9	16.3	17.7	19.4
Rukpokwu	9.8	13.9	13.7	12.2	12.8

3.4.1 Load Forecasting on Greater Port Harcourt Using Quadratic Regression Model

The regression model here comprises of time series and time trend coupled with regression analysis which provides a non-linear relationship between the forecast values of maximum annual load consumed on Greater PH 33kV feeder where $P(j) = a_1 + a_2 w_j + a_3 w_j^2$.

Table 3.3: Forecasted Greater Port Harcourt Load Demand

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2015	1	2.6	1	1	1	2.6	2.6
2016	2	4.9	4	8	16	9.8	19.6
2017	3	5.1	9	27	81	15.3	45.9
2018	4	6.0	16	64	256	24	96
2019	5	7.5	25	125	625	37.5	187.5
TOTAL	15.0	26.1	55.0	225.0	979.0	89.2	351.6

Putting the results of the table above into equations (3.4), (3.5) and (3.6) respectively, the following were obtained:

$$5_{a_1} + 15_{a_2} + 55_{a_3} = 26.1$$

$$15_{a_1} + 55_{a_2} + 225_{a_3} = 89.2$$

$$55_{a_1} + 225_{a_2} + 979_{a_3} = 351.6$$

After the mathematical analysis, the following were obtained thus:

$$a_1 = 1.5, \quad a_2 = 1.48 \text{ and } a_3 = 0.06$$

Substituting these values into equation (3.4) results to:

$$p_{(j)} = 6.5 - 2.0w_j + 0.4w_j^2$$

3.4.2 Load Forecasting on NTA Using Quadratic Regression Model

The regression model here comprises of time series and time trend coupled with regression analysis which provides a non-linear relationship between the forecast values of maximum annual load consumed on NTA 33kV feeder where $P(j) = a_1 + a_2 w_j + a_3 w_j^2$.

Table 3.4: Forecasted NTA Load Demand

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2015	1	9.6	1	1	1	9.6	9.6
2016	2	13.8	4	8	16	27.6	55.2
2017	3	15.5	9	27	81	46.5	139.5
2018	4	16.5	16	64	256	66.0	264
2019	5	17.4	25	125	625	87.0	435
TOTAL	15.0	72.8	55.0	225.0	979.0	236.7	903.3

Putting the results of the table above into equations (3.4), (3.5) and (3.6) respectively, the following were obtained:

$$5_{a_1} + 15_{a_2} + 55_{a_3} = 72.8$$

$$15_{a_1} + 55_{a_2} + 225_{a_3} = 236.7$$

$$55_{a_1} + 225_{a_2} + 979_{a_3} = 903.3$$

After the mathematical analysis, the following were obtained thus:

$$a_1 = 5.42, \quad a_2 = 4.96 \text{ and } a_3 = -0.52$$

Substituting these values into equation (3.1) results to:

$$p_{(j)} = 5.22 + 5.14w_j - 0.545w_j^2$$

3.4.3 Load Forecasting on UPTH Using Quadratic Regression Model

The regression model here comprises of time series and time trend coupled with regression analysis which provides a non-linear relationship between the forecast values of maximum annual load consumed on UPTH 33kV feeder where $P(j) = a_1 + a_2 w_j + a_3 w_j^2$.

Table 3.5: Forecasted UPTH Load Demand

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2015	1	7.6	1	1	1	7.6	9.6
2016	2	9.0	4	8	16	18.0	36.0
2017	3	16.3	9	27	81	48.9	146.7
2018	4	17.7	16	64	256	70.8	283.2
2019	5	19.4	25	125	625	97.0	485
TOTAL	**15.0**	**70.0**	**55.0**	**225.0**	**979.0**	**242.3**	**958.5**

3.4.3 Load Forecasting on UPTH Using Quadratic Regression Model

The regression model here comprises of time series and time trend coupled with regression analysis which provides a non-linear relationship between the forecast values of maximum annual load consumed on UPTH 33kV feeder where $P(j) = a_1 + a_2 w_j + a_3 w_j^2$.

Putting the results of the table above into equations (3.4), (3.5) and (3.6) respectively, the following were obtained:

$$5_{a_1} + 15_{a_2} + 55_{a_3} = 70.0$$

$$15_{a_1} + 55_{a_2} + 225_{a_3} = 242.3$$

$$55_{a_1} + 225_{a_2} + 979_{a_3} = 958.5$$

After the mathematical analysis, the following were obtained thus:

$$a_1 = 1.66, \quad a_2 = 5.50 \; and \; a_3 = 0.38$$

Substituting these values into equation (3.1) results to

$$p_{(j)} = 20.02 + 0.57 w_j + 0.04 w_j^2$$

3.4.4 Load Forecasting on Rukpokwu Using Quadratic Regression Model

The regression model here comprises of time series and time trend coupled with regression analysis which provides a non-linear relationship between the forecast values of maximum annual load consumed on Rukpokwu 33kV feeder where $P(j) = a_1 + a_2 w_j + a_3 w_j^2$.

Table 3.6: Forecasted Rukpokwu Load Demand

YEAR	w_j	p_j	w_j^2	w_j^3	w_j^4	$w_j p_j$	$w_j^2 p_j$
2015	1	9.8	1	1	1	9.8	9.8
2016	2	13.9	4	8	16	27.8	55.6
2017	3	13.7	9	27	81	41.1	123.3
2018	4	12.2	16	64	256	48.8	195.2
2019	5	12.8	25	125	625	64.0	320
TOTAL	**15.0**	**62.4**	**55.0**	**225.0**	**979.0**	**191.5**	**703.9**

Putting the results of the table above into equations (3.4), (3.5) and (3.6) respectively, the following were obtained:

$$5_{a_1} + 15_{a_2} + 55_{a_3} = 62.4$$

$$15_{a_1} + 55_{a_2} + 225_{a_3} = 191.5$$

$$55_{a_1} + 225_{a_2} + 979_{a_3} = 703.9$$

After the mathematical analysis, the following were obtained thus:

$$a_1 = 7.04, \quad a_2 = 3.99 \; and \; a_3 = -0.59$$

Substituting these values into equation (3.1) results to:

$$p_{(j)} = 7.04 + 3.99 w_j + 0.59 w_j^2$$

4. RESULTS AND DISCUSSION

4.1 Forecast Result Summary

The results obtained from the regression analysis being essentially the forecast values in MW on Greater PH 33kV feeder, NTA 33kV feeder, UPTH 33kV feeder and Rukpokwu 33kV feeder are shown in Table 4.1 and Graphs 4.1, 4.3, 4.5 and 4.7 respectively. The forecasted loads for each of the four feeders are incrementally for the 3-years' time span.

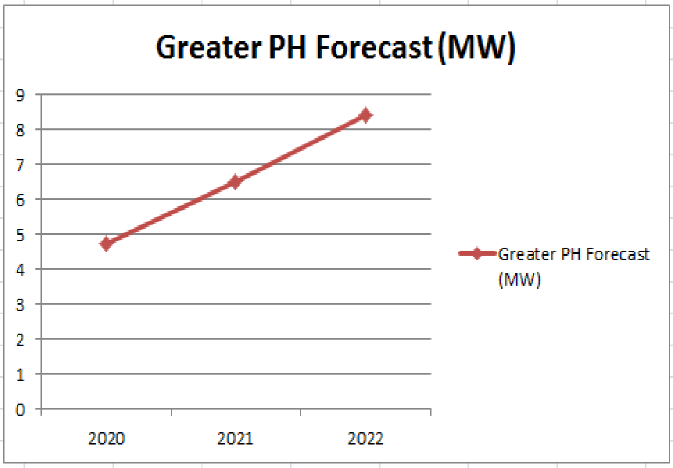
The annual growth rate for forecast loads curled out of the feeder load forecast values for 3-years in MW on Greater PH 33kV feeder, NTA 33kV feeder, UPTH 33kV feeder and Rukpokwu 33kV feeder are shown in Table 4.2 and Graphs 4.2, 4.4, 4.6 and 4.8 respectively. The results indicated large load increase on each of the four feeders except that UPTH had a downward demand between the years 2021 and 2022 largely due to load rejection according to historical data.

Table 4.1: Feeder Load Forecast Values for 3-Years (MW)

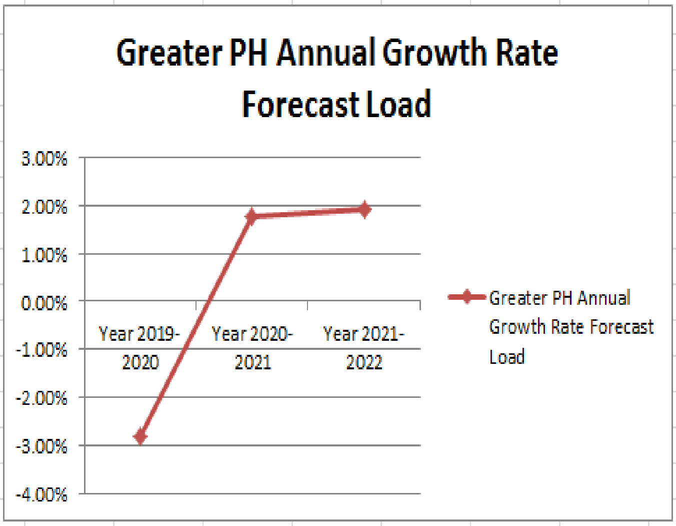
YEAR	Greater PH Forecast (MW)	NTA Forecast (MW)	UPTH Forecast (MW)	Rukpokwu Forecast (MW)
2020	4.7	17.42	11.14	12.66
2021	6.48	24.98	21.58	13.7
2022	8.38	33.58	29.74	22.36

Table 4.2: Annual Growth Rate for Forecast Loads for 3-Years (%)

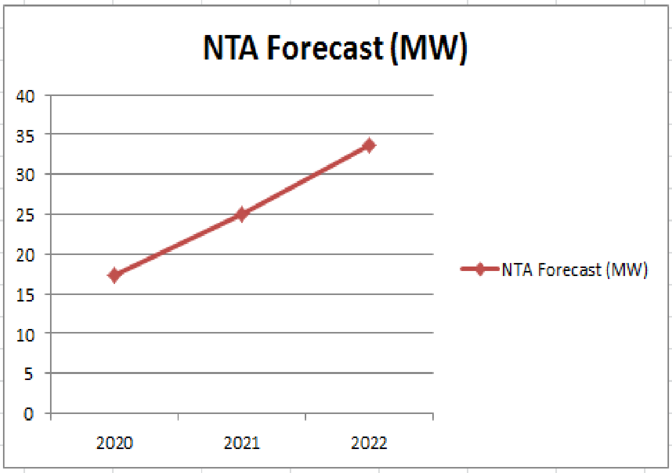
Feeder	Year 2019-2020	Year 2020-2021	Year 2021-2022
Greater PH	-2.80%	1.78%	1.90%
NTA	0.02%	7.56%	8.60%
UPTH	-8.26%	10.44%	8.16%
Rukpokwu	-0.14%	1.04%	8.66%



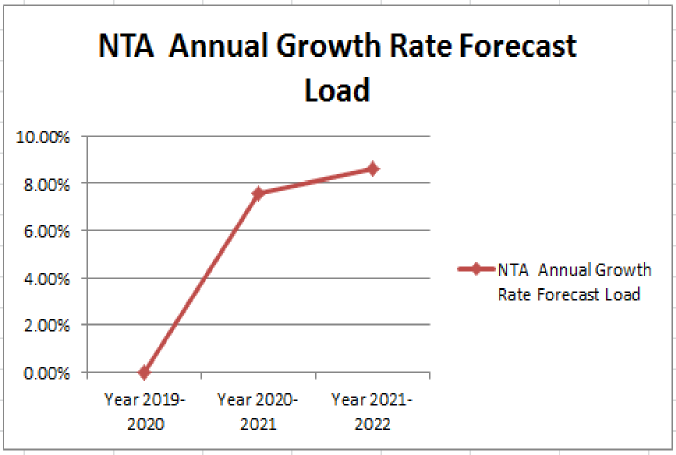
Graph 4.1: Graph Displaying Greater Port Harcourt Load Forecast Based on Historical Data



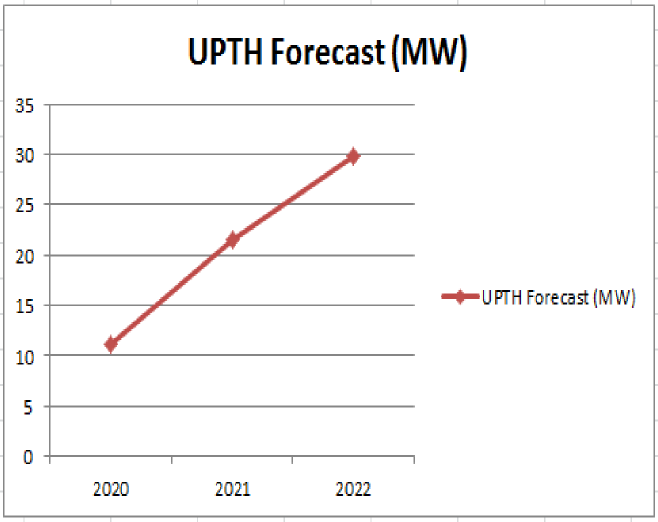
Graph 4.2: Annual Growth Rate for Forecast Load on Greater PH for 3-Years (%)



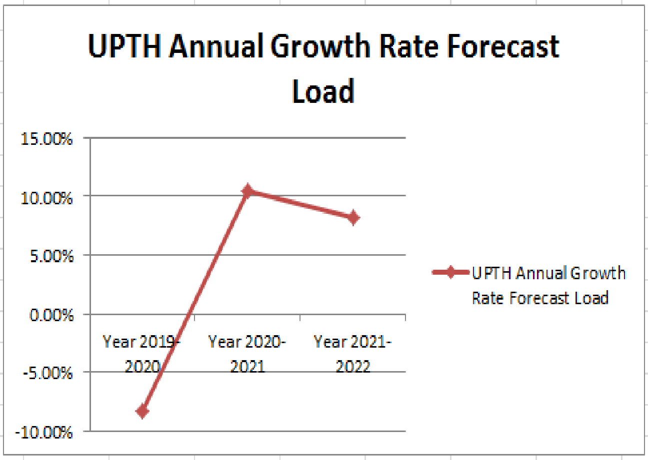
Graph 4.3: Graph Displaying NTA Load Forecast Based on Historical Data



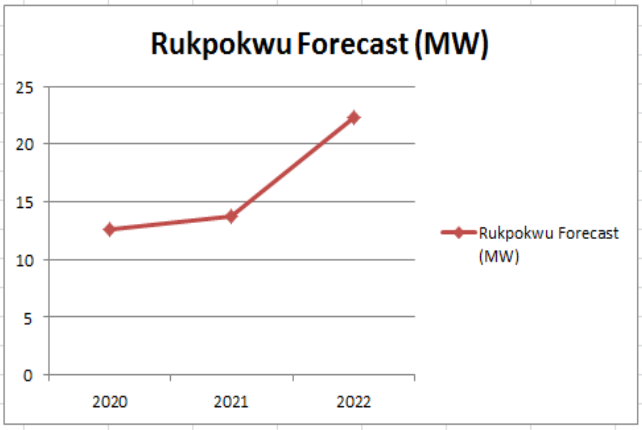
Graph 4.4: Annual Growth Rate for Forecast Load on NTA for 3-Years (%)



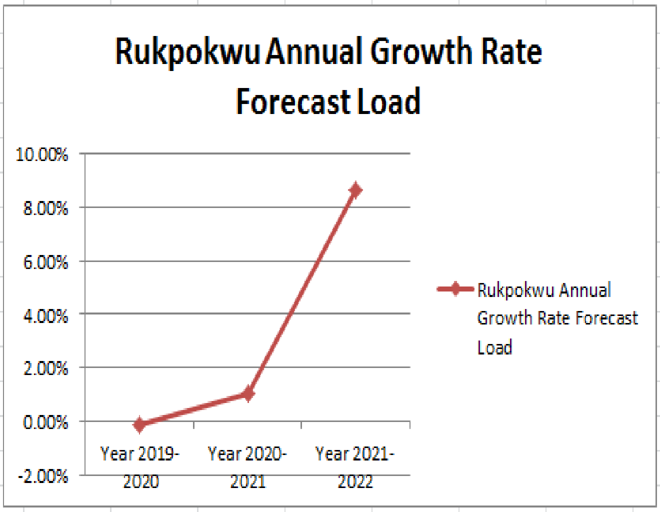
Graph 4.5: Graph Displaying UPTH Load Forecast Based on Historical Data



Graph 4.6: Annual Growth Rate for Forecast Load on UPTH for 3-Years (%)



Graph 4.7: Graph Displaying Rukpokwu Load Forecast Based on Historical Data



Graph 4.8: Annual Growth Rate for Forecast Load on Rukpokwu for 3-Years (%)

5. CONCLUSION

5.1 Conclusion

Quadratic regression model as used in this study, being a hybrid model involving time series and time trend approach mixed with regression analysis has become very simple for industrial use in estimation of load demand particularly in electricity distribution networks. The annual growth rate for forecast loads on Greater PH 33kV feeder indicated -2.8%, 1.78% and 1.9% for the years 2019-2020, 2020-2021 and 2021-2022 respectively while the annual growth rate for forecast loads on NTA 33kV feeder showed 0.02%, 7.56% and 8.6% for the years 2019-2020, 2020-2021 and 2021-2022 respectively. Also the annual growth rate for forecast loads on UPTH 33kV feeder indicated -8.26%, 10.44% and 8.16% for the years 2019-2020, 2020-2021 and 2021-2022 respectively though with a downward demand in 2021-2022 owing to load rejection while the annual growth rate for forecast loads on Rukpokwu 33kV feeder indicated -0.14%, 1.04% and 8.66% for the years 2019-2020, 2020-2021 and 2021-2022 respectively.

The study has actually prepared a 3-year load forecast which can essentially be used for power system planning particularly in distribution networks. This is in agreement with the assertion of Atla [9] who opined that from 1-10years which is a long-term time span, the load forecast can serve for power system planning.

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