GSJ: Volume 8, Issue 3, March 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

Electrical Load Evaluation in Igwuruta, Port Harcourt for Improved Distribution

[1]OkachiCheta Emmanuel and [2]Prof. D C.Idoniboyeobu
[1,2]Department of Electrical Engineering, Power OptionRivers State University, Port Harcourt.
[1]*chetaokachi@gmail.com* [2]*idoniboyeobu.d@ust.edu.ng.*

ABSTRACT: *This study of the Electrical Load Evaluation in Igwuruta, Port Harcourt for improved distribution. Electrical load analysis identities potential problems in the distribution network such as energy usage, harmonic inference, unexpected spikes that a visual inspection alone may not identify. The 33KV Old Airport feeders that supply electricity to Igwuruta, Port Harcourt was critically examined in this study. This study used Electrical Transient Analyzer Programme (ETAP) and from the simulation, the existing distribution network had overloading of transformers and low voltage profile. To solve the problems, optimal capacitor bank of 48000KVR were introduced to the entire system network to improve voltage performance and voltage upgrade on the distribution network. The simulation of the improved distribution network shows that the voltage profile has improved with the statutory limit between 95% - 105% and by the penetration of the capacitor bank in the network, the voltage was improved by 18.4% bus 2, bus 3: 18.4% and bus 27: 5.96% and all the transformer were within the normal operating condition.*

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Load evaluation verifies whether electrical systems are safe and efficient, and that installations show no signs of overload. Load analysis highlights potential problems in the distribution network such as energy usage, harmonic inference or unexpected spikes that a visual inspection alone may not identify. Electric Power System is made up of the Generating System, Transmission Station and Distribution Stations Respectively. Electric power is transmitted by high voltage transmission lines from sending end sub-receiving and end substation. At the receiving end substation, the voltage is been stepped down to a lower value which are 33kv or even 11kv as the case may be for customer usage.(Centrica Business solution,2019).

However, in Nigeria the limiting factors to efficient and reliable power supply apart from low power generation may include poor transmission feeders, poor or inefficient voltage control system due to lack of planning, faulty distribution system on the part of the electrical supplier (PHED). Voltage drop along the line and from the distribution system due to the flow of current and load variations on the consumer end, transmission and distribution network, damage of substations, short circuit or over loading of electrical mains (supply) and tripping of power system. These factors have resulted to unreliable frequent power outages and voltage variations. The demand for electrical power always exceeds the supply in practice especially in a developing country like Nigeria resulting to the interruption of an electrical supply which can be avoided by load-shedding, thereby causing excessive load on the feeders and the generating plant, leading to epithetic power supply system.

Distribution transformers step down the voltage to the level suitable for household and commercial utilities and hence feed several customers through the secondary distribution lines (distributors) at the same voltage. Residential and commercial customers are connected to the secondary distribution line through the service drops. Although electrical power consumers are in need of higher amount of electrical power may be connected directly to the primary distribution line or the sub-transmission level.

The research gives steady state solution of the voltage at all the buses for a particular condition. In the study fast Decoupled Newton – Raphson load flow analysis was used to analyze electrical power supply to Igwuruta Town Port Harcourt because thus method gives the solution of non-linear simultaneous equation in polar form. The total time taken to get the convergent criteria is less, and the number of iterations required to get the convergent criteria are limited as it does not depend on the buses. Igwuruta is located in Ikwerre Local Government Areas of Rivers State, Nigeria. Electricity is being supplied to Igwuruta from the 33kv old Air-Port feeder, which the main source is from Port Harcourt Main Transmission Station 3x60 MVA. However, challenges such as low voltages are experiences in some areas which led to the installation of transformer without planning, resulting to overloading the of the feeder as the city expands and voltage drops are experienced in the transmission due to the distance covered by the line which serves the area. Despite these challenges, there is the insufficient megawatt from the National Grid to the state, electricity exercise control over the socioeconomic development of the state. In regards to this,

this academic research will identity the numerous problems on the network and it will becomes paramount to carryout proper load flow analysis with a view to achieve efficient supply of power in Igwuruta area in particular and the state at large.

1.2 Statement of Problems

Admitting the decline nature of the power sector in Nigeria. Especially in the Igwuruta Town, Port Harcourt electricity power distribution network is faced with problem such as over loading of distributed transformers by the customer usage, low voltage experiences, voltage drops due to the distance covered by the transmission line, insufficient power supply from the National Grid, poor maintenance on the transmission and distribution line etc. But a comprehensive and proper load flow analysis using fast decoupled method will be used to achieve and restore steady and efficient supply of power in Igwuruta town and the state at large by solving the problems such as over loading of distributed transformers by the customer usage, low voltage experiences, the installation of transformer without planning etc.

1.3 Research Aim

The aim of this study is to conduct an analysis of electrical load evaluation in Igwuruta town, Port Harcourt for improved Distribution using fast decoupled method.

1.4 Objectives of the Research

The objectives of this research are considered as follows:

(1) To assess the physical conditions of the electric power distribution network for Igwuruta town, Port Harcourt, in order to obtain relevant information/Data for analysis of voltage problems.

GSJ: Volume 8, Issue 3, March 2020
ISSN 2320-9186

(2) To carryout field survey on the distributions lines and equipment and to improve the distribution network using optimal capacitor replacement.

(3) To model and to simulate the network using ETAP.

(4) To improve the power using capacitor bank.

(5) To validate the existing network with the capacitor bank for improved performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Importance of Load Flow Studies

Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. The increasing presence of distributed alternative energy sources, often in geographically remote locations, complicates flow studies and has triggered a resurgence of interest in the research work. In a three phase as power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Load flow studies provides a systematic mathematical approach for determination of various bus voltage, there phase angle active and reactive power flows through different branches generators and loads under steady state condition.(Centrica Business solution, 2019). In order to obtain a reliable power system operation under normal balanced three phase steady state conditions, it is required to have the followings:

- Generation supplies the load demand and losses.
- Bus voltage magnitudes remain close to rated values.
- Generator operates within specific real and reactive power limits.

- Transmission lines and transformer are not overloaded.

According to the scholar Ahmed, 2013 pinned that load flow analysis is the solution for the operating condition of a power system. Load flow analysis is used for power system planning, operational planning and operations construct (Brown 2013) also employed in multiple assessments, stability analysis and system optimization.

2.2 Literature Survey/Techniques of Load Flow Analysis

In the literature, there are a number of efficient and reliable load flow solution techniques, such as Gauss-seidel, Newton – Raphson and fast Decoupled load flow. In 1967, Tinney and Hart developed the classical Newton based power flow solution method. Later work by (Stott and Alsac 1974), made the fast decoupled Newton method and the algorithm remains unchanged for different applications.

Even though this method worked well for transmission systems, but its convergence performance is poor for most distribution systems due to the high R/X ratio which deteriorate the diagonal dominance of the Jacobian matrix for this reason, various other types of methods consist of backward/forward sweeps on a ladder system. The formulation of the algorithm for those were different from the Newton's power flow method, which made those methods hard to be extended to other applications in which the Newton method seemed more appropriate.

(Tripathy et al 2004), presented a Newton like method for solving ill-conditioned power systems. Their method showed voltage convergence but could not be efficiently used for optimal power flow calculations.

2.3 Load Flow Analysis Using PSAT Soft for Test System Simulation

Power system analysis toolbox (PSAT) is an open source MATLAB and Graphical user interface (GUI)/octave-base software package for analysis and design of small to medium size power systems. The tool box is provided with a GUI and a Simulink editor for editing or designing a single line diagram of any power system networks. PSAT can perform power flow, continuation power flow (CPF) optimal power flow (off), small signal stability analysis.

(Abungu and Kipkirui 2009) state that decoupled load flow method using MATLAB 7.6 (r2013b) to develop an efficient and reliable program and PSAT as a validating tool. The procedural methods calculated and analyzed a well-conditioned load study with minimal losses on the buses; branches and the minimal number of iteration required for convergence were noted. IEEE 14 bus system was used as the test system in the study.

2.4 Radial Distribution Network (RDN) of Load flow Algorithm

Li et al, 2014, in their view stated that algorithm have been developed to tackle the load flow power problem. They formed node-branch incidence matrix that depict the relationship between the bus injection powers and branch powers, then an estimated voltage drop and angle formulas were used along with the incidence matric to solving the load flow power. Li et al, 2016, modifies the previously mentioned algorithm to counter the fundamental error problem resulting in high precision results for both weakly meshed/meshed networks.

Jabr.et al, 2012 state that RDN used the same convex formulation to obtain the optimal configuration for minimizes its real power waste. The modeling of the load power of Radial Distribution Network as Quadratically constrained convex optimization problem (QCCOP) convexification of the continuous decision variables of the optimization problem guaranteed the global optimality of the acquired solution. Moreover, the solution was obtained using interior – point method algorithm through CPLEX optimization software after passing the parameters from

MATLAB. The proposed algorithm has shown high computational efficiency, which paves the way for real time optimization problems regarding the operation of Radial Distribution Network.

2.5 Determination of Bus Voltages, Power Losses and Load Flow in the NorthernNigeria 33kv Transmission Sub-Grid

According to the scholar (Izuegbunam*et al*, 2011) researchers, the Nigerian Electric Power Transmission network operated by Transmission Company of Nigeria (TCN) operates at a very high pressure of 330kv while its lower transmission pressure is 132kv.

The planning, design and operation of power systems requires load flow computations to analyse the steady state performance of the power system under various operating conditions and to study the effects of changes in the configuration of equipment. In their view, the very low bus voltage and poor power magnitude obtained from this study without voltage compensation revealed the reality of the perpetual poor power supply to the North West part of Nigeria.This project which seems to be a prototype of the entire network can be solved using load flow studies which involves the use of computer programs designed specifically for this purpose.

2.6 A Promising Method for Uncertain Load Flow Studies

According to (Su, 2005) and (Chen et al., 2008), probabilistic methods are tools for planning studies. Though there are different short comings as a result of non-normal probability distribution and the statistical dependence of the input data as well as the problems associated with identifying probability distribution for some input data accurately.In their view (Zian Wang et al., 2009) suggested a method for solving the load flow using interval arithmetic taking the uncertainty at the nodal values. Their articles also stated that the required solution to the non-linear equations can be obtained by interval Newton operator, Krawczyk operator or Hansen-Sengupta operator.

(Barboza et al., 2004) also gave the methodology for solving the uncertain power flow problems and a mathematical representation was applied to the load flow analysis by considering Krawczyk's method to solve the nonlinear equations. It is mentioned that the existing problem of excessive conservation in solving the interval linear equation could be overcome by Krawczyk's method. In this method the linearized power flow equations should be preconditioned by an M-matrix in order to guarantee convergence. The scholar also said that (Wang et al., 2005) the set of non-linear equations were solved by Gauss-Seidel method. Preconditioning is required but if interval input is too cumbersome, convergence is not guaranteed, that is why this method cannot give an exact solution. (Yu et al., 2009) Fast Decoupled power flow using interval arithmetic has been used to obtain the solution to the power flow with uncertainty.

This algorithm converges very fast and considers retaining the midpoint of the load flow studies. This is a specific feature that ensures the convergence in accordance with the punctual load flow studies. The algorithm is effective and avoids unnecessary computation effort like preconditioning.

2.7 Performance of Newton-Raphson Technique in Load Flow Analysis Using Matlab

In the view of (Klingman and HinimeIbau 2008) the slack bus set the angle difference between two voltages, the angle of the slack bus is not important, although it sets the reference angles of all the other bus voltages.The main objective for the calculation of power flow study is to find the magnitude of voltage */V/* and the phase angle (δ) of the power losses at each bus section, the real and reactive power flowing in each line of the power system.It was observed that Newton-Raphson's approach has made the calculations easier because the number of buses increased while the number of iterations decreased.

2.8 Electrical Load Flow Studies for Efficient Power Supply in Bayelsa State Using NewtonRaphson Technique

According to the scholars, (Idoniboyeobu and Nemine 2017), the load flow analysis is the backbone of power system analysis and design. It is the necessary for planning, operation, economic scheduling and exchange of power between utilities. The work is to determine the voltage magnitude, phase angle at the buses, real and reactive power of the transmission lines, to help the system engineering during operation and future expansion of the network.

2.9 Power Flow Analysis of Abule-Egba 33KV Distribution Grid System with Real Network Simulations

Load flows are required to analyze the steady state performance of the power system during planning, design and operation of electrical power systems. These load flow studies can be done using computer programs designed specifically for this purpose.According to (Abdulkareem, *et al,* 2014) model and simulation are methods used to overcome the computational problems of power flow solution using load flow iterative technique such as Newton-Raphson and Gauss-Seidel. It needs a model based on real condition. The making of this model must be based on real and valid data so that the model can represent real condition.

2.10 Analysis of the Load Flow Problem in Power System Planning Studies

In an electrical Power system, power flows from generating station to the load through different branches of the network. According to (Afolabi, *et al.,* 2015) states that the flow of active and reactive power is known as load flow or power flow. Power flow analysis is an important tool used by mostly power engineers for planning and determining the steady state operations of a power system. Also (Mageshvaran*et al.,* 2008) said that load flow studies is to determine the various bus voltages/phase angles, active and reactive power flow through different branches, generators, transformers, settings and load under steady state conditions. The power system is modeled by an electric circuit which consist of generation, transmission and distribution networks. Elgerd, 2012 and Kothari and Nagreth, 2007, said that the main information obtained from the load flow or power flow analysis consist of phase angles of load flow bus voltage and magnitude, reactive powers and voltage phase angles of generator buses, real and reactive power flow on transmission lines and power of the reference bus; other variables also being specified.

The load flow problem equations are non-linear and as such it requires iterative techniques such as Newton- Raphson, fast decoupled and Gauss- seidel etc. in solving it. According to Aroop et al., 2015 and Milano, 2009, the development of these methods mainlyled to the basic requirement of load flow calculation such as convergence properties, memory requirement, computing efficiency, convenience and flexibility of the implementation. However, it was concluded that in planning of a power system, Gauss-Seidel method can be used especially for a small system with less computational complexity due to the good computational characteristics it exhibited. The effective and most reliable amongst the three load flow methods is the fast decoupled method because it converges fast and is more accurate.

2.11 Application of Fast Decoupled Load Flow Method for Distribution Systems with High R/X Ratio Lines

(Ochi, *et al*, 2013) in their view proposed 'a fast decoupled load flow calculation method for distribution systems with high R/X ratio. The method was based on a coordinate transformation in Y-matrix for Jacobian matrix in the load flow method. But comparing it with the Newton-Raphson's method, it was found that a short computational time was realized although its convergence characteristics worsen. In a bid to solve the problem, a coordinate transformation in Y-matrix of the fast decoupled method for better convergence was employed (Ochi *et al.*, 2013).

2.12 Impact of Distributed Generation on the Quality of Power Supply in Nigeria; Port Harcourt Network Case Study

According to Ajabuego et al, (2017) in their work considered the impact of Distributed, Generation (DG) on the quality of electricity supply in Port Harcourt network. They gave account on the impact of both the present and the future load demand. In achieving this, power flow analysis and continuous power flow (CPF) optimization method was used to achieve the simulation. The simulation was done using MATLAB 7.9 Power System Analysis Toolbox (PSAT) Simulink environment to analyse thenetwork. The result shows that the dispersion level of DG's among the buses increases, there was a very remarkable improvement in the voltage profile, real and reactive power and load ability of the network.

2.13 Load Flow Analysis of Port Harcourt Electricity Network by Fast Decoupled and Newton-Raphson Techniques

Ibeni (2017) in his work on Load Flow Analysis of Port Harcourt Electricity Network by using Fast Decoupled and Newton-Raphson methods showed that the power dispatched from the national grid network to the transmission substations were inadequate, and as such each injection substation had percentage of loading of the power available.

From the simulation results, it showed that sufficient power is required from the grid to the various injection substations via Port Harcourt Town (Z4) control transmission substation because the lack of adequate power supply from the grid to the transmission substations down to the distribution injection substations will result to power sharing and to address this anomaly it was recommended that: The 33KV distribution network be expanded by installing more transformers, protective systems, and capacitors banks as realized from the affected buses so as to keep the desirable voltage limits; the injection substations for the network under consideration should be made to operate at least 80 per cent of power supply to the secondary distribution network; the reactive power demanded locally at the bus injection substation can be used to minimize the line power loss associated with the network; there should be a periodic load flow analysis carried out by the Electricity Distribution Company to ascertain the status of the network without over stressing it.

2.14 Comparison between Load Flow Analysis Methods in Power System using MATLAB

According to Kriti (2014), in his work on the 'Comparison between Lord Flow Analysis, Methods in Power System Using MATLAB'. He stated that the analysis, designing, and comparison between different load flow system techniques such as Newton-Raphson, Gauss-Seidel etc. in power system using MATLAB was done successfully and the desired results were obtained. In Gauss-Seidel method, it was found that the rate of convergence was slow, it can be easily programmed and the number of iterations increases directly with the number of buses in the system whereas in the Newton-Raphson method, the convergence was very fast and the number of iterations is independent of the size of the system; the solution is high as obtained. It was stated as observed that in Newton Raphson method, convergence is not sensitive to the choice of slack bus. In conclusion it was practical that only the Newton-Raphson and the Fast decoupled load flow methods were the most popular methods. The fast decoupled load flow is definitely superior to the Newton-Raphson method because of its speed and storage capability (Kriti, 2014).

2.15 Load Flow Analysis Using ETAP Software for Network Simulation

Jayaprakash, et al, (2016) in their work on load flow analysis to investigate the performance of electrical system during normal and abnormal operating conditions, provided information needed to: minimize MW and MVar losses; optimize circuit usage; develop practical voltage profiles; develop equipment specification guidelines and identifies transformer tap settings.ETAP is a computer based software that simulates real time steady-state power system operations, enabling the computation of system bus voltage profiles, real and reactive power flow and line losses etc. (Jayaprakash, *et al.*, 2016).

ETAP offers the most accurate load flow analysis tools on the market, create and evaluate electrical system designs effectively. ETAP calculate voltage drop and power losses and efficiently build and evaluate system models using the advanced power flow analysis. ETAP system models efficiently and effectively function such as automatic device evaluation, alarms for critical and marginal units, a powerful results report comparison analyzer and intelligent, user friendly graphics make it the most reliable load flow analysis software (Ahmed 2017).

ETAP load flow software provides results, power factors for each branch, directional currents flows, and voltage drop calculations throughout each electrical system model. ETAP allows for multiple grid connections, detailed generator modeling, solar turbines and induction generators for radial and mesh networks. ETAP interactively utilizes multiple calculation methods in order to calculate the best possible results.

2.16 Summary of Review Literature

The problem of power losses, voltage breakdown, voltage instability etc. are major concern particularly to the distribution network at large. The rate of power voltages in the distribution network is becoming an uncontrollable situation. The major contribution of this work is that, it has identified the associated problems on the on the 33KV distribution network as a result of overload which were captured via simulation of the existing network for the purpose of overload. Based on the system overload analysis were made using optimal capacitor replacement method by optimal of sizing of capacitor bank with the capacitor of 48000KVAR were used to compensate the entire system network to improve the condition of the system (33kv distribution network). De-coupled correction method should be used when installing capacitor bank in a network.

GSJ: Volume 8, Issue 3, March 2020
ISSN 2320-9186

CHAPTER 3

MATERIAL AND METHOD

3.1 Materials

The major source of data for this research work was gotten from Port Harcourt Electricity Distribution Company (PHEDC). Gathering/sourcing for an important task, various books, thesis, publications and theories have been referred to. The data gathered are: installed capacity of transmission substation, installed capacity of injection substation, examined feeders, total number and power rating of distribution transformers and single line diagram of power distribution network for Igwuruta Town, Port Harcourt (source, PHEDC)

Method: Fast decoupled method was used for computing bus voltages and the simulation on each of the feeders was done using ETAP version 16.00 in order to improve the existing system condition performance.

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ISSN 2320-9186

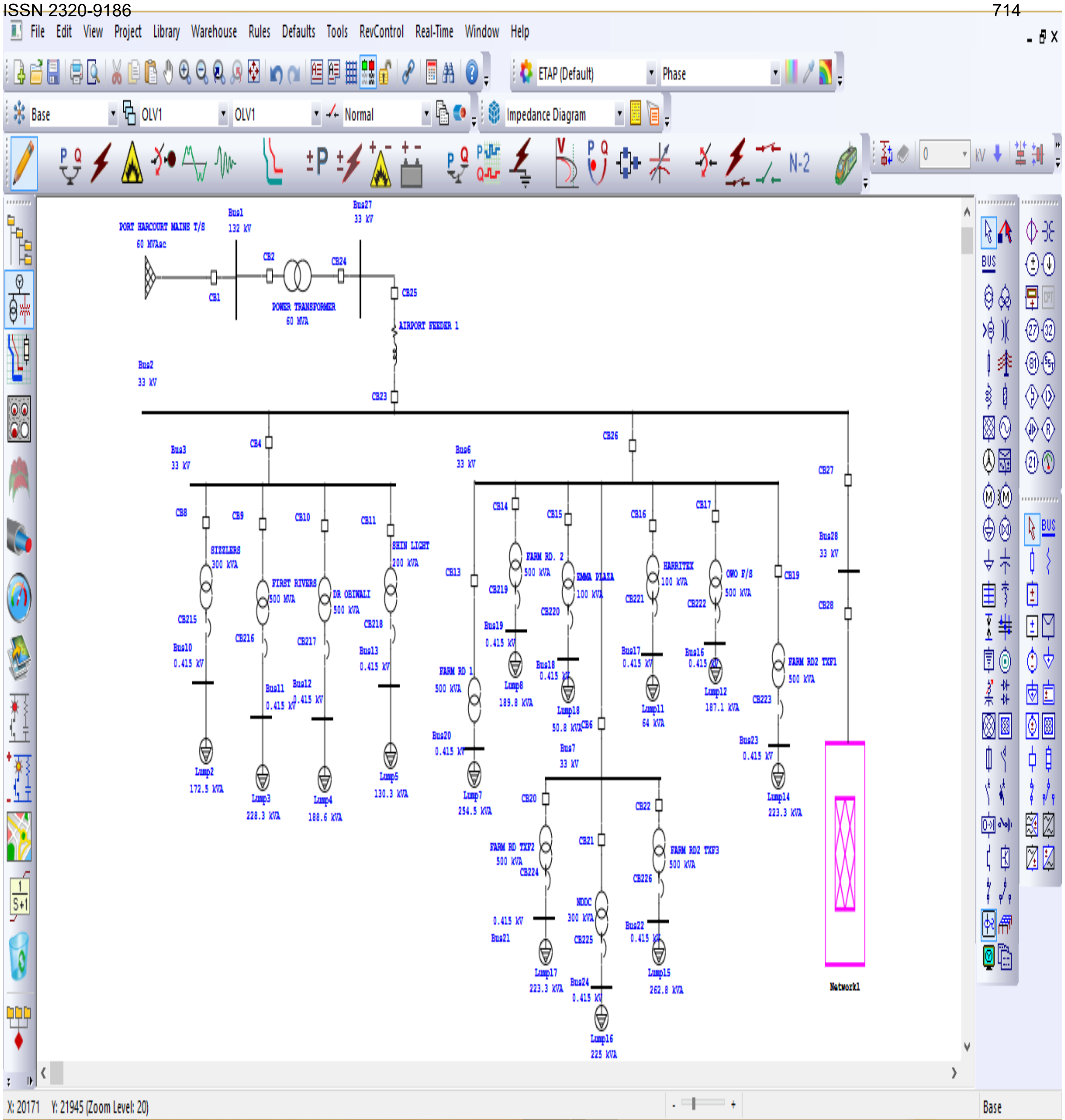

Plate 1: Systematic diagram of 33KV Old Airport Feeder from Port Harcourt main transmission station (Existing case study not simulated)

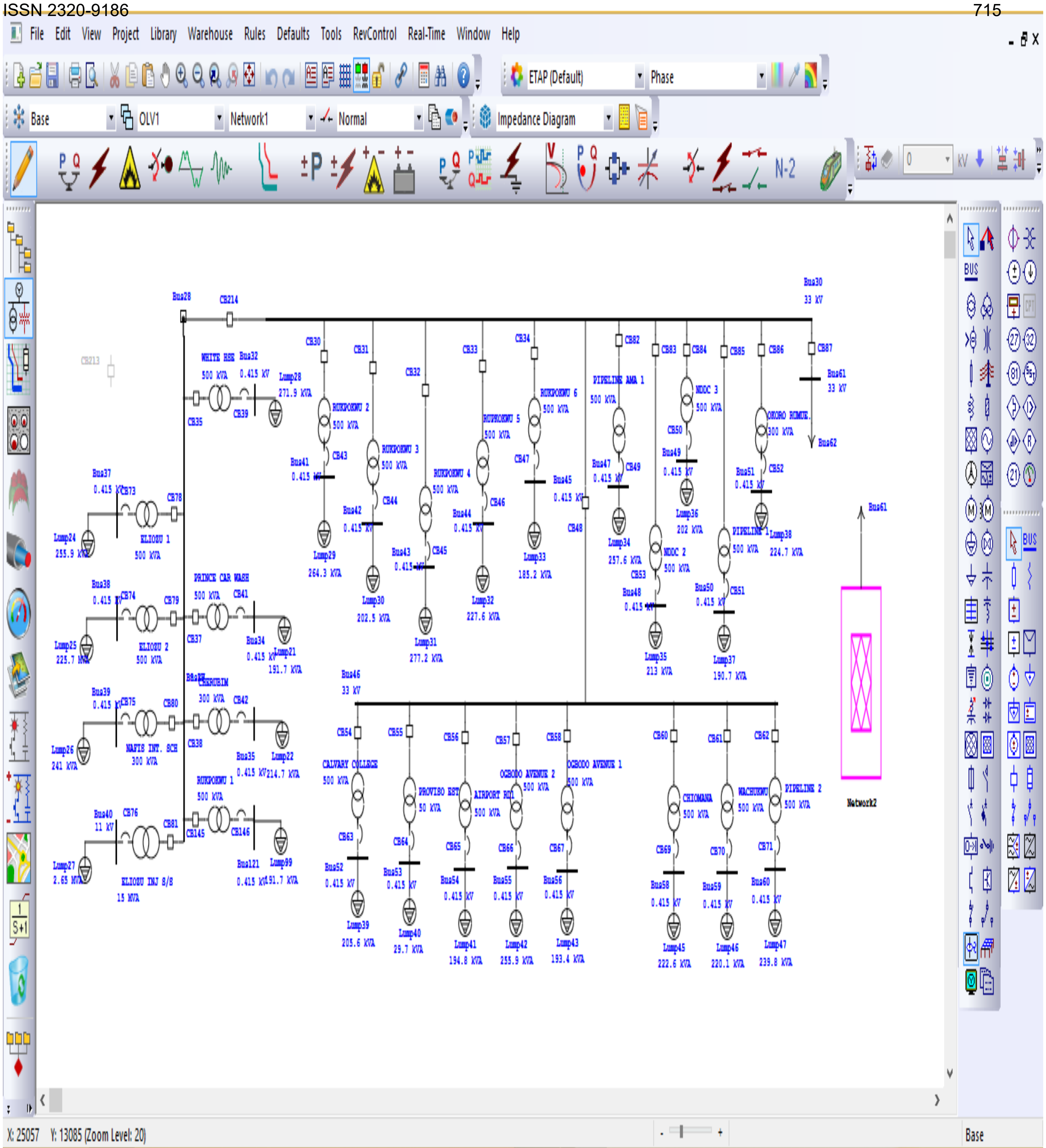

Plate 2: Existing line diagram of Old Airport Feeder (case study simulated)

Table 3.1: Some of the Transformers in Igwuruta Town, their Locations and Readings

S/N	Transformers Locations	Transformers Rating (KVA)	Red Phase (A)	Yellow Phase (A)	Blue Phase (A)	Neutral
1.	Sizzlers	300	249	218	222	31
2.	First River	500	304	298	310	41
3.	Dr. Obi Wali	500	244	253	261	29
4.	Shining Light Fast	200	162	171	194	17

Source: Port Harcourt Electricity Distribution Company (PHEDC).

3.4 Calculation of the Transformers load, Percentage Loading, Active Power, Reactive Power and Complex Power in Igwuruta Town Distribution Network.

1. Sizzlers Transformer (300KVA)

$$\text{Current I} = \frac{I_R + I_Y + I_B + I_N}{3}$$

$$= \frac{249 + 218 + 222 + 31}{3}$$

$$= \frac{720}{3}$$

$$= 240A$$

Load SVA on the transformer

$$SVA = \sqrt{3}\ V\ x\ I$$

$$= \sqrt{3}\ x\ 0.415KV\ x\ 240A$$

$$= 1.7320\ \text{x}\ 0.415\text{kv}\ \text{x}\ 240\text{A}$$

$$= 172.51\text{KVA}$$

But, % loading $= \frac{SVA}{SMAX}\ x\ 100$

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ISSN 2320-9186

$$= \frac{172.51KVA}{300} \ x \ 100$$

$$\% \ \text{loading} = 58\%$$

Active power, P = $\sqrt{3} \ \ V \, I \cos = 172.51 KVA$

$$\cos\phi = 0.8$$

$\therefore$ Active Power = 172.51 x 0.8
= 138.01KVA

Reactive Power, Q $= \sqrt{3} \ \ VI \sin\phi$

and, $\sqrt{3} \ VI = 172.51$

$\sin\phi = 0.6$

$\therefore$ Reactive power = 172.51 x 0.6

Q = 103.51KVA

Complex power, S = P + jQ

S = 138.01 + j103.51

Lump load $= \frac{SMAX \quad X \quad \% \ \ loading}{100}$

$$= \frac{300 \ x \ 58}{100} = 174KVA$$

3.5 **Presentation of calculated values of the distribution transformers in Igwuruta Town, with their locations capacity, load current, lump load, active power and reactive power.**

Table 3.2: Transformers Locations, Percentage Loading, active power, reactive power in Igwuruta Town Distribution Network

S/N	Transformers Locations	Transformers (KVA)	Load Current (A)	Lump Load (KVA)	Reactive Power (KVA_R)	Active Power (KVA)
1.	Sizzlers	300	240	174	103.51	172.51
2.	First River	500	317.67	230	137.00	182.66
3.	Dr. Obi Wali	500	262.33	190	113.14	150.85
4.	Shining Light Fast	200	181.33	130	78.20	104.27

3.6 Determination of over Loaded Transformer

The determination of the overload transformer can be done using apparent power performance index to find the percentage loading of the transformers on rating for design purpose, transformer with loadings in excess of this figures are considered overloaded.

$$\% \text{ loading} = \left(\frac{SMVA}{SMAX}\right) x\ 100$$

Where;

S_{max} is the MVA rating of the transformer

S_{MVA} is the operating MVA from power flow calculation

NT is the number of transformers.

Distribution line parameters

Resistance of line per kilometer

$$R_o = \frac{1000\ x\ \ell}{A}\ \Omega/km \quad (3.1)$$

Where;

ℓ = Resistivity of Aluminum ACSR = $3.82 \times 10^{-7}\Omega/m$

A = area of conductor = $150mm^2$

$$Y_{21} = Y_{12} = -Y_{12} \quad (3.2)$$

$$Y_{31} = Y_{13} = -Y_{13} \quad (3.3)$$

$$Y_{41} = Y_{14} = -Y_{14} \quad (3.4)$$

Bus Admittance Matrix

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & O & O \\ Y_{31} & O & Y_{33} & O \\ Y_{41} & O & O & Y_{44} \end{bmatrix} \quad (3.5)$$

From Ohm's law the current entering only of the buses is given by;

$$[I] = [Y_{Bus} \ [V] \quad (3.6)$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & O & O \\ Y_{31} & O & Y_{33} & O \\ Y_{41} & O & O & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \quad (3.7)$$

The current entering bus I_1 is given by;

$$I_1 = Y_{11} V_1 + Y_{12} V_2 + Y_{13} V_3 + Y_{14} V_4 \quad (3.8)$$

The current entering bus I_2 is given by

$$I_3 = Y_{21} V_1 + Y_{22} V_2 \quad (3.9)$$

The current entering bus I_3 is given by;

$$I_3 = Y_{31} V_1 + Y_{33} V_3 \quad (3.10)$$

The current entering bus I_4 is given by;

$$I_4 = Y_{41} V_1 + Y_{44} V_4 \quad (3.11)$$

Complex power injected into bus I is given by;

$$S^* = P_1 + jQ = V_1 \ I_1^* \quad (3.12)$$

$$S^* = P_1 - jQ_1 = V_1^* \ I_1 \quad (3.13)$$

Therefore, from equation (3.13)

$$I_1 = \frac{P_1 - jQ_1}{V_1^*} \quad (3.14)$$

Similarly, I_2, I_3 and I_4 injected into bus 2, 3 and 4 is given as;

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ISSN 2320-9186

$$I_2 = \frac{P_2 - jQ_2}{V_2^*} \quad (3.15)$$

$$I_3 = \frac{P_3 - jQ_3}{V_3^*} \quad (3.16)$$

$$I_4 = \frac{P_4 - jQ_4}{V_4^*} \quad (3.17)$$

Complex power injected into the ith bus is given as;

$$S_1 = P_1 + jQ_i$$

$$= V_1 \; I_1^*$$

$$S_1^* = P_1 + jQ_1$$

$$= V_1^* \; I_1$$

$$\therefore \; P_i - jQ_i = V^* \; I_i \quad (3.18)$$

But current entering the ith bus of anη bus system is given as;

$$I_1 = y_n v_1 + y_{12} v_2 + y_{13} v_3 + ... \; y_n v_n$$

$$I_1 = \sum_{k=1}^{\eta} \; Y_{1k} \; V_k \quad (3.19)$$

Substitute I_1 from equation (3.19) into equation (3.18)

$$P_1 - jQ_1 = V^* \left(\sum_{k=1}^{\eta} \; \mathrm{Y}_{ik} \; V_k \right) \quad (3.20)$$

Let $V^* = V_1 \; (-\delta), V_k = V_k \; (\delta_k) \;$ *and* $\; Y_{1k} = Y_{1k} \; (\theta_{ik})$ (3.21)

Substitute equation (3.21) into equation (3.20).

$$P_1 - jQ_1 = V_1 \sum_{k=1}^{\eta} \; Y_{1k} \; V_k \; (\delta_k + \theta_{ik} - \delta_1) \quad (3.22)$$

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$$P_1 - jQ_1 = \sum_{k=1}^{\eta} |Y_{1k}| \; |V_1| \; |V_k| \left[\cos(\theta_{1k} + \delta_k - \delta_1) + j \sin(\theta_{ik} + \delta_k - \delta_1)\right]$$

Separating the real and imaginary parts

$$\text{Real power, } P_1 = \sum_{k=1}^{\eta} |Y_{1k} \; V_1 \; V_k| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (3.23)$$

$$\text{Reactive power, } Q_1 = \sum_{k=1}^{\eta} |Y_{ik} \; V_1 \; V_k| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (3.24)$$

V_1 = Bus voltage of bus i

P_1 = Active power injected into ith bus

Q_1 = reactive power injected into ith bus

Y_{ik} = Off diagonal element of the Y-buss matrix

Y_{ii} = Diagonal element of the Y-bus matrix

V_i = Voltage at bus η

FAST DECOUPLED METHOD

This method is the modification of newton – Raphson, which takes the advantage of the weak, coupling between P - δandQ - /V/ due to the high X:R ratios. The Jacobian matric are obtained after partial derivatives of equations (3.23) and (3.24) are expressed which gives linearized relationship between angle. The equation can be written in matrix form as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (3.25)$$

Equation (3.25) is reduced to half by ignoring the element of J_2 and J_3, equation (3.25) is simplified as;

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & O \\ O & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (3.26)$$

Expanding equation (3.26) give two separate matrixes,

$$\Delta P \ J_1 \ \Delta\delta \left[\frac{\partial P}{\partial \delta}\right]\Delta\delta \tag{3.27}$$

$$\Delta Q \ J_4 \ \Delta|v| \left[\frac{\partial P}{\partial |v|}\right]\Delta|v| \tag{3.28}$$

$$\frac{\Delta P}{V_1} = - \ B^{I} \ \Delta\delta \tag{3.29}$$

$$\frac{\Delta Q}{V_1} = - \ B^{II} \ \Delta|v| \tag{3.30}$$

B^1 and B^{11} are the imaginary parts of the bus admittance, it is better to ignore all shunt connected elements, as to make the formation of J_1 and J_4 simple. This allow for only one single matrix than performing repeated inversion. The successive and voltage magnitude and phase angle changes are;

$$\Delta\delta = - \left[B^1\right]^{-1} \ \frac{\Delta P}{|V|} \tag{3.31}$$

$$\Delta|V| = - \left[B^{11}\right]^{-1} \ \frac{\Delta Q}{|V|} \tag{3.32}$$

3.7 **Software Selection**

ETAP is a fully graphical enterprise package that runs on Microsoft ® windows ® 2003, 2008, 2012, XP, vista, 7 and 8 operating systems. ETAP is the most comprehensive analysis tool for the decision and testing of power systems available. Using its standard offline simulation modules. ETAP can utilize real-time operating data for advanced monitoring, real – time simulation, optimization, energy management systems, and high – speed intelligent load shedding.

ETAP enables engineers to handle the diverse discipline of power systems for a broad spectrum of industries in one integrated package with multiple interface views such as AC and DC networks, cable raceways, ground grid, GIS, panels, are flash, protective device coordination/selectively and AC and DC control system diagram.

DESIGN CALCULATION OF CAPACITOR BANK

The analysis and the calculation of the size of capacitor bank to used is a major tool for power improvement, therefore capacitor bank will assist to regulate, control and compensate for power loss, reactive power losses and voltage profile inadequacy. The location of the capacitor bank must be taken into consideration when depends of the location of the inductive loads and their requested reactive power.

- Centralized correction: One capacitor bank installed near the main in coming switchboard.
- Decoupled correction: Capacitor banks are installed hear distribution switchboards that supply voltage to the main consumer responsible for the low power factor.
- Local correction: Capacitor banks are installed near individual consumers.

Presentation of collected data from the system network (Igwuruta network).

The following data were collected; Bus 2, Bus 3, Bus 4 from the simulated result, the total power in KW

BUS 2

Capacitor Bank formular sizing for improve performance

CKvar = kw (tan ϕ_1 - tanϕ_2) (3.33)

Where,

Capacitor Bank in KVAr

Present power factor $(Pf)_1$ = tan ϕ_1

Desired power factor $(Pf)_2$ = tanϕ_2

System frequency (f) = 50H_2

From equation above, CKvar = kw (tan ϕ_1 - tanϕ_2)

Total Active power KW

Present power factor $(Pf)_1$ =0.8

Desired power factor $(Pf)_2$ = 0.9

System frequency (f) = 50H_2

From equation (3.33) CKvar = kw (tan ϕ_1 - tanϕ_2)

cosϕ_1= 0.8

$\phi_1 = \cos^{-1}(0.8) = 36.87^o$

$\phi_2 = \cos^{-1}(0.9) = 25.84^o$

CKVar = 16959.410 (tan 36.87 – tan 25.84)

= 16959.410 (0.7500 – 0.4842)

= 16959.410 (0.2658)

= 4507.77KVar

Table 3.3: Presentation of Calculated values of capacitor bank in each of the buses.

Bus ID	Active power (KW)	Capacitor Bank (KVA_r)	No. of capacitor bank/size (KVA_r)	The sizes of capacitor bank per bus (KVA_r)
Bus 2	16959.410	4507.77	400 x 12	4800
Bus 3	415.049	110.32	200 x 1	200

After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

CHAPTER 4

RESULTS AND DISCUSSION

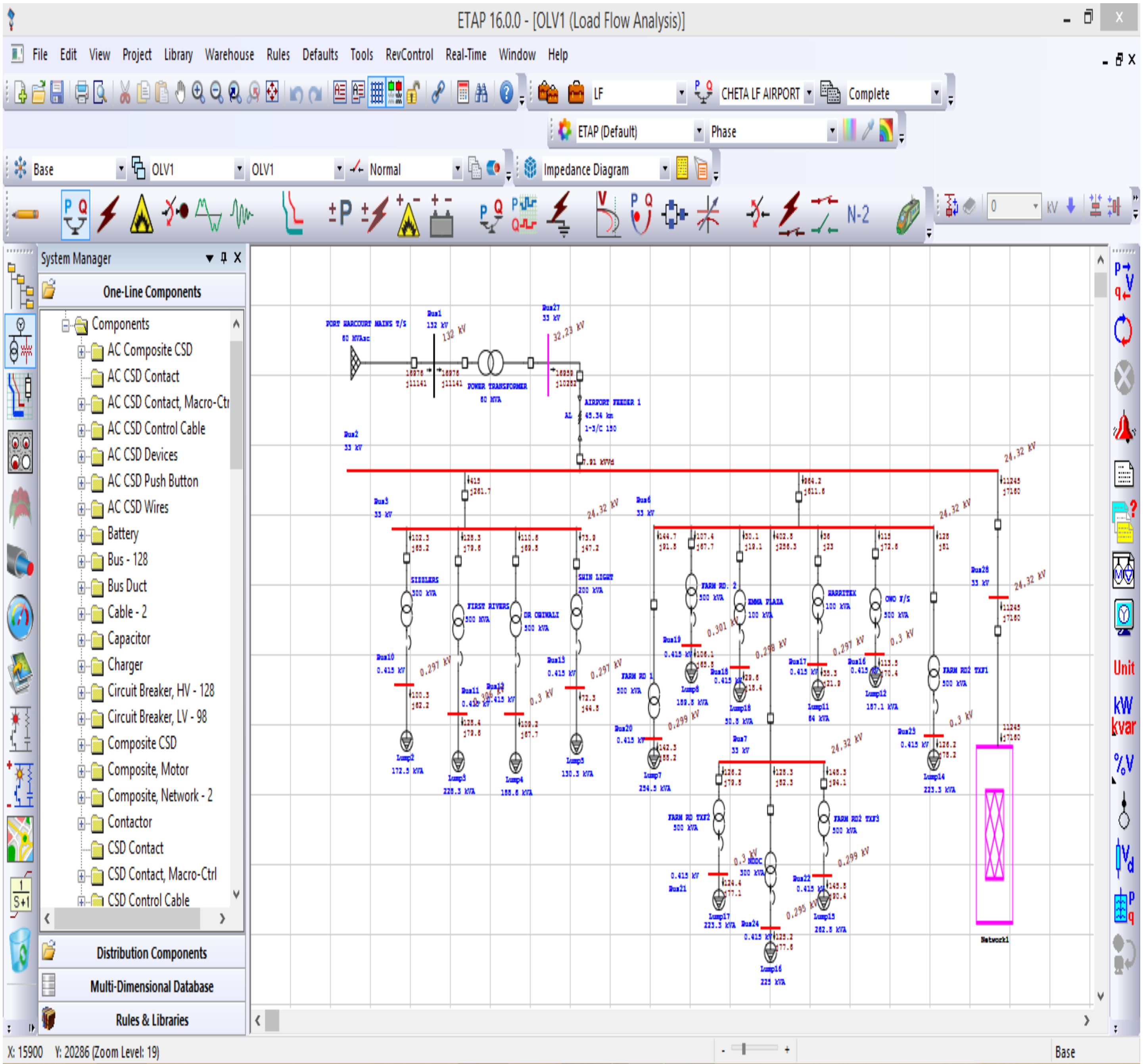

Plate 8:Improved systematic line diagram of 33kv Old Airport Feeder (using capacitor bank).

4.1 Presentation of result and discussion base on analytical methods are presented in tabular and graphical form are shown below:

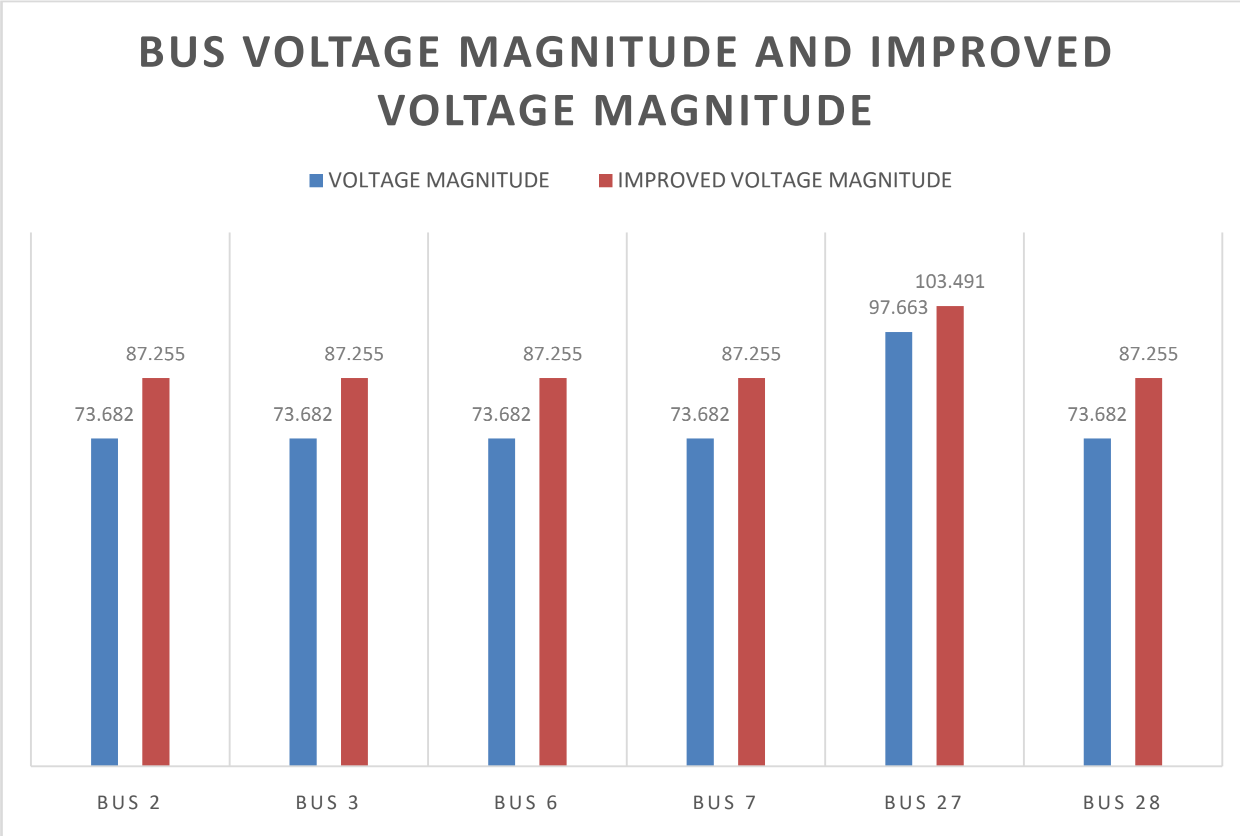

Plate 18:Plot of Bus Voltage Magnitude [Existing] and Bus Voltage Magnitude [Improved] Vs Bus Voltage Number.

Table 4.1: Bus Voltage Magnitude (Existing) and Bus Voltage Magnitude (Improved) against Bus voltage Number.

Bus 2	73.682	87.255
Bus 3	73.682	87.255
Bus 6	73.682	87.255
Bus 7	73.682	87.255
Bus 27	97.663	103.491
Bus 28	73.682	87.255

The above table shows the existing bus voltage magnitude and bus voltage magnitude (improved) against the bus number.

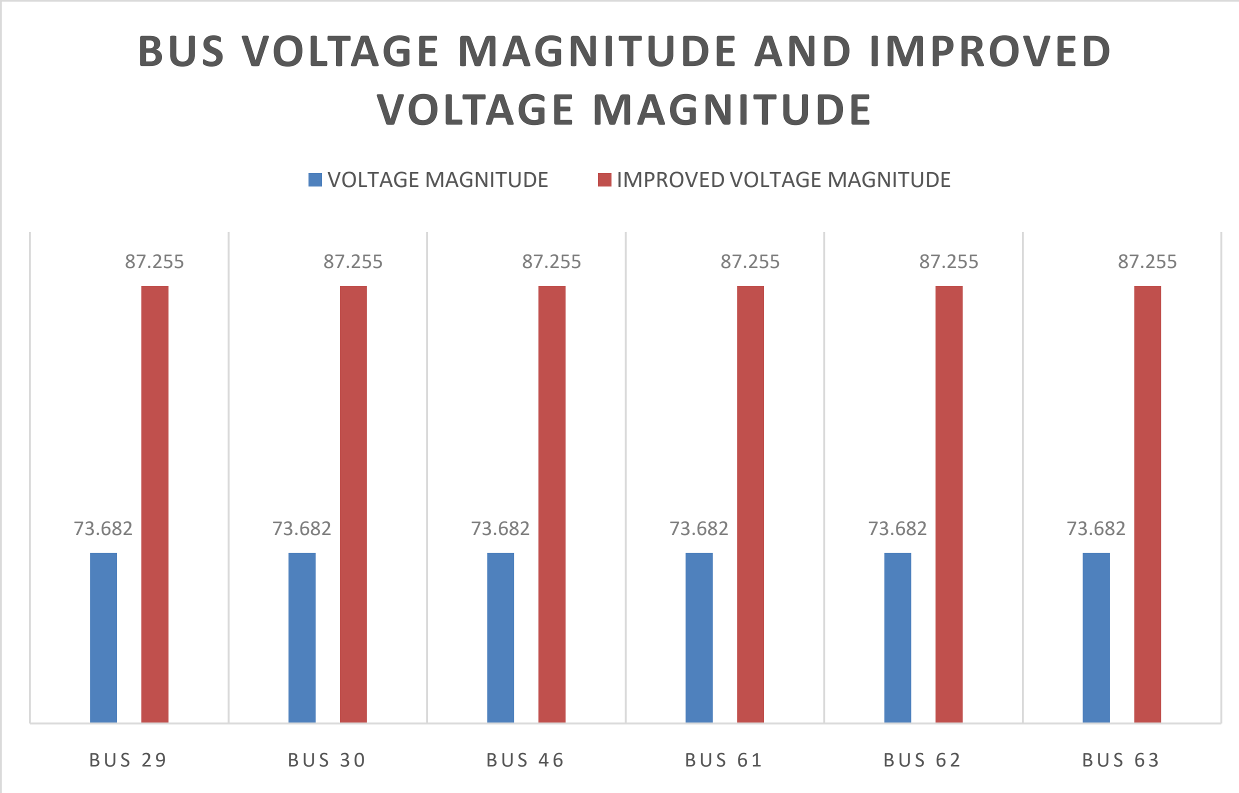

Plate 19: Plot of Bus Voltage Magnitude [Existing] and Bus Voltage Magnitude [Improved] Vs Bus Voltage Number.

Table 4.2: Bus Voltage Magnitude (Existing) and Bus Voltage Magnitude (Improved) against Bus voltage Number.

Bus 29	73.682	87.255
Bus 30	73.682	87.255
Bus 46	73.682	87.255
Bus 61	73.682	87.255
Bus 62	73.682	87.255
Bus 63	73.682	87.255

The above table shows the existing bus voltage magnitude and bus voltage magnitude (improved) against the bus number.

4.2 Discussion of Result

After simulation on the system it shows that some buses are under existing operating condition, such buses are Bus 2, 3, 6, 7, 27, 28, 29, 30, 46, 61, 62, 63, 64, 65, 66, 68 and 101 are not within the acceptable normal voltage of ± 5% of the dealed voltage as a result of overloading, poor transmission feeders, power or inefficient voltage control system due to lack of planning, faulty distribution system on the part of the electrical supplier (PHED) and as such case it creates voltage instability in the system network. The examination of the 33kv distribution network revealed the effect of poor power quality on the expected voltage of the distributed line in the study case Igwuruta, especially, the case of overload on the existing transformers and cables.

However, to improve the distribution network capacitor bank was used to reduces loss (I^2 R loss) associated with transmission and distribution of the current to the consumer's loads, improve voltage regulation, quality of power, power factor, voltage profile of the system. Therefore, capacitor bank will assist to regulate control and compensate for power loss, reactive power losses and voltage profile inadequacy.

To improve the efficiency of the system two (2) capacitor bank rated at 16000KVAR each were optimally sized and allocated to support the voltage at the critical buses (bus 62 and 63) in order to enhanced power system operation by minimizing losses and improve the profile of the voltage. It will also helped to enhanced power flow on the critical part of the system network. Therefore, the problem of voltage fluctuation and harmonies can be overcome by the penetration of the FACTS-controller. A flexible AC transmission system consisting of power electronic devices along with power system devices to enhance the controllability and stability of the distribution system and increase the power transfer capabilities. After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

After careful examination of the study case (Igwuruta 33kv distribution network), the research work showed that the existing state of the electrical power network of Iguruta 33kv distribution network taking its supply of power from 33kv Airport feeder that was transmitted from Port Harcourt main in Trans-Amadi. The research was modeled in Electrical Transient Analyzer Programme (ETAP 16.00 version) with the application of power flow equation, voltage equation sizing of capacitor equation etc, for reason of ascertaining the system (network) conditions in the areas of voltage stability (whether there is a strong mismatch between nominal declared voltage with regards to IEE regulation and the existing operating voltage) in order into enhance system performance.

Importantly, the study engaged optimal capacitor placement of improving system overload by determining the optimal size of capacitor bank required to improve the specific bus overload problem of the system (network in a view to enhance power quality, voltage profile and power factor. The fixing of the sized capacitor bank at the affected buses improved the voltage profile and performance on the network. After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

Sequel to the findings, it is deduced that power flow studies are key for future planning of power system expansion as well as determining the best and reliable operating condition of the existing system.

5.2 Recommendations

Based on the analysis and findings, the following recommendations are pointed out to ensure optimal performance and reliability of the 33kv distribution.

- Replacement of undersized cables in the network.
- Fixing capacitor bank compensator where necessary in order to reduce voltage instability problems, electricity cost due to excessive losses.
- Periodic load flow analysis should be carried out by the Port Harcourt Electricity Distribution Company (PHEDC) to know the status of the network without over stressing the system (ETAP 16.00 software).
- Additional 500KVA transformer should be added in the network especially to where the system experiences critical overload.

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