Nigerian Research Journal of Engineering and Environmental Sciences 4(2) 2019 pp. 937-951

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Power Flow Analysis of Ugbowo 2×15 MVA, 33/11 kV Electric Distribution Network using Newton Raphson's Computational Method

***[1]Akpojedje, F.O., [2]Ogujor, E.A. and [3]Abu, Y.O.**
[1]Department of Electrical/Electronic Engineering Technology, School of Engineering Technology, National Institute of Construction Technology and Management (NICTM), Uromi, Nigeria.
[2]Department of Electrical and Electronic Engineering, University of Benin, PMB 1154, Benin City, Nigeria.
[3]Department of Science Laboratory Technology, Faculty of Life Sciences, University of Benin, PMB 1154, Benin City, Nigeria.
*francetech007@yahoo.com; f.akpojedje@nict.edu.ng

ARTICLE INFORMATION

Article history:
Received 23 Jul, 2019
Revised 07 Oct, 2019
Accepted 13 Oct, 2019
Available online 30 Dec, 2019

Keywords:
ETAP software
Power flow
Simulation
Voltage violation
Voltage magnitude

ABSTRACT

In recent times, the rate of frequent power outages and high level of regimented load shedding has called for serious concern. Therefore, it is necessary to ascertain whether the electric power is economically transported over the power lines with maximum efficiency and reliability at almost fixed voltages and frequency within the statutory limits to consumers' terminal. As a result, it became imperative to carry out power flow study of the network under investigation. Thus, this paper examines the power flow analysis of an electric distribution network with aid of computer simulations. A model of the distribution network of Ugbowo, Benin City, Edo State, Nigeria was made using the Electrical Transient Analysis Programme (ETAP) software. By making the model, the active and reactive powers of the network, voltage magnitudes, phase angle of the entire network can be observed if the model is simulated. The results of the simulations obtained from the existing Ugbowo 2×15 MVA, 33/11 kV distribution system under investigation indicated that the four (4) feeders of the network and its associated load buses have low voltage violations. In other words, the entire one hundred and forty-two (142) load buses showed low voltage violations and it is on red alert, revealing the reality of the epileptic nature and high level of regimented load shedding in the distribution network today. Therefore, the distribution system is in urgent need of voltage profile improvement techniques to ameliorate the current situation of voltage violations and poor power quality in the network.

1. INTRODUCTION

Power flow is the flow of active and reactive powers in a network. Hence, power flow studies provide a systematic mathematical approach for the determination of various bus voltages, their phase angles, active and reactive power flow through different branches, generators and loads under steady state conditions

(Akpojedje, 2017). Therefore, "power flow analysis is executed to find the sensitivity of feeder status or bus status with variation of power loading, conductor length and total capacity of distribution transformers. The results of the analysis are used to check whether the electrical power transported from generator to consumers through the network power lines is stable, reliable, economical and has quality (Abdulkareem et al., 2014). In other words, the power flow analysis reveals the performance of the network. The major goal of this revelation in the network is to investigate whether all bus voltages are within the statutory limits of ±6% and that the flow of reactive power in the network is reasonable as to ensure acceptable quality of service (QoS) being given to the consumers (Akpojedje, 2017). Consequently, when planning, designing and operating power systems; whether existing or proposed, power flow computations required to analyze the steady state performance of the network under various operating conditions and also, to examine the effect of changes in the network configuration (Abdukareem et al., 2014).

For distribution systems, the power flow analysis is very important and fundamental and this is for grid operators to analyze the performance and also, know the wellbeing of the network (Idoniyeobu and Ibeni, 2017). The distribution network being one of the power value chain that links or evacuates the bulk power from transmission network to consumers in the grid, needs critical evaluation by the distribution system operators (DSOs) if quality of service to customers is their priority (Akpojedje et al., 2014). To carry out the evaluation in the network, complex and tedious computations are undergone under steady state conditions (Akpojedje, 2017).

From historical survey, it is noticed that in the second half of the twentieth century, after the large technological developments in the field of digital computer and high-level programming languages and, development of many methods for solving the load flow problem such as Gauss-Siedel (bus impedance matrix), Newton-Raphson's (NR) and its decoupled version ameliorate the cumbersomeness in computational processes (Idoniboyeobu and Ibeni, 2017). The tediousness in computational problems of these methods is overcome by performing power flow studies using computer programmes specifically designed for this purpose (Onohaebi, 2012). Using this computer programmes, models are formulated to mimic the network and simulation on the computer real-time or off-line which make it simpler to make changes at will to simulate the changes on the network. Making good simulation, a model that is based on real condition is needed (Abdulkareem, et al., 2014). Development of this model must be based on real and valid data obtained from real-life network so that the model can represent the real condition of network being simulated (Bhailla, 2006). The simulation of the model, is expected to reveal the true or near the true situations of the network status and model is a representation of a system; and electrical distribution network is a system (Abdukareem, et al., 2014). Consequently, this paper aims at modeling and simulating Ugbowo 2×15 MVA, 33/11 kV electrical distribution system with the aim of evaluating the current status of the system.

2. MATERIALS AND METHODS

2.1. Description of Ugbowo Electricity Distribution Network

The single line diagram of Ugbowo 2×15 MVA, 33/11 kV distribution network is depicted in Figure 1. The utility company (Benin Electricity Distribution Company) has multi – voltage systems with substations and transformers between each levels of the voltages. It consists of a single 33 kV Oluku sub-transmission line feeding the Ugbowo 11 kV injection substation. The Benin Electricity Distribution Company (BEDC) which is responsible in the distribution of electricity to consumers and this covers four (4) states (Edo, Delta, Ekiti and Ondo States) in Nigeria. The Ugbowo 2×15 MVA, 33/11 kV distribution network is under the Edo State distribution system and which comprises of four (4) feeders:

i. The 11 kV FGGC Feeder which has about twenty (20) 11/0.415 kV transformers with only fifteen (15) of the transformers in service at the time of writing.

ii. The 11 kV Uselu Feeder which has about forty (40) 11/0.415 kV transformers with only thirty-seven (37) of the transformers in service at the time of writing this paper.

iii. The 11 kV Eguaedaiken Feeder which has about forty-seven (47) 11/0.415 kV transformers with only thirty-nine (39) of the transformers in service at the time of writing.

iv. The 11 kV Ugbowo Feeder which has about fifty-three (53) 11/0.415 kV transformers with only fifty-one (51) of the transformers in service at the time of writing

The single line diagram in Figure 1 gives a clear overview of the Ugbowo 2×15 MVA, 33/11 kV distribution network.

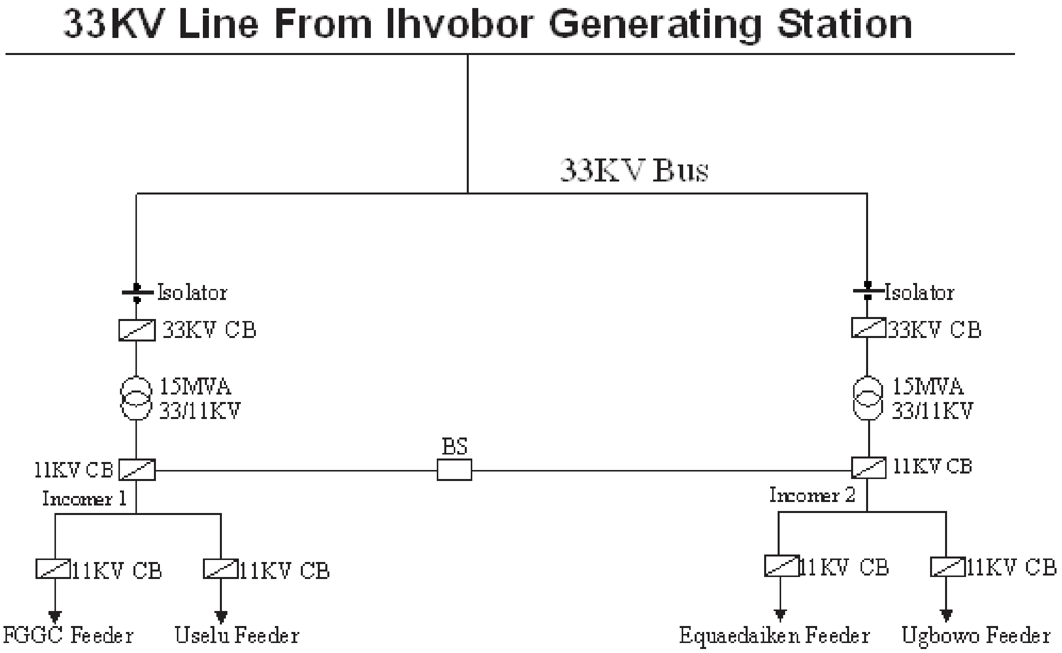


Figure 1: Single line diagram of Ugbowo 2×15 MVA, 33/11 kV injection substation and its associated feeders

2.2. Materials

In this research work, the materials needed for the power flow analyses are the network data such as: line data, bus data, single line diagram of network, ETAP 12.6 software, and personal computer.

2.3. Solution of Static Power Flow Equations

It is important to note that the voltages and power flows in an electrical system can be determined for a given set of loading and operating conditions (Idoniboyeobu and Ibeni, 2017). The parameters determined during power flow studies under steady state conditions are: real power (P) flow, reactive power (Q) flow, magnitude of voltages (V), phase angle of voltage (δ), line power losses (Lp_L), etc. The solution of the static power flow equations is difficult because of the nonlinear characteristics of the equations. Consequently, solutions are possible only through iterative numerical methods using the robust computational techniques such as Newton-Raphson (NR) computational technique which is adopted in this research paper (Akpojedje, 2017).

Power flow studies are commonly known as load flow studies, which form an important part of power system analysis in term of evaluation of the system. In determining power problem, the system is assumed to be under steady state conditions and a single phase can be model for the entire network. In power system networks, four quantities are associated with each bus of the network which are: voltage magnitude ($|V|$), phase angle (δ), active or real power (P) and reactive power (Q). In this research work, Newton-Raphson (NR) method was used for solving the nonlinear algebraic equations of the network.

2.3.1. Bus variable of power flow studies

At each bus of power system, there are four quantities: P, Q, V, δ and two out of these four quantities are specified while the remaining two quantities are determined. Table 1 show the types of buses and their known and unknown variable to be determined in each bus.

Table 1: Bus variable of power flow studies

Bus type	Known variables	Unknown variables
Slack/Reference/Swing Bus	V, δ	P, Q
PV/Generator/Voltage Control Bus	P, V	Q, δ
PQ/Load Bus	P, Q	V, δ

2.3.2. Modeling of power relations

Considering current I$_i$ entering ith bus of an n bus system of a typical power network shown in Figure 2.

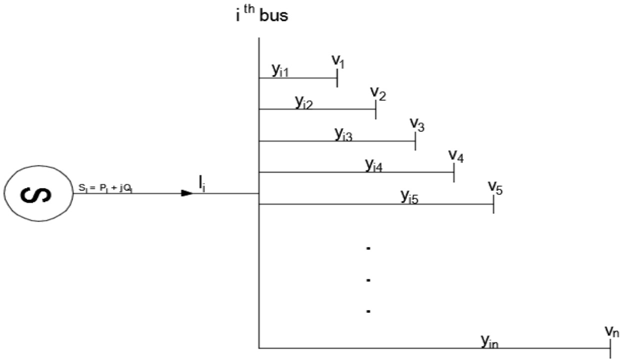


Figure 2: Typical n-bus of a power system (Akpojedje, 2017)

The voltage at ith bus is given as:

$$V_i = |V_i|\angle\delta_i = |V_i|(Cos\delta_i + jSin\delta_i) \tag{1}$$

The self-admittance at ith bus is given as:

$$Y_{ii} = |Y_{ii}\angle\gamma_{ii} = |Y_{ii}||(Cos\gamma_{ii} + jSin\gamma_{ii}) \tag{2}$$

Similarly, the transfer admittance between ith bus and pth bus is give as:

$$Y_{ip} = |Y_{ip}\angle\gamma_{ip} = |Y_{ip}||(Cos\gamma_{ip} + jSin\gamma_{ip}) \tag{3}$$

Since we are considering a current entering I_i^{th} bus of n bus system as shown in Figure 2, the total current in I$_i$ is given as:

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + Y_{i4}V_4 + Y_{i5}V_5 + \ldots\ldots\ldots\ldots + Y_{in}V_n \quad (4)$$

Writing Equation 4 in a short form:

$$I_i = \sum_{p=1}^{n} Y_{ip}V_p \quad (5)$$

The complex power injected into ith bus is given as:

$$S_i = P_i + jQ_i = V_i I_i^* \quad (6)$$

$$S_i = P_i - jQ_i = V_i^* I_i \quad (7)$$

Substituting Equation 5 into Equation 7 results in:

$$S_i = P_i - jQ_i = V_i^* \sum_{p=1}^{n} Y_{ip}V_p \quad (8)$$

Therefore:

$$P_i - jQ_i = V_i^* \sum_{p=1}^{n} Y_{ip}V_p \quad (9)$$

$$V_i^* = |V_i|\angle -\delta_i = |V_i|(Cos\delta_i - jSin\delta_i) \quad (10)$$

$$P_i - jQ_i = |V_i| \sum_{p=1}^{n} Y_{ip}V_p \angle -\delta_i \quad (11)$$

$$P_i - jQ_i = |V_i| \sum |Y_{ip}||V_p| \angle(\delta_p + \gamma_{ip} - \delta_i) \quad (12)$$

$$P_i - jQ_i = |V_i| \sum Y_{ip}|V_p| \angle -(\delta_i - \gamma_{ip} - \delta_p) \quad (13)$$

$$P_i = |V_i| \sum_{p=1}^{n} |Y_{ip}||V_p| Cos(\delta_p + \gamma_{ip} - \delta_i) \quad (14)$$

$$Q_i = -|V_i| \sum_{p=1}^{n} |Y_{ip}||V_p| Sin(\delta_p + \gamma_{ip} - \delta_i) \quad (15)$$

Equations 14 and 15 are called the static power flow equations which constitute a set of nonlinear equations in terms of independent variables, voltage magnitude and phase angle.

Where:

V_i = Voltage at bus I, V_p = Voltage at bus p, δ_i = Angle of deviation at bus I, δ_p = Angle of deviation at bus p, γ_{ip} = Phase angle of transfer admittance between bus i and p, Y_{ip} = Transfer admittance between bus i and p, I_i = Current injected into bus I, P_i = Real or active power at bus I and Q_i = Reactive power at bus i

2.3.3. Newton – Raphson (NR) algorithm for power flow solution

Expanding equation 14 and 15 in Taylor Series to about initial estimate and neglecting all higher order terms result in set of the equations of form is given as:

$$P_i = |V_i|\sum_{p=1}^{n}|Y_{ip}||V_p|Cos(\delta_p + \gamma_{ip} - \delta_i) = P_i(|V|, \delta) \tag{16}$$

$$Q_i = -|V_i|\sum_{p=1}^{n}|Y_{ip}||V_p|Sin(\delta_p + \gamma_{ip} - \delta_i) = Q_i(|V|, \delta) \tag{17}$$

Both real and reactive powers are function of $(|V|, \delta)$ where

$$|V| = (|V_1|,......., |V_n|^T)\delta = (\delta_1,......, \delta_n)^T \tag{18}$$

Let P_i (Scheduled) and Q_i (Scheduled) be the scheduled powers at the load buses. In the course of iteration x should tend to that value which makes

$$P_i(Sch) - P_i(x) = 0 \text{ and } Q_i(Sch) - Q_i(x) = 0 \tag{19}$$

Writing equation 19 for all load buses, we got its matrix form as:

$$\begin{bmatrix} P(sch) - P(x) \\ Q(Sch) - Q(x) \end{bmatrix} = \begin{bmatrix} \Delta P(x) \\ \Delta Q(x) \end{bmatrix} \cong 0 \tag{20}$$

It should be known, at the swing bus (bus number 1), P_1 and Q_1 are unspecified. Therefore, the value $P_1(x)$ and $Q_1(x)$ do not enter into Equation 19 and Equation 20. Therefore, x is a 2(n-1) vector (n – 1 load buses), with each element function of (n – 1) variable given as the vector (x) (Kothari and Nagrath, 2008).

$$x = \begin{bmatrix} \delta \\ |V| \end{bmatrix} \tag{21}$$

In general, for the (k + 1)th iteration:

$$(J(x^k))\Delta x^k = -f(x^k) \tag{22}$$

And:

$$x^{(k+1)} = x^k + \Delta x^k \tag{23}$$

Hence, neglecting the higher order terms as stated earlier:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{11}(x) & J_{12}(x) \\ J_{21}(x) & J_{22}(x) \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{24}$$

Where J(x) is the Jacobian matrix, where each J_{11}, J_{12}, J_{21}, J_{22} are (n – 1) x (n – 1) matrices.

The elements of $J_{11}(x)$, $J_{12}(x)$, $J_{21}(x)$, $J_{22}(x)$ are:

$$\frac{\partial P_i}{\partial \delta_i}, \frac{\partial P_i}{\partial |V_i|}, \frac{\partial Q_i}{\partial \delta_i}, \frac{\partial Q_i}{\partial |V_i|}, \text{ Where i = 2, ……., n; p = 2,……., n.} \tag{25}$$

From Equations 16 and 17 we have:

The diagonal element J_{11}:

$$\begin{aligned} \frac{\partial P_i}{\partial \delta_i} &= -|V_i||V_p||Y_{ip}|Sin(\gamma_{ip} + \delta_p - \delta_i) \\ &= |V_i| \sum_{\substack{p=1 \\ p \neq 1}} |V_p||Y_{ip}|Sin(\gamma_{ip} + \delta_p - \delta_i) \end{aligned}$$

Where i ≠ p and where i = p respectively (26)

The off-diagonal element J_{12}:

$$\begin{aligned} \frac{\partial P_i}{\partial |V_i|} &= |V_p||Y_{ip}|Cos(\gamma_{ip} + \delta_p - \delta_i) \\ &= 2|V_p||Y_{pp}|Cos\gamma_{pp} + \sum_{\substack{p=1 \\ p \neq 1}}^{n} (|V_p||Y_{ip}|Cos(\gamma_{ip} + \delta_p - \delta_i) \end{aligned}$$

Where i ≠ p and i = p respectively (27)

For the diagonal element J_{22}:

$$\begin{aligned} \frac{\partial Q_i}{\partial \delta_i} &= |V_i||Y_{ip}|Cos(\gamma_{ip} + \delta_p - \delta_i) \\ &= -|V_i| \sum_{\substack{p=1 \\ p \neq 1}}^{n} |V_p|Cos(\gamma_{ip} + \delta_p - \delta_i) \end{aligned}$$

Where i ≠ p and i = p respectively (28)

For the off diagonal J_{21}:

$$\begin{aligned} \frac{\partial Q_i}{\partial |V_i|} &= -2|V_p||Y_{ip}|Sin(\gamma_{ip} + \delta_p - \delta_i) \\ &= 2|V_p||Y_{pp}|Sin\gamma_{pp} + \sum_{\substack{p=1 \\ p \neq 1}}^{n} (|V_p||Y_{ip}|Sin(\gamma_{ip} + \delta_p - \delta_i) \end{aligned}$$

Where i ≠ p and i = p respectively (29)

The term $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the differences between the scheduled values and the computed values, termed as power residual, is given as:

$$\Delta P_i^{(k)} = P_i^{(Sch)} - P_i^{(k)} \tag{30}$$

$$\Delta Q_i^{(k)} = Q_i^{(Sch)} - Q_i^{(k)} \tag{31}$$

The bus voltage magnitudes and angles are updated or estimated with the following equations:

$$|V_i|^{(k+1)} = |V_i|^k + |\Delta V_i|^k \tag{32}$$

$$\delta_i^{(k+1)} = \delta_i^k + \Delta\delta_i^k \tag{33}$$

2.4. Modeling of Distributed Loads in the Network

According to Subrahmannyam (2009) and Abdulkareem et al. (2014), in an unbalanced distribution system, loads can be uniformly distributed along a line. When the loads are uniformly distributed, it is not necessary to model each and every load in order to determine the voltage drop from the source end to the last loads (Abdulkareem, et al., 2014). Shimohammadi and Cheng (1995) opined that the total distributed load on each phase of a line section is lumped half – half at the line sections of two end buses. The load at bus p and bus q in Figure 3 was modeled as spot loads as shown below. The spot load equivalent single line diagram is shown in Figure 4.

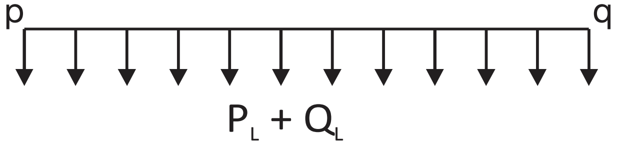


Figure 3: Single-line diagram of a distributed equivalent load (Abdulkareem et al., 2014)

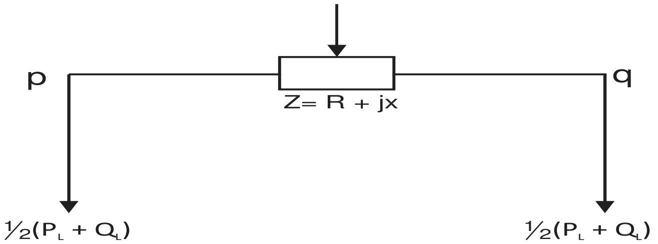


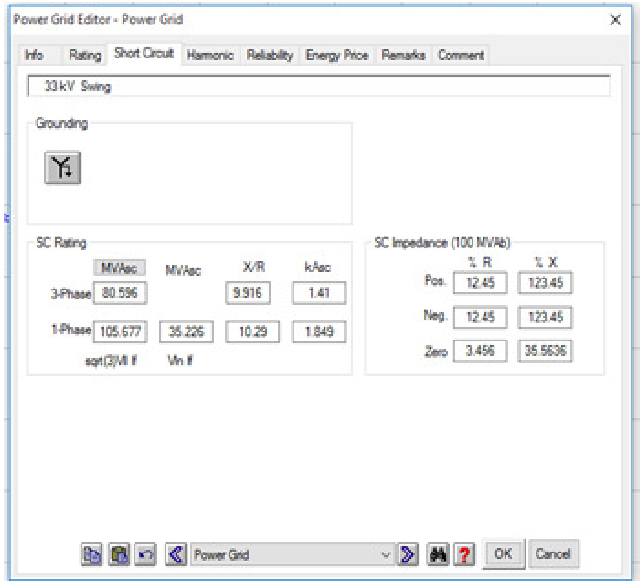
Figure 4: Single-line diagram of a spot load equivalent (Abdulkareem et al., (2014)

The section to be modeled are those which draw power from the Ugbowo 2×15 MVA, 33/11 kV injection substation under Ugbowo distribution network. This injection substation contains four (4) feeders. Figure 5 gives the explanation of the derived components and what they are modeled with (Abdulkareem et al., 2014):

i. The 33 kV Oluku sub-transmission feeder, fed the Ugbowo 33/11 kV injection substation from Ihovbor generating station was modeled by power grid in the software which is an interfacing point to the power grid whose voltage and frequency are supported by a larger system and unlikely to change. "It is valid to assume this equivalent machine to have constant internal voltage source and an infinite inertia" (Abdulkareem, et al., 2014). Therefore, the power grid was modeled in power station with the following Thevenin's equivalent shown in Figure 5.

Figure 5: Thevenin's equivalent of the power grid

From Figure 5, Ei was calculated from the internal bus voltage and the Req and Xeq were calculated from the positive sequence R and X of the Power Grid Editor as in Figure 6.



33 kV Swing

Grounding

SC Rating

	MVAsc	MVAsc	X/R	kAsc
3-Phase	80.596		9.916	1.41
1-Phase	105.677	35.226	10.29	1.849
	sqrt(3)Vll If	Vln If		

SC Impedance (100 MVAb)

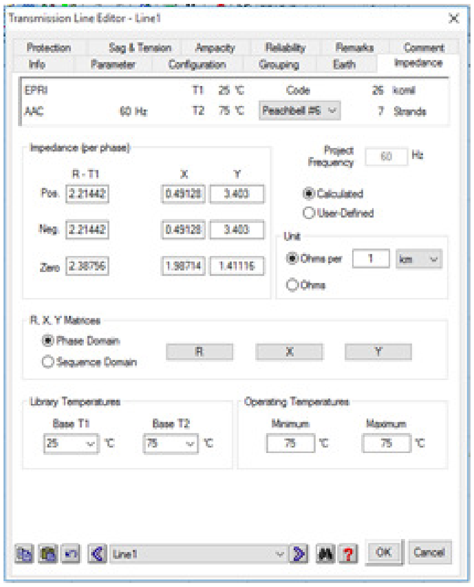
	% R	% X
Pos.	12.45	123.45
Neg.	12.45	123.45
Zero	3.456	35.5636

Figure 6: Dialog box of the power grid utility in the ETAP software

ii. The feeder pillars: These are represented by bus bars in the ETAP model of the network.

iii. The lumped loads: These are loads which represent the dynamic nature with which the loads tapped from the transformer that are utilized

The dialog box of the sub-transmission lines and the four (4) feeders of the Ugbowo injection substation are presented in Figure 7 and 8.



EPRI T1 25 °C Code 26 kcmil
AAC 60 Hz T2 75 °C Peachbell #6 7 Strands

Impedance (per phase)

	R - T1	X	Y
Pos.	2.21442	0.49128	3.403
Neg.	2.21442	0.49128	3.403
Zero	2.38756	1.98714	1.41116

Project Frequency 60 Hz

● Calculated
○ User-Defined

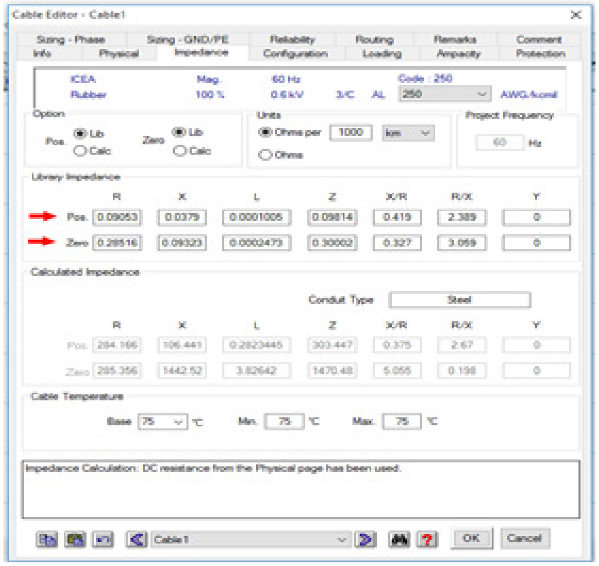
Unit
● Ohms per 1 km
○ Ohms

R, X, Y Matrices
● Phase Domain
○ Sequence Domain

Library Temperatures
Base T1 25 °C
Base T2 75 °C

Operating Temperatures
Minimum 75 °C
Maximum 75 °C

Figure 7: A dialog box indicating the Oluku 33 kV sub-transmission line parameters that feeds Ugbowo injection substation



ICEA Mag. 60 Hz Code : 250
Rubber 100 % 0.6 kV 3/C AL 250 AWG/kcmil

Option
Pos. ● Lib ○ Calc
Zero ● Lib ○ Calc

Units
● Ohms per 1000 km
○ Ohms

Project Frequency
60 Hz

Library Impedance

	R	X	L	Z	X/R	R/X	Y
Pos.	0.09053	0.0379	0.0001005	0.09814	0.419	2.389	0
Zero	0.28516	0.09323	0.0002473	0.30002	0.327	3.059	0

Calculated Impedance

Conduit Type: Steel

	R	X	L	Z	X/R	R/X	Y
Pos.	284.166	106.441	0.2823445	303.447	0.375	2.67	0
Zero	285.356	1442.52	3.82642	1470.48	5.055	0.198	0

Cable Temperature
Base 75 °C Min. 75 °C Max. 75 °C

Impedance Calculation: DC resistance from the Physical page has been used.

Cable1

Figure 8: A dialog box indicating the 11 kV feeder line parameter that feeds incomer 11 kV bus bars

2.5. Modeling the Single Line Diagram and Simulation of Ugbowo Distribution Network

From Figure 9 showing the single-line diagram of the distribution network to be simulated, the distribution network was modeled; the simple rules and procedures of drawing a single – line was adopted i.e., starting from top to bottom, left to right etc. The modeling in ETAP was carried out as follows:

i. The Power plant: This represents the network up to the secondary distribution point and it is set to swing mode because it makes up the difference between the scheduled loads and generated power (Saddat, 2004; Abdulkareem, et al., 2014).

ii. Modeling of the sub-transmission line which transports electricity from the Ihovbor generating station at Ihovbor community with its parameters given in Figure 9.

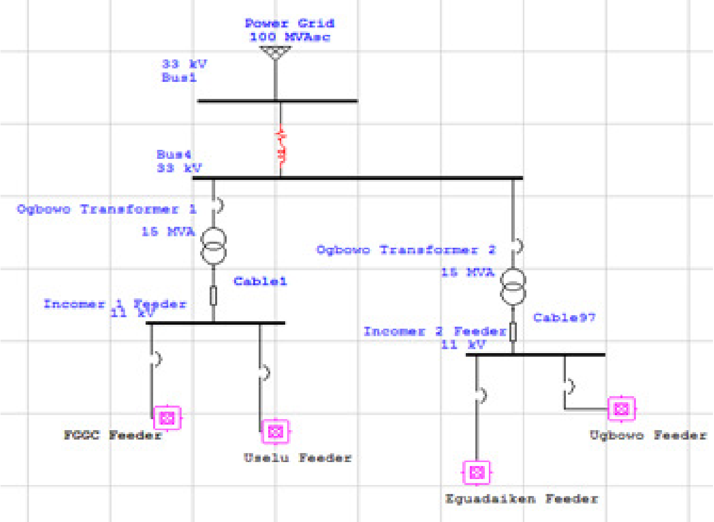


Figure 9: Single-line diagram of Ugbowo 2×15 MVA, 33/11 kV distribution network modeled in ETAP software

As seen from the single line diagram of Ugbowo 2×15 MVA, 33/11 kV distribution network modeled in ETAP, it takes it supply from the Ihovbor generating station through Oluku community down to Ugbowo 33/11 kV injection substation, and step its voltage down from 33 kV to 11 kV. The injection substation comprises of four (4) feeders which distribute the step down voltage to various outdoor stations. **T**he Ugbowo 2×15 MVA, 33/11 kV injection substation h**as** the following feeders:

i. FGGC 11 kV Feeder: This FGGC feeder feeds the FGGC road down to Technical, Uselu, S&T Barack and its environs. This feeder lies within the Ugbowo injection substation having a total line length of 7.5 km.

ii. Uselu 11 kV Feeder: This feeder feeds the Uselu area down to Psychiatric Hospital, Obakozuwa, Ayilala areas, etc. This feeder also lies within the Ugbowo injection substation having a total line length of 7.8 km

iii. Eguaedaiken 11 kV Feeder: This feeder feeds the Ojo road to down Mike Bread, Mela Motel, Evbareke, BEDC Office, etc. This feeder lies within the injection substation as well having total line length of 5.7 km

iv. Ugbowo 11 kV Feeder: This feeder feeds the CBN area down to Ohunwu, EDPA and its environs, etc. This feeder lies within the injection having total line length of 7.4 km.

All the four (4) feeders and injection substation are modeled in ETAP software and four (4) feeders' models are in composite networks because of the largeness of network feeders but when the composite is double clicked, it opens up into a large network of distribution outdoor transformers and their feeder pillars. A typical sample of this double clicked feeder model is presented in Figure 10 and similarly, other feeders of the network follow same pattern.

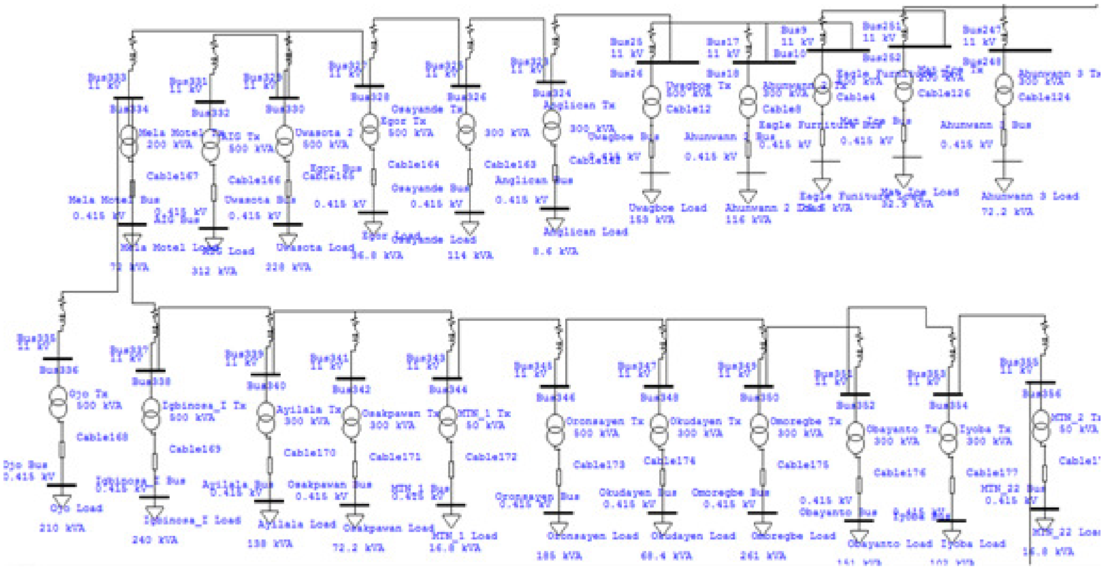


Figure 10: Eguaedaiken 11 kV feeder

2.6. Simulation of Power Flow Model of Ugbowo 2×15 MVA, 33/11 kV Distribution Network in ETAP

Figure 11 shows the model ready for the power flow analysis of the network under investigation in ETAP. The power flow analysis, was limited to the results tab and ticking an option in the dialog box as a pointer to what will be shown when the run power flow button is clicked.

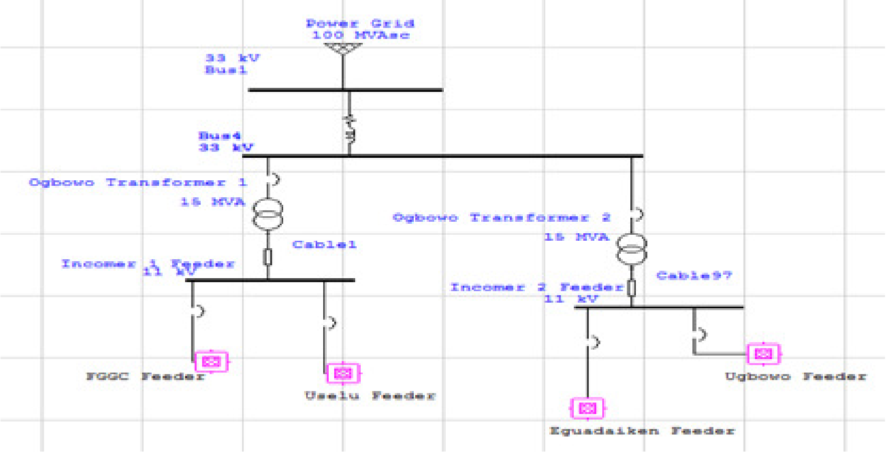
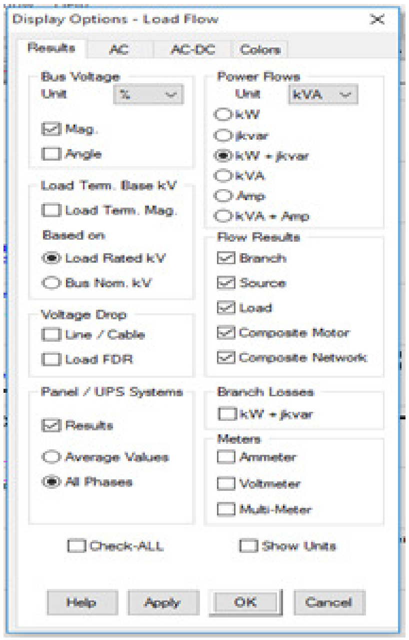


Figure 11: Single-line diagram of the modeled distribution network ready for power flow analysis



Bus Voltage
Unit %
☑ Mag.
☐ Angle

Load Term. Base kV
☐ Load Term. Mag.
Based on
● Load Rated kV
○ Bus Nom. kV

Voltage Drop
☐ Line / Cable
☐ Load FDR

Panel / UPS Systems
☑ Results
○ Average Values
● All Phases

Power Flows
Unit kVA
○ kW
○ jkvar
● kW + jkvar
○ kVA
○ Amp
○ kVA + Amp

Flow Results
☑ Branch
☑ Source
☑ Load
☑ Composite Motor
☑ Composite Network

Branch Losses
☐ kW + jkvar

Meters
☐ Ammeter
☐ Voltmeter
☐ Multi-Meter

☐ Check-ALL
☐ Show Units

Figure 12: Display option window of load flow analysis

3. RESULTS AND DISCUSSION

This section presents the results obtained after modeling and simulation of the electric power distribution network of the Ugbowo 2×15 MVA, 33/11 kV injection substation and its associated feeders. The computer simulations were done after modeling the electric power distribution network with one hundred and forty-two (142) buses, four (4) feeders and with respective outdoor substation 11 kV feeder lines in the ETAP version 12.6. The results are presented in Figure 13.

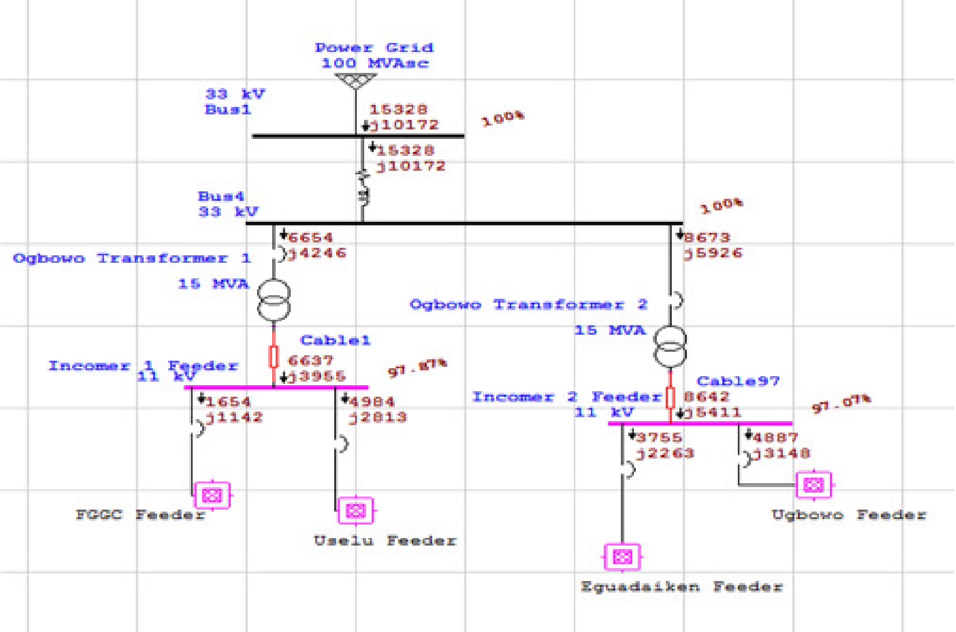
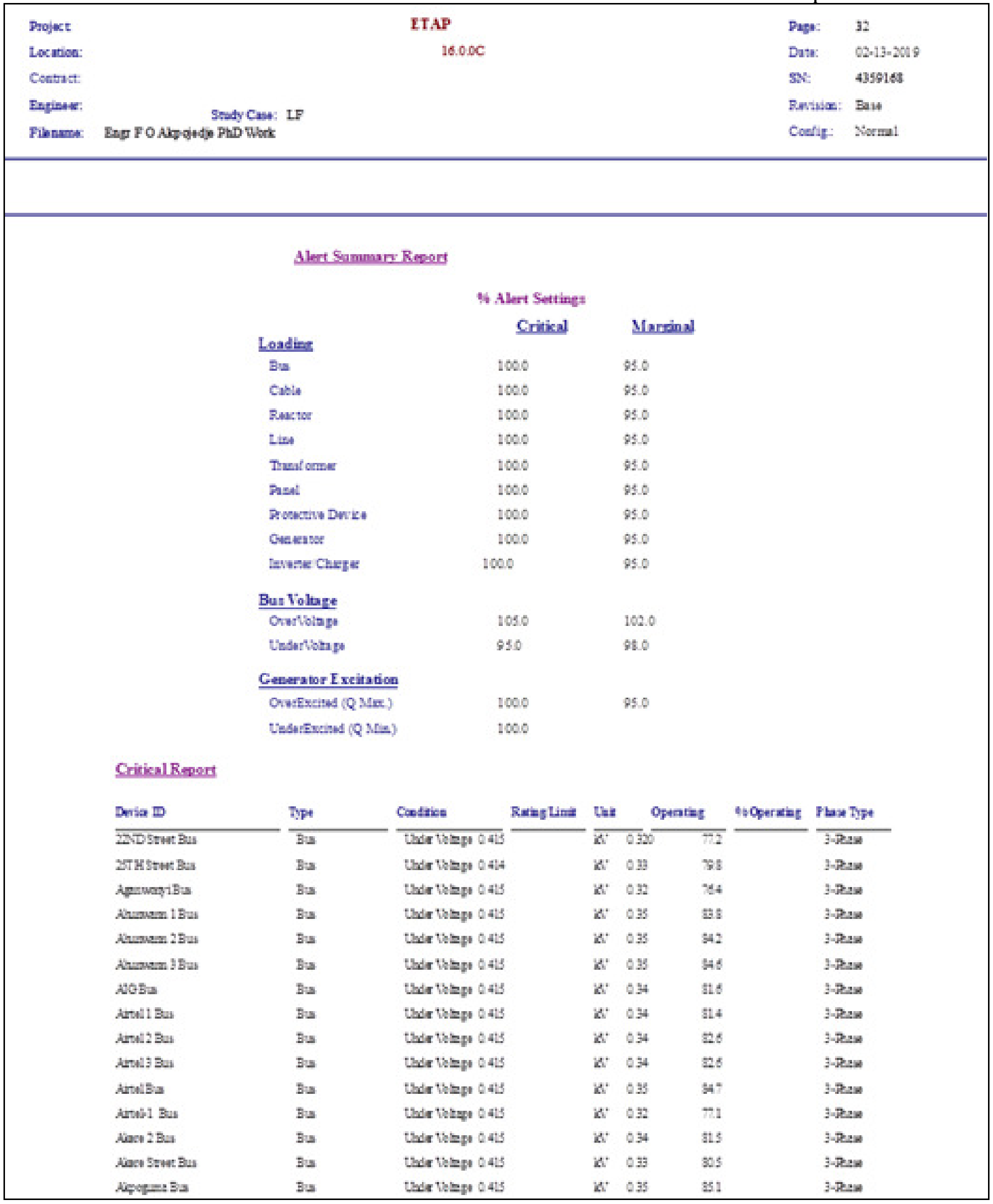


Figure 13: Results of the load flow of the Ugbowo distribution network

The selection type made in this research paper in the power flow section was kW+jkVAr and this is shown in Figure 13 display. The real power supplied to FGGC 11 kV feeder was 1.65 MW while the reactive power is 1.14 MVAr. Similarly, for the Uselu, Eguaedaiken and Ugbowo 11 kV feeders respectively was 4.98 MW, 3.76 MW and 4.89 MW for real power and 2.81 MVAr, 2.26 MVAr and 3.15 MVAr for reactive power respectively. From the power flow analysis simulated, it shows that the Ugbowo distribution network's 11 kV load buses are on red alert indicating results of undervoltage in the network as showed in Table 2, which means that there are high violations with respect to the statutory limits permitted by the Distribution Code for the Nigeria Electricity Distribution System Version 01 and IEEE standard of ±6%.

It is observed from investigation after the power flow run, that the one hundred and forty-two (142) load buses of the Ugbowo distribution network underwent violations. It is also observed from the data collected from the field measured that the power factor of each load bus was at variances whether higher or lower than the standard power factor of the defunct PHCN (Power Holding Company of Nigeria) of 0.85 (PHCN, 2013) for the Ugbowo distribution lines. The power flow analysis implemented for the Ugbowo 2×15 MVA, 33/11 kV distribution network shows that the network is on a red alert at every load bus of the entire network showing the conditions of various feeder pillars that underwent undervoltage. I.e., there is low voltage violation currently existing in the Ugbowo 2×15 MVA, 33/11 kV distribution network at various level as shown in Table 2.

Table 2: Red alert view of the critical condition of the various feeder pillars



Project:		ETAP		**Page:**	32
Location:		16.0.0C		**Date:**	02-13-2019
Contract:				**SN:**	4359168
Engineer:	Study Case: LF			**Revision:**	Base
Filename:	Engr F O Akpojedje PhD Work			**Config.:**	Normal

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

Critical Report

Device ID	Type	Condition	Rating Limit	Unit	Operating	% Operating	Phase Type
22ND Street Bus	Bus	Under Voltage 0.415		kV 0.320	77.2		3-Phase
25TH Street Bus	Bus	Under Voltage 0.414		kV 0.33	79.8		3-Phase
Agmwenyi1Bus	Bus	Under Voltage 0.415		kV 0.32	76.4		3-Phase
Ahanwenn 1 Bus	Bus	Under Voltage 0.415		kV 0.35	83.8		3-Phase
Ahanwenn 2 Bus	Bus	Under Voltage 0.415		kV 0.35	84.2		3-Phase
Ahanwenn 3 Bus	Bus	Under Voltage 0.415		kV 0.35	84.6		3-Phase
AIG Bus	Bus	Under Voltage 0.415		kV 0.34	81.6		3-Phase
Airtel 1 Bus	Bus	Under Voltage 0.415		kV 0.34	81.4		3-Phase
Airtel 2 Bus	Bus	Under Voltage 0.415		kV 0.34	82.6		3-Phase
Airtel 3 Bus	Bus	Under Voltage 0.415		kV 0.34	82.6		3-Phase
Airtel Bus	Bus	Under Voltage 0.415		kV 0.35	84.7		3-Phase
Airtel-1 Bus	Bus	Under Voltage 0.415		kV 0.32	77.1		3-Phase
Akece 2 Bus	Bus	Under Voltage 0.415		kV 0.34	81.5		3-Phase
Akece Street Bus	Bus	Under Voltage 0.415		kV 0.33	80.5		3-Phase
Akpogume Bus	Bus	Under Voltage 0.415		kV 0.35	85.1		3-Phase

4. CONCLUSION

The analysis of the power flow study implemented on the Ugbowo 2×15 MVA, 33/11 kV distribution grid provides the mimicry of the entire network. The very low voltage of the load buses and poor power magnitude obtained from the study of the Ugbowo distribution network 11 kV feeder show the epileptic power supply at the Ugbowo distribution network. This has resulted to high level of regimented load shedding in the distribution network thereby reducing the availability of power to consumers and the system reliability. Also, the quality of service (QoS) to customers in the network is poor as a result of the high voltage violations in the network load buses. Therefore, the network is on a red alert with urgent needs of voltage profile improvement techniques to ameliorate the current scenario or situation of voltage violations and quality of service to consumers in the network.

5. ACKNOWLEDGEMENT

The authors are grateful to the Benin Electricity Distribution Company (BEDC), Ugbowo branch for their assistance in getting relevant data used for this study. With high sincerity, the authors appreciate the contributions of the entire Distribution System Operators (DSOs) of Ugbowo injection substation for their immense contributions.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Akpojedje, F. O. (2017). *Electrical Power System III.* Unpublished Lecture Note, Department of Electrical and Electronic Engineering, National Institute of Construction Technology and Management (NICTM), Uromi, Edo State, Nigeria.

Akpojedje, F. O., Okakwu, I. K., Onogbotsere, M. E. and Egedi-Idu, S. O. (2014). Reliability estimation of injection substations based on outages scheduling in Nigeria power system. *Journal of the Nigerian Association of Mathematical Physics,* 28(2), pp. 405-414.

Abdulkareem, A., Awosope, C. O. A., Orovwode, H. E and Adelakun, A. A. (2014). Power Analysis of Abule – Egba 33kV distribution grid system with real network simulations. *IOSR Journal of Electrical and Electronics Engineering (IOSR- JEEE),* 9(2), pp. 67 – 80.

Bhailla, M. S. (2000). Proceedings of National Conference and Regulation in Infrastructure Services. New Delhi, India.

Idoniboyeobu, D. C and Ibeni, C. (2017). Analysis for electrical load flow studies in Port Harcourt, Nigeria, using Newton Raphson fast decoupled techniques. *American Journal of Engineering Research* (AJER), 6(12), pp. 230 – 240.

Kothari, D. P and Nagrath, I. J. (2008). Power System Engineering. *McGraw Hill Education (India) Private Limited, Green Park Education, New Delhi.*

PHCN (2013). Power Factor for Ugbowo Distribution Grid. *Power Holding Company of Nigeria (PHCN) Plc.*

Shimohammadi, D and Cheng, C. S. (1995). A Three-phase power flow for real-time distribution system analysis. *IEEE Transaction on Power System,* 10(2). pp. 671-679.

Saddat, H. (2004). Power system analysis. Second Edition, pp. 225 – 227.

Subrahmannyam, J. B. V. (2009). Load flow solution of unbalanced radial distribution systems, *Journal of Theoretical and Applied Information Technology,* 6(1), pp. 40-51.

Onohaebi, S. O. (2012). *Power System Analysis*. Unpublished M.Eng Lecture Notes, Department of Electrical and Electronic Engineering, University of Benin, Benin City, Edo State, Nigeria.