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A Concise Analysis of Abuad Distribution Network

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Abstract - *This study gives a concise analysis of theAfe Babalola University, Ado-Ekiti (ABUAD) distribution network. ABUAD is the fastest growing private university in Nigeria and in West Africa. The University has a robust power distribution network with stable electricity for staff, students and the entire community. The university has a total installed capacity of 5.35 MVA while the actual load demand is 2 MW; meaning that some of the transformers are under-utilized. During peak and off peak period, the bus voltage gives reading readings which are below the acceptable range of* $\pm 6\,V$. *To improve the distribution system of this university, synchronization of the transformers is required.*

Keywords: *ABUAD, electricity, demand, network.*

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I. Introduction

The solution to an electrical power system which provides voltages at all the buses, power flows and losses in the line at some levels of power generation, transmission and distribution is referred to as load flow. The essence of load flow is to carry out load forecast, power system planning and operation. Load flow is expected to be carried out on daily basis so as to understand the behavior of the system at different operating condition (Musti & Ramkhelawan, 2012).

Many researchers have used various computational techniques for load flow. These techniques include the use of applications such as Excel, Matlab, PowerWorld, and Power Simulator for Engineering. The power flow analysis can also be carried out to find the sensitivity of feeder status when it is subjected to varying load condition with respect to the length and total capacity of the distribution transformers. To determine the efficiency of what is generated at the generating stations, what is transmitted and what is distributed, power load flow must be carried out (preferable with appropriate computer applications).Several researchers analysed load flow by hand; but due to advancement in technology, computer simulation (which provides more efficient, fast, and accurate results) has taken over. Simply put, power flow is usually determined by the voltage at each bus of the network and the impedance of the line between the buses (Kirtley, 2011). The power system can be viewed as a collection of buses connected together by lines (cables). Each bus includesequipment such as transformers; which connect the systems to the loads.

Load flow analysis is very important in problem investigation, planning and the smooth operation power systems. The load flow equation is a non-linear algebraic equation without differential equations (Wang, 2008). Electrical networks transport electrical energy using a hierarchical structure of transmission and distribution networks and this happens in a limited number of control centers where the system is continuously monitored and controlled.

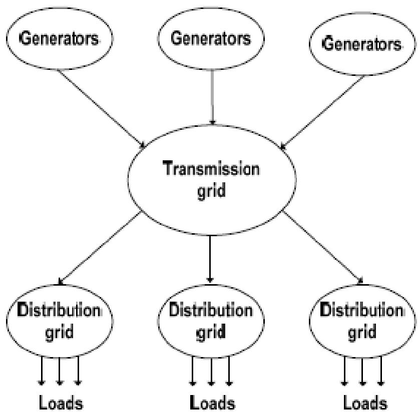

Figure 1: Conventional way of operating power system

Figure 1 shows the grid connection of generators. This grid connection is old method of transmitting electric power to different load centers. Technology is paving way for more advance methods; one of such called distributed generation. This distributed generation has the advantage of reduced power loss due to long line resistance.
This study employedElectrical Transient Analyzer Program (ETAP) to simulate Afe Babalola University, Ado Ekiti (ABUAD) power network so as to be able to suggest suggestive plan and load forecast for the school. ETAP is a new and reliable power system computer application that can accurately determine load flow.

II. Review of Load Flow Methods

Load flow problems consist of setting up some quantities which include generator bus, load bus, fixed impedance, and infinite bus. For the generator bus, the magnitude of the real power and terminal voltage are specified; in load bus, the real and reactive power are specified; for the fixed impedance, a fixed, linear impedance connected to a bus constrains the relationship between voltage and current; while in infinite bus, voltage source of constant magnitude and phase angle are connected (Kirtley, 2011).
There are three basic methods that can be used in solving load flow analysis. These methods are given as (Wang, 2008);

1. Newton-Raphson method,
2. Fast Decoupled method and
3. Gauss-Seidel method

2.1 Fast Decoupled Method

The basic idea of the fast decoupled method is the expression of the nodal power as a function of voltages in polar form. By using the active power mismatch and the reactive power mismatch in modifying the voltage angle and voltage magnitude respectively, we can solve both the active power and reactive power equations separately.

By computing the load flow calculation, the derivation of the fast decoupled method from Newton method would be easily carried out. Newton method focuses on solving the load flow correction equation, thus, when the nodal power equation is expressed in polar form, the correction equation becomes

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} - \begin{bmatrix}H & N\\ J & L\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V/V\end{bmatrix} \qquad (1)$$

Where P and Q are the real and reactive power.
It can also be written as

$$\begin{gathered}\Delta P - H\Delta\theta + N\Delta\, V/V\\ \Delta Q - J\Delta\theta + L\Delta\, V/V\end{gathered} \qquad (2)$$

In high voltage power system, the active power flow and the reactive power flow are mainly related to the angle of the nodal voltage phasor and its magnitude respectively. The element values of matrix N and J in load flow calculation are relatively very small;hence, the first step to be taken in simplifying Newton method is to neglect N and J to give

$$\left.\begin{aligned}\Delta P - H\Delta\theta\\ \Delta Q - L\Delta\, V/V\end{aligned}\right\} \qquad (3)$$

The second step in simplifying Newton method is to approximate the coefficient matrices of the equation (3) above as constant and symmetric matrices.
As the phase angle difference across a transmission line is usually not very large (does not exceed $10° \rightarrow 20°$), the relation can be written as

$$\left.\begin{aligned}\cos\theta_{ij} \approx 1\\ G_{ij}\sin\theta_{ij} \ll B_{ij}\end{aligned}\right\} \qquad (4)$$

The admittance B_{Lj} corresponding to the node reactive power is certainly far smaller than the imaginary part of the node self-admittance, giving,

$$B_{Li} - \frac{Q_i}{V_i^2} \ll B_{ii} \qquad (5)$$

And

$$Q_i \ll V_i^2 B_{ii} \qquad (6)$$

The coefficient matrix is the imaginary part of the nodal admittance matrix of the system and thus is a symmetric and constant matrix.
2.2 Newton Raphson Method
The Newton-Raphson method is an iterative technique for solving systems of simultaneous equations in the general form and it is written as

$$\left.\begin{aligned}f_j(X_1,\dots X_n,\dots X_r) = K_n\\ f_j(X_1,\dots X_n,\dots X_r) = K_n\\ f_n(X_1,\dots X_n,\dots X_r) = K_r\end{aligned}\right\} \qquad (7)$$

Wheref_1,....f_n....f_r are differentiable functions of the variables $X_1, \ldots X_n, \ldots X_r$ and K_1, ...K_n....K_r are constants applied to the load flow problem, the variables are the nodal voltage magnitudes and phase angles, the functions are the relationships between power, reactive power and node voltages.The constants are the specified values of power and reactive power at the generator and load nodes.
In general, for a system with r nodes, then at node n,
$I_n = Y_{n1}V_1 + Y_{n2}V_2 + \ldots + Y_{nn}V_n + \ldots + Y_{nr}V_r = \sum_{k=1}^{r} Y_{nk}V_k$ (8)
Power and reactive power functions can be derived by starting from the general expression for injected current at a node,

$I_n = \sum_{k=1}^{r} Y_{nk}V_k$ (9)

So the complex power input to the system at node n is
$s_n = V_n I_n^*$ (10)
Where the superscript * denotes the complex conjugate. Substituting from (8) with all complex variables written in polar form, we have
$s_n = V_n \sum_{k=1}^{r} Y_{nk}^* V_k^* = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| < \{\delta_n - \delta_k - \theta_{nk}\}$ (11)
The power and reactive power inputs at node n are derived by taking the real and imaginary parts of the complex power and they are given as
$P_n = \Re\{s_n\} = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| \cos\{\delta_n - \delta_k - \theta_{nk}\}$ (12)
$Q_n = \Im\{s_n\} = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| \sin\{\delta_n - \delta_k - \theta_{nk}\}$ (13)

The load flow problem is to find values of voltage magnitude and phase angle, which, when substituted into (12) and (13), produces values of power and reactive power equal to the specified set values at that node,P_{ns} and Q_{ns}. The first step in the solution is to make initial estimates of all the variables $|V_n^\circ|$ andδ_n° where the superscript ° indicates the number of iterative cycles completed. Using these estimates, the power and reactive power input at each node can be calculated from (12) and (13). These values are compared with the specified values to give a power and reactive power error. For node n,
$\Delta P_n^\circ = P_{ns} - \sum_{k=1}^{r} |V_n^\circ||V_k^\circ||Y_{nk}| \cos\{\delta_n^\circ - \delta_k^\circ - \theta_{nk}\}$ (14)
$\Delta Q_n^\circ = Q_{ns} - \sum_{k=1}^{r} |V_n^\circ||V_k^\circ||Y_{nk}| \sin\{\delta_n^\circ - \delta_k^\circ - \theta_{nk}\}$ (15)
2.3 Gauss-Seidel Method
The Gauss-Seidel Method is another iterative technique for solving the load flow problem, by successive estimation of the node voltages. Equation (8) can be rearranged to give an expression for the complex conjugate of the current input at node n. The expression is given as
$I_n^* = \sum_{k=1}^{n-1} Y_{nk}^* V_k^* + Y_{nn}^* V_n^* + \sum_{k=n+1}^{r} Y_{nk}^* V_k^*$ (16)
Substituting for $I_n^*$from (16) into (10) gives
$\frac{s_n}{V_n} = \sum_{k=1}^{n-1} Y_{nk}^* V_k^* + Y_{nn}^* V_n^* + \sum_{k=n+1}^{r} Y_{nk}^* V_k^*$ (17)
and re-arranging gives
$V_n^* = -\sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^*}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^*}{Y_{nn}^*} + \frac{s_n}{V_n Y_{nn}^*}$ (18)
A direct solution cannot be obtained from (18) because the node voltage V_n appears on both sides of the equation. However, this equation is used in the Gauss-Seidel method as the basis for an iterative solution. If V_n^p and V_n^{p+1}denote the values of the voltage at node n after p and p+1 iteration cycles, (18) can be written as
$V_n^{*(p+1)} = -\sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^{*(p+1)}}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^{*(p)}}{Y_{nn}^*} + \frac{s_n}{V_n^{(p)} Y_{nn}^*}$ (19)

Note that in evaluating the nth node voltage, the latest estimates of the other node voltages are used. In the p+1th iteration cycle when performing the calculation for node n, the voltages at the nodes k=1…n-1 are available, but for the other node voltages the values from the previous (p^{th}) cycle has to be used. The foregoing discussion is appropriate to load nodes. At the floating bus, the voltage $V_n$is known and so does not need to be calculated. Generator nodes are particularly problematical for the Gauss-Seidel Method. At these nodes the power p_n and voltage magnitude $|V_n|$are specified, so in (19),V_n^{p+1}cannot be calculated because Q_n (the imaginary part of s_n) is unknown. This difficulty is addressed by first calculatingQ_n with the voltage component given as
$(V_n^{*(p+1)})^\# = -\sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^{*(p+1)}}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^{*(p)}}{Y_{nn}^*} + \frac{p_n}{V_n^{(p)} Y_{nn}^*}$ (20)
can be calculated immediately and substituted into (19) to give
$V_n^{*(p+1)} = (V_n^{*(p+1)})^\# + \frac{j Q_n}{V_n^{(p)} Y_{nn}^*}$ (21)
but for a generator node, the magnitude $|V_n|$ is known, so considering the magnitudes in (21),
$|V_n|^2 = \left[\Re\{(V_n^{*(p+1)})^\# + \frac{j Q_n}{V_n^{(p)} Y_{nn}^*}\}^2 + \Im\{(V_n^{*(p+1)})^\# + \frac{j Q_n}{V_n^{(p)} Y_{nn}^*}\}^2\right]$ (22)

which can be solved for Q_n (by iteration if necessary). The calculated value of Q_n is substituted back into (21) and the new estimate of generator node voltage is found. When compared to the Newton-Raphson Method, the Gauss-Seidel Method involves simple calculations but has a low rate of convergence. Therefore, it is common practice to accelerate the iterative process by adding an extra term proportional to the difference between the new and previous values to the newly-calculated value of each variable as shown in (23) below.

$$V_n^{*(p+1)}\Big|_{accelerated} = V_n^{*(p+1)} + a*\{V_n^{*(p+1)} - V_n^{*(p)} \quad (23)$$

2.4 Computer Simulation of Load Flow

Many researchers have moved far from calculating the load flow of any network byhand. For some years ago, computers have taken over the tedious exercise involved in solving load flow manually.

Eseosa & Ogujor, 2012 used ETAP and Newton Raphson methods to carry out load flow analysis on the 330 kV of the entire Nigeria Power Network. The study determined the bus voltages, power losses and flows in the Nigeria 330 kV integrated power. Nigeria power network has 52 buses, 17 generating stations, 64 transmission lines and 4 control centers. The result showed that the total power losses of 92.63331 MW emanate from the network. The transmission lines contribute 90.300 MW losses while the remaining 2.3331 MW was the losses from the generating stations.

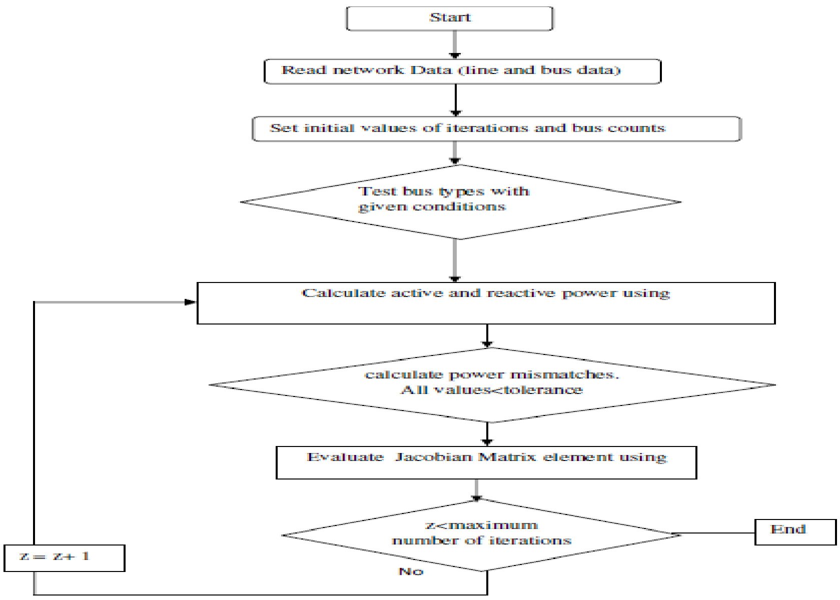

Figure 2: Flow chart of Newton Raphson method ((Eseosa & Ogujor, 2012)

The flow chart of Newton Raphson method is shown in Figure 2.

Thanigaivel & Azeezur, 2016carried out a study on power flow analysis and protection coordination of real time system for Sri Muthukumaran Institute of Technology (SMIT) system. The software used was ETAP. The single line diagram was drawn in the one line view and the load flow analysis was performed by using the ETAP. The ETAP was able to perform the load flow and the protection coordination effectively. Jaleel & Shabna, 2013 employed Newton-Raphson in ETAP to evaluate flow analysis and reliability of 220 kV Kerala Power system. The information obtained from the load are magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. The various reliability indices were also obtained which can be used as a measure of system reliability. The optimal capacitor placement was done using ETAP.

Afolabi et al., 2015 also used MATLAB to carry out a study on the analysis of the load flow problems in power systems planning. The study considered IEEE 9-bus, IEEE 30-bus, and IEEE 57-bus systems. The test case was performed for Gauss-Seidel, Network-Raphson and Fast Decouple methods. The load flow result indicated that the iteration time for Gauss-Seidel is the longest compared to the other methods. Newton Raphson has more computational time due to complexity of the Jacobian matrix for each iteration but still, it converges fast enough because of the lower number of iterations are carried out. For this reasons, Afolabi et al., 2015 suggested that Guass-Seidel method should be used for small power network but the most effective and reliable methods is the Newton-Raphson method because it converges fast and its more accurate.

III. Methodology

The methods adopted during this research are as follows;

1. Collection of data and one line diagram of ABUAD power network at the Works Department.

2. Modeling of the one-line diagram of the network in ETAP
3. Reading and studying the result of the computer application to know the deficient buses
4. Determining the load forecast using linear iterative method

Table 1: Transformer Condition and Ratings

Name of Substation	TRANSFORMER RATING (kVA)	Route (m)	Remark
Fidelity	50	100	Ok and in use
ABUAD INN	500	60	Ok and in use
TDC	500	400	Ok and in use
COLLEGE 1	500	600	Ok and in use
COLLEGE 2	500	675	Ok and in use
ENGINEERING COLLEGE	500	725	Ok and in use
STAFF QUARTERS	500	930	Ok and in use
FEMALE HOSTEL	500	1330	Ok and in use
MALE HOSTEL	500	1530	Ok and in use
VENTURE/CAFÉ	500	1230	Ok and in use
INTERNATIONAL SCHOOL	500	300	Ok and in use
FARM	300	2500	Ok and in use

Table 1 gives the status of the transformers installed in the distribution system of ABUAD network.

3.1. Presentation of Data

Data collected are as follows;

1. Documents containing list of all 11/0.415 kV transformers connected to the injection substation and their ratings.
2. Samples of conductors used to run the 33 kV to central substation and from the central substation to the various substations.
3. Single lines diagram of the entire network
4. Route length of the various substations.

IV. Result and Analysis

After modeling the network in ETAP, it was observed that ABUAD network has voltage at each substation that is not within the acceptable limit of $\pm 6\ V$. Table 3 gives the voltage profile result from the ETAP 7.0.

Table 2: Peak Load Demand

S/N	Name of Substation	Rating of Transformer (kVA)	Peak Load			Off Peak Load		
			kW	p.f	kVA	kW	p.f	kVA
1	Fidelity	50	13.2	0.77	17.1	9	0.83	10.8
2	ABUAD INN	500	133	0.78	170.5	100	0.88	113.6
3	TDC	500	27	0.8	33.8	23	0.98	23.5
4	COLLEGE 1	500	178	0.98	181.6	120	0.99	121.2
5	COLLEGE 2	500	162	0.94	172.3	130	0.93	139.9
6	ENGINEERING COLLEGE	500	261	0.72	362.5	200	0.8	250
7	STAFF QUARTERS	500	236	0.805	293.2	220	0.88	250
8	FEMALE HOSTEL	500	209	0.73	286.3	180	0.89	202.2
9	MALE HOSTEL	500	216	0.85	254.2	200	0.87	229.9
10	VENTURE/CAFE	500	118	0.726	162.5	100	0.91	109.9
11	INTERNATIONAL SCHOOL	500	14	0.713	19.6	3	0.99	3.03
12	FARM	300	165	0.82	201.2	100	0.89	112.4

Table 2 is the actual peak load demand reading of ABUAD network.

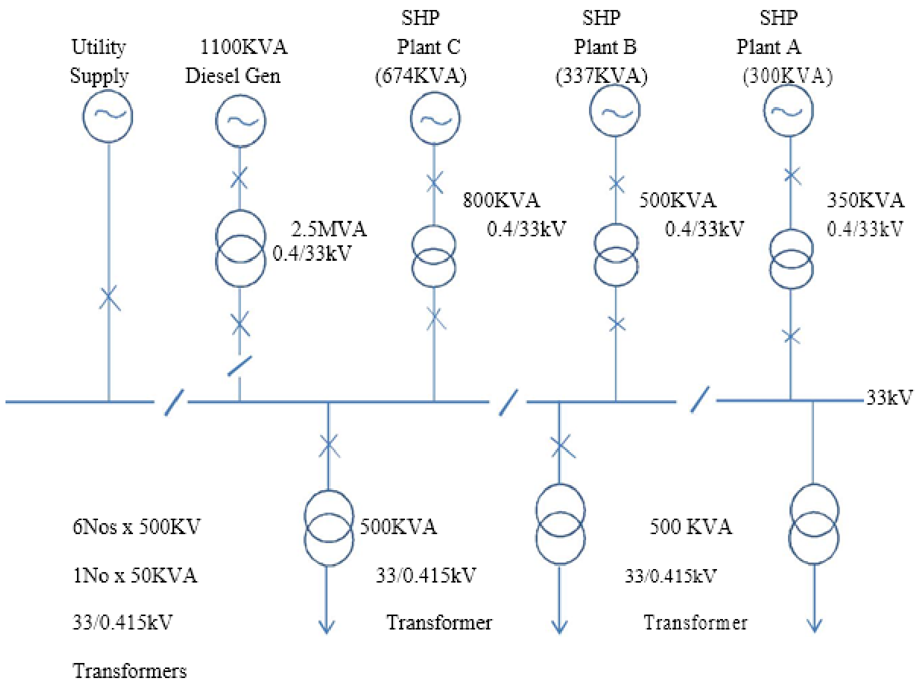

Figure 3: One line diagram of the network.

Figure 3 is the one-line diagram of ABUAD network.

Table 3: Load flow result for peak period.

Bus ID	Nominal kV	Voltage (%)	Voltage Drop (%)	MW Loading	Remark
COLLEGE 1 BUS	0.415	85.52	14.48	0.13	Voltage Drop Outside acceptable limit
COLLEGE 2 BUS	0.415	85.41	14.59	0.118	Voltage Drop Outside acceptable limit
ENGINEERING BUS	0.415	83.21	16.79	0.181	Voltage Drop Outside acceptable limit
FARM BUS	0.415	84.41	15.59	0.117	Voltage Drop Outside acceptable limit
FEMALE HOSTEL BUS	0.415	83.86	16.14	0.147	Voltage Drop Outside acceptable limit
FIDELITY BUS	0.415	86.22	13.78	0.01	Voltage Drop Outside acceptable limit
INN LOAD BUS	0.415	86.43	13.57	0.1	Voltage Drop Outside acceptable limit
INTER. LOAD BUS	0.415	87.17	12.83	0.011	Voltage Drop Outside acceptable limit
MALE HOSTEL BUS	0.415	84.25	15.75	0.153	Voltage Drop Outside acceptable limit
QUARTERS BUS	0.415	83.89	16.11	0.166	Voltage Drop Outside acceptable limit
TDC BUS	0.415	86.81	13.19	0.02	Voltage Drop Outside acceptable limit
VENTURES BUS	0.415	85.13	14.87	0.086	Voltage Drop Outside acceptable limit

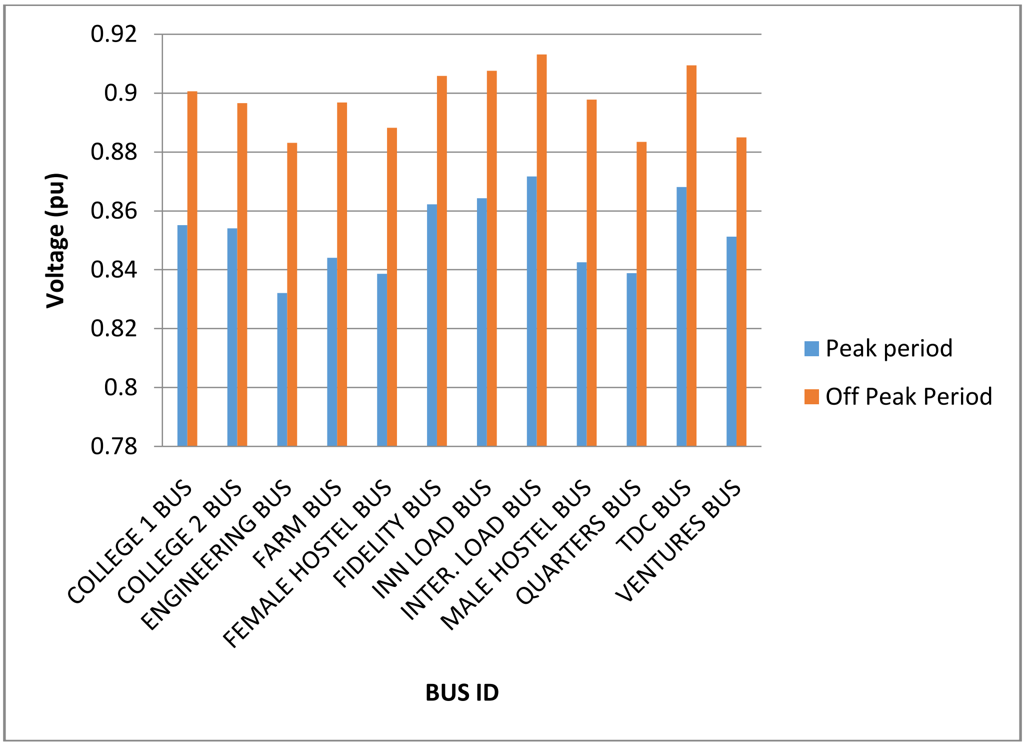

Figure 4: Peak and off peak load flow graph.

Table 3 is the simulation reading of the network as modelled in ETAP 7.0. The reading shows that the voltage at each bus is less than the required voltage which should be $\pm 6\ V$
Figure 4 is a graph showing the peak and off-peak simulation reading of the network.
The summary of the load flow report is presented in Table 4 and 5.

Table 4: Summary of load flow report for peak period

Loads	12
Load-MW	1.361
Load-Mvar	1.059
Generation-MW	0
Generation-Mvar	0
Loss-MW	0.122
Loss-Mvar	0.183
Mismatch-MW	0
Mismatch-Mvar	0

Table 5: Summary of load report for off peak period

Loads	12
Load-MW	1.174
Load-Mvar	0.621
Generation-MW	0
Generation-Mvar	0
Loss-MW	0.073
Loss-Mvar	0.063
Mismatch-MW	0
Mismatch-Mvar	0

V. Conclusion

The load flow result from the analysis of ABUAD distribution network indicates the following;

1. The load flow analysis carried on the network shows that a total twelve (12) load buses in the network.
2. There is voltage violation in all the twelve (12) substations during peak and off period.

It can therefore before be concluded that the energy demand at ABUAD is approximately 2 MW. Also, the network is subjected to voltage violation as a result of losses due to resistive losses in the long distance line. To overcome this challenge, it is necessary to synchronize the transformers within the university community.

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