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Load Flow Analysis of a 15Mva Injection Substation

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Abstract

This study presents the load flow analysis of Otovwodo 33/11kV injection substation, Nigeria. It is an obvious fact that the planning, design and operation of power systems require load flow calculations to analyze the steady state of the system under various operating conditions, and equipment configuration. This load flow helps to determine the state of the power system for a given load and generation distribution. This paper presents the computer aided power flow analysis of the existing Otovwodo33/11kV distribution network using the ETAP 7.0 software. The result showed that out of 91load feeders of which 6 is out of service, voltage violation occurred in all for peak period but for off-peak period, fifty five (55) violation was recorded while thirty (30) was within the statutory voltage range.

Key words: load flow, ETAP, voltage, and buses.

1.0 Introduction

Load flow studies are used to guarantee that electrical power transfer from generators to consumers through the grid system is steady, economic and reliable. Customary methods for solving the load flow problem are iterative, using the Newton-Raphson or the Gauss-Seidel method [1,2].

The load-flow analysis has a critical part for the configuration of a distribution network. A proficient and great conveging of load-flow of distribution system is not only useful to acquire voltage and power loss of the network but also necessary for accurate selection of branch conductor and other aspect of planning. Load-flow methods like Newton- Raphson, and fast decoupled load-flow method proposed in [2] and [3] and can be effectively utilized for transmission and distribution systems.

The accurate t electrical performance and power flows of the system working under steady state needed in productive way. Load flow study gives the real and reactive power losses of the system and voltages at different buses of the system. With the developing market in the present time, effective planning can only be assured with the assistance of effective load flow study[4].

In this paper, Electrical Transient Analyzer Program (ETAP) 7.0 software program was used in carrying out the load flow study. ETAP Real-Time is a fully integrated suite of electrical software applications that provides intelligent power monitoring, energy management, system optimization, advanced automation, and real-time prediction. With the data (route lengths, transformer ratings, peak load readings, power factor e.t.c) gotten from the field for the 91 substations (with six (6) out of service) they were fed into the software. The load flow was analyzed using Newton-Raphson method which is embedded in the software.

2.0 Review of Load Flow Methods

There are a few methodologies to solving power flow. Numerous researchers thought of distinctive strategies for unraveling load flow of which all still encompass the three main methods for the analysis of power flow. These methods include Newton-Raphson, Fast Coupled Iteration and Gauss Seidel methods [5].

This paper reviews two of out of these three.

A. Newton Raphson Method

The Newton-Raphson method is an iterative technique for solving systems of simultaneous equations in the general form:

$$f_1(X_1, \ldots X_n, \ldots X_r) = K_1$$

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$f_j(X_1, .X_n, .. X_r) = K_n$ (1)

$f_n(X_1, ... X_n, ... X_r) = K_r$

Where f_1,....f_n....f_r are differentiable functions of the variables $X_1, ... X_n, ... X_r$ and K_1, ...K_n....K_r are constants. Applied to the load flow issues, the variables are the nodal voltage magnitudes and phase angles, the functions are the relationships between power, reactive power and node voltages, while the constants are the specified values of power and reactive power at the generator and load nodes.

As a rule, for a system with r nodes, then at node n:

$I_n = Y_{n1}V_1 + Y_{n2}V_2 + .. + Y_{nn}V_n + ... + Y_{nr}V_r = \sum_{k=1}^{r} Y_{nk}V_k$ (2)

Power and reactive power functions can be gotten by beginning from the general expression for injected current at a node:

$I_n = \sum_{k=1}^{r} Y_{nk}V_k$ (3)

So the complex power input to the system at node n is:

$s_n = V_n I_n^*$ (4)

Where the superscript * signifies the complex conjugate. Substituting from (4) with all complex variables written in polar form:

$s_n = V_n \sum_{k=1}^{r} Y_{nk}^* V_k^* = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| < \{\delta_n - \delta_k - \theta_{nk}\}$ (5)

The power and reactive power inputs at node n are derived by taking the real and imaginary parts of the complex power:

$P_n = \Re\{s_n\} = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| \cos\{\delta_n - \delta_k - \theta_{nk}\}$ (6)

$Q_n = \Im\{s_n\} = \sum_{k=1}^{r} |V_n||V_k||Y_{nk}| \sin\{\delta_n - \delta_k - \theta_{nk}\}$ (7)

The load flow problem is to find values of voltage magnitude and phase angle, which, when substituted into (7) and (6), produce 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: $|V_n^\circ|$, δ_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 (6) and (7). These values are compared with the specified values to give a power and reactive power error. For node n:

$\Delta P_n^\circ = P_{ns} - \sum_{k=1}^{r} |V_n^\circ||V_k^\circ||Y_{nk}| \cos\{\delta_n^\circ - \delta_k^\circ - \theta_{nk}\}$ (8)

$\Delta Q_n^\circ = Q_{ns} - \sum_{k=1}^{r} |V_n^\circ||V_k^\circ||Y_{nk}| \sin\{\delta_n^\circ - \delta_k^\circ - \theta_{nk}\}$ (9)

The power and reactive power errors at each node are related to the errors in the voltage magnitudes and phase angles, e.g. $\Delta|V_n^\circ|$, $\Delta\delta_n^\circ$ by the first order approximations:

$$\begin{bmatrix} \vdots \\ \Delta P_n^\circ \\ \vdots \\ \cdots \\ \vdots \\ \Delta Q_n^\circ \\ \vdots \end{bmatrix} = \begin{bmatrix} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \frac{\partial P_n}{\partial \delta_{n-1}} & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial \delta_{n+1}} & \vdots & \vdots & \vdots & \frac{\partial P_n}{\partial |V_{n-1}|} & \frac{\partial P_n}{\partial |V_{n-1}|} & \frac{\partial P_n}{\partial |V_{n-1}|} & \vdots \\ & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \\ & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \frac{\partial Q_n}{\partial \delta_{n-1}} & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial \delta_{n+1}} & \vdots & \vdots & \vdots & \frac{\partial Q_n}{\partial |V_{n-1}|} & \frac{\partial Q_n}{\partial |V_n|} & \frac{\partial Q_n}{\partial |V_{n+1}|} & \vdots \\ & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \end{bmatrix} \begin{bmatrix} \Delta \delta_{n-1}^\circ \\ \Delta \delta_n^\circ \\ \Delta \delta_{n+1}^\circ \\ \cdots \\ \Delta|V_{n-1}^\circ| \\ \Delta|V_n^\circ| \\ \Delta|V_{n+1}^\circ| \end{bmatrix} \quad (10)$$

Where the matrix of partial differentials is called the Jacobian matrix, [J]. The elements of the Jacobian are calculated by differentiating the power and reactive power expressions (6) and (7) and substituting the estimated values of voltage magnitude and phase angle.

At the next stage of the Newton-Raphson solution, the Jacobian is inverted. Matrix inversion is a computationally-complex task with the resources of time and storage increasing rapidly with the order of [J]. This requirement for matrix inversion is a major drawback of the Newton-Raphson method of load flow analysis for large-scale power systems. However, with the inversion completed, the approximate errors in voltage magnitudes and phase angles can be calculated by pre-multiplying both sides of (10):

$$\begin{bmatrix} \Delta \delta_{n-1}^\circ \\ \Delta \delta_n^\circ \\ \Delta \delta_{n+1}^\circ \\ \cdots \\ \Delta|V_{n-1}^\circ| \\ \Delta|V_n^\circ| \\ \Delta|V_{n+1}^\circ| \end{bmatrix} = [J^0]^{-1} \begin{bmatrix} \vdots \\ \Delta P_n^\circ \\ \vdots \\ \cdots \\ \vdots \\ \Delta Q_n^\circ \\ \vdots \end{bmatrix} \quad (11)$$

The approximate mistakes from (11) are added to the beginning evaluations to create new evaluated estimations of node voltage magnitude and angle. For node n:

$|V_n^1| = |V_n^\circ| + \Delta|V_n^\circ|$ (12)

$\delta_n^1 = \delta_n^0 + \Delta\delta_n^0$ (13)

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Since first-request estimates are utilized as a part of (10) the new estimates (indicated by the superscript | in equation (12) are not correct answers for the problem. Notwithstanding, they can be utilized within an alternate iterative cycle, involving the solution of Equations (6) to(13). The methodology is repeated until the contracts between successive estimates are within an acceptable tolerance band.

The description above relates particularly to a load node, where there are two unknowns (the voltage magnitude and angle) and two mathematical statements identifying power and reactive power. For a generator node the voltage magnitude $|V_n|$ and power P_n are specified, but the reactive power is not specified. The order of the calculation can be reduced by 1. There is no compelling ensure that the reactive power is at a set value and only the angle of the node voltage needs to be calculated, so one row and column are removed from the Jacobian. For the floating bus, both voltage magnitude and angle are specified, so there is no compelling reason to calculate these quantities [5, 6]

A. Gauss-Seidel Method

The Gauss-Seidel Method is another iterative technique for solving the load flow problem, by progressive estimation of the node voltages. Equation (2) can be modified to give a representation for the complex conjugate of the current input at node n:

$$I_n^* = \sum_{k=1}^{n-1} Y_{nk}^* V_k^* + Y_{nn}^* V_n^* + \sum_{k=n+1}^{r} Y_{nk}^* V_k^* \quad (14)$$

Substituting for I_n^* from (12) into (4):

$$\frac{s_n}{V_n} = \sum_{k=1}^{n-1} Y_{nk}^* V_k^* + Y_{nn}^* V_n^* + \sum_{k=n+1}^{r} Y_{nk}^* V_k^* \quad (15)$$

and re-arranging:

$$V_n^* = - \sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^*}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^*}{Y_{nn}^*} + \frac{s_n}{V_n Y_{nn}^*} \quad (16)$$

The node voltage V_n shows up on both sides of (16), which can't, in this way, be utilized to give a direct solution. In any case, this equation is used in the Gauss-Seidel technique as the premise 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, (16) can be written:

$$V_n^{*(p+1)} = - \sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^{*(p+1)}}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^{*(p)}}{Y_{nn}^*} + \frac{s_n}{V_n^{(p)} Y_{nn}^*} \quad (17)$$

Note that in assessing the nth node voltage, the most recent of the other node voltages are utilized. In the p+1th iteration cycle when performing the calculation for node n, the voltages at the nodes k=1…n-1 are available, however for the other node voltages the values from the previous (p^{th}) cycle have 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 determined, so in (17) V_n^{p+1} can't be calculated because Q_n (the imaginary part of s_n) is unknown. This difficulty is addressed by first calculating Q_n, as follows:

the voltage component: $$(V_n^{*(p+1)})^{\#} = - \sum_{k=1}^{n-1} \frac{Y_{nk}^* V_k^{*(p+1)}}{Y_{nn}^*} - \sum_{k=n+1}^{r} \frac{Y_{nk}^* V_k^{*(p)}}{Y_{nn}^*} + \frac{p_n}{V_n^{(p)} Y_{nn}^*} \quad (18)$$

can be calculated immediately and substituted into (17):

$$V_n^{*(p+1)} = (V_n^{*(p+1)})^{\#} + \frac{jQ_n}{V_n^{(p)} Y_{nn}^*} \quad (19)$$

but, for a generator node, the magnitude $|V_n|$ is known, so considering the magnitudes in (19):

$$|V_n|^2 = \left[\Re \{(V_n^{*(p+1)})^{\#} + \frac{jQ_n}{V_n^{(p)} Y_{nn}^*}\}^2 + \Im\{ (V_n^{*(p+1)})^{\#} + \frac{jQ_n}{V_n^{(p)} Y_{nn}^*}\}^2 \right] \quad (20)$$

Which can be solved for Q_n (by iteration if necessary). The calculated value of Q_n is substituted back into (19) and the new estimate of generator node voltage is found[7, 8, 9].

At the point when compared to the Newton-Raphson Method, the Gauss-Seidel Method includes simple calculations; however it is slow to converge. Therefore, it is common practice to accelerate the iterative process, by adding to the newly-calculated value of each variable an extra term proportional to the difference between the new and previous values. For example:

$$V_n^{*(p+1)} \Big|_{accelerated} = V_n^{*(p+1)} + a * \{V_n^{*(p+1)} - V_n^{*(p)} \quad (21)$$

3.0 Otovwodo Network Overview

Otovwodo, 15MVa, 33/11Kv injection substation, known as (U16) as its communication name is located at otovwodo junction, along Ughelli – Patani Express Road, Ughelli, Delta State, Nigeria.It gets its supply from the 33Kv transmission via the Transcorp generating Power Limited which is also located on Ughelli – Patani Express Road, Ughelli, Delta State. The generating power plant generates at 16Kv and it is stepped up to 132Kv and fed into a 30 MVA 33/11 Kv transformer, which in turn feeds the Otovwodo 15 MVA, 33/11KV Injection Substation. The distance from the generating station to injection substation is 18km with cross sectional area of 120mm², while that from Otovwodo substation to various distribution substations is 100mm². Fig. 1 shows the photo view of the 15MVA transformer as well as the switch yard and Fig. 2 shows the one line diagram of the entire Network.

Fig 1: Otovwodo, 15MVA, 33/11KV Injection Substation.

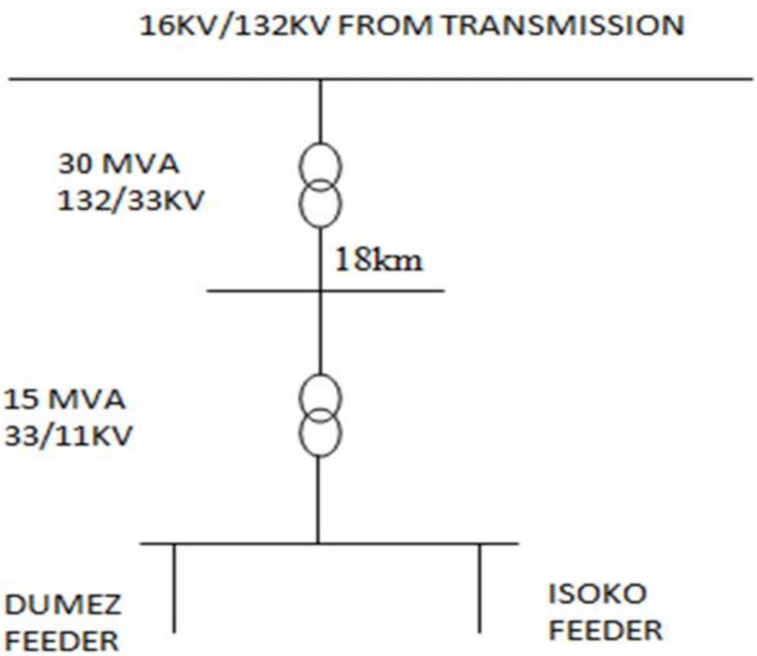

Fig 2: One line Diagram Showing Power Source for Injection Substation.

4.0 Simulation Result and Analysis

The simulation of the network is presented in Table 1. The load flow method used was Newton-Raphson and it converged at less than 99 iterations.

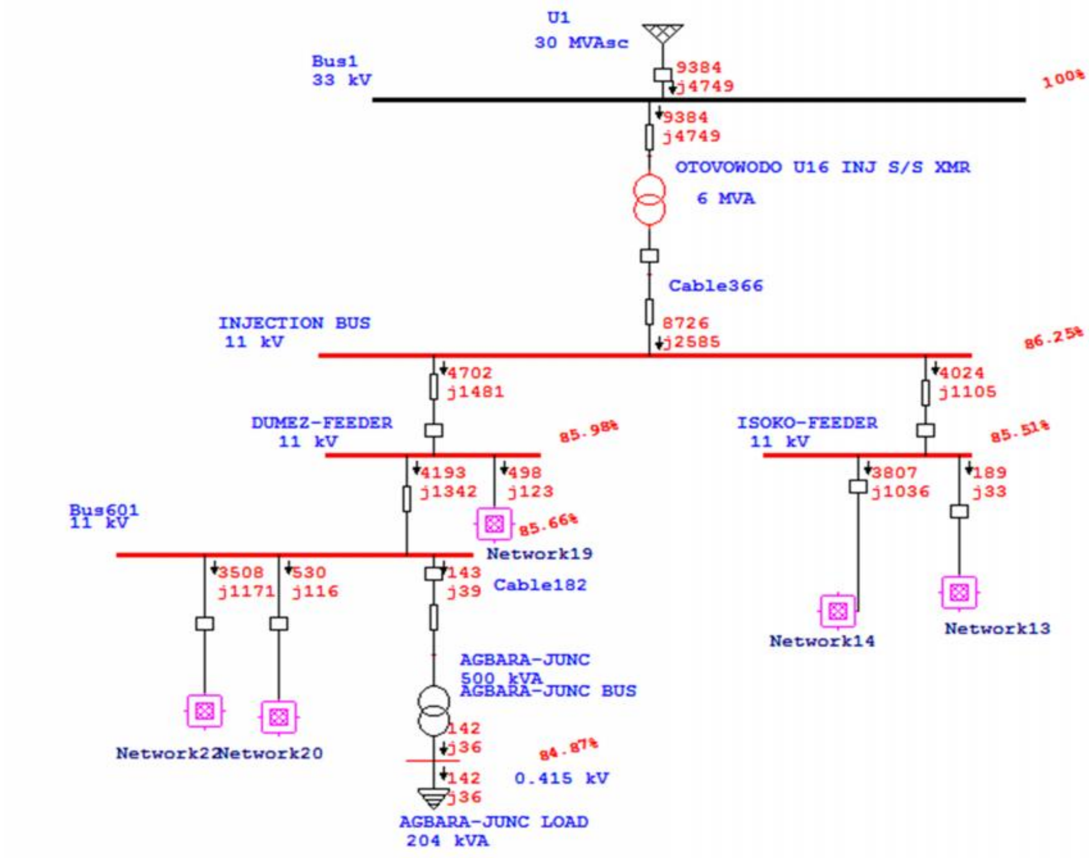

Fig 3: Simulation View of Etap Software Showing Network.

Table 1: Load Flow report of the network showing the various Voltages at each Bus.

(a)

Bus ID	Voltage/pu	% Voltage Drop
Ogele Bs	0.7771	22.29
Amekpa 2 Bs	0.7904	20.96
Pipeline Bs	0.7918	20.82
Holy Salvation Bs	0.7949	20.51
2nd Amekpa Bs	0.7965	20.35
Orubu Bs	0.7983	20.17
Amekpa 1 Bs	0.7987	20.13
Afiesere Bs	0.8024	19.76
Low Cost Bs	0.805	19.5
Ikprukpru 1 Bs	0.8062	19.38
Gana Jnc Bs	0.8066	19.34
Olori Rd Bs	0.8151	18.49
Mudi 2 Bs	0.8157	18.43
Olori Est Bs	0.8184	18.16
Cassidy Bs	0.8187	18.13
Amekpa 3 Bs	0.8195	18.05
Ikprukpru 4 Bs	0.8199	18.01
Shell (S/S) Bs	0.8235	17.65
Mudi 1 Bs	0.8236	17.64
Ikpruikpru 3 Bs	0.8239	17.61
Round Abt Bs	0.8276	17.24
Pti Bs	0.8278	17.22
Slaughter Rd Bs	0.8283	17.17
Robert A Bs	0.8288	17.12
Sadjere Bs	0.8301	16.99
Dortie Bs	0.8305	16.95
Ikprukpru 2 Bs	0.8324	16.76
Upper Agbarho 2bs	0.8324	16.76
Omenemu Bs	0.8328	16.72

(b)

Bus ID	Voltage/pu	% Voltage Drop
Agbarha Jncbs	0.833	16.7
Otovwodo 2bs	0.8349	16.51
Ighabomi Bs	0.8361	16.39
Upper Agbaroho 1 Bs	0.8368	16.32
Mtn 1(Pl) Bs	0.8371	16.29
Utoro Bs	0.8371	16.29
Ofor 2Bs	0.8374	16.26
Ncc Bs	0.8383	16.17
Onogharigho Bs	0.8383	16.17
Union Bank Bs	0.8386	16.14
Makolomi Bs	0.8393	16.07
Saniko Bs	0.8393	16.07
Ighoja Bs	0.8396	16.04
Ofor 1 Bs	0.84	16
Daniel Ue Bs	0.8411	15.89
Upper Agbarho 3Bs	0.8421	15.79
Olori Rdjn Bs	0.8439	15.61
Nnpc Bs	0.8446	15.54
Otovwodo 3Bs	0.8448	15.52
Oviri Cd Bs	0.8453	15.47
Awirhi Bs	0.8464	15.36
Evwieta Bs	0.8464	15.36
D'Rose Bs	0.8476	15.24
Eti Bs	0.8476	15.24
Uduere 1bs	0.8479	15.21
Poc Water Bus	0.8489	15.11
Shell (Pl)	0.8494	15.06

(c)

Bus ID	**Voltage/pu**	**% Voltage Drop**
Upper Agbarho5Bs	0.8496	15.04
Marvel Sch Bs	0.8497	15.03
Owevwe Bs	0.85	15
Grubbs Bs	0.8513	14.87
Agbarha Rd Bs	0.8522	14.78
Heros Faith Bs	0.8523	14.77
First Bank Bs	0.8527	14.73
Opherin Bs	0.8535	14.65
Ovie Bus	0.8542	14.58
Omabewe 2bs	0.8545	14.55
Ecobank Bs	0.8546	14.54
Mtn Pl Bs	0.8553	14.47
Oviri Ogbor Bs1	0.8558	14.42
Mtn Ii Bs	0.856	14.4
Omabewe 1bs	0.8571	14.29
Etefe Bs	0.8572	14.28
Upper Agbarho 4bs	0.8583	14.17
Okpho Agbara Bs	0.8584	14.16
Oteri Bs	0.8584	14.16
Uba Bs	0.8613	13.87
Uduere 2bs	0.8636	13.64
Bishop Ebs	0.8637	13.63
Ogablor Cd Bs	0.8639	13.61
Ncc-Airtel Bs	0.8645	13.55
Oduophori Bs	0.8659	13.41
Winners Bs	0.868	13.2
Mr Biggs Bs	0.8714	12.86
Oviri-Ogbor Bs2	0.8723	12.77
Otovwodo 4bs	0.8783	12.17

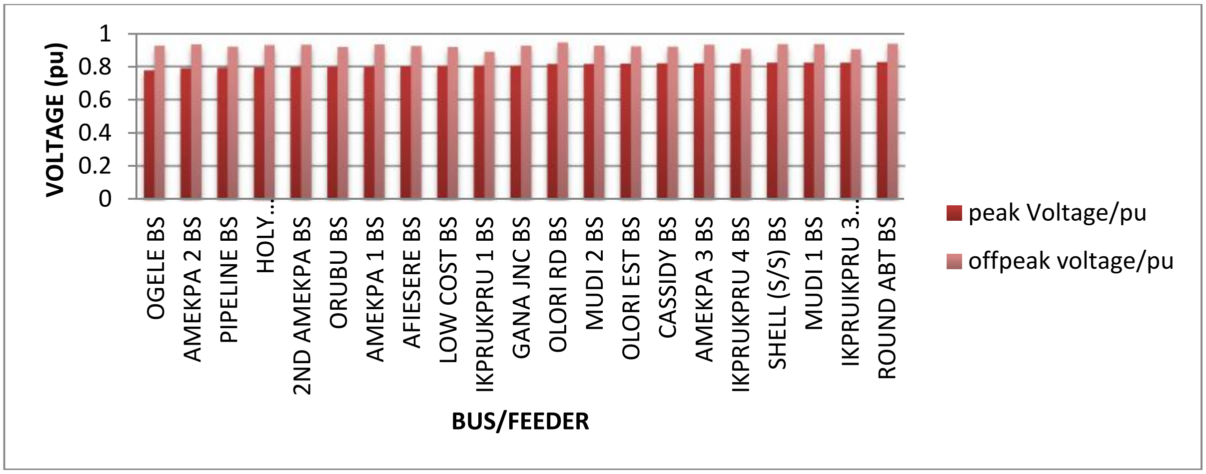

Fig 4: Peak and Off-Peak voltage without SVC (Ogele – Round About)

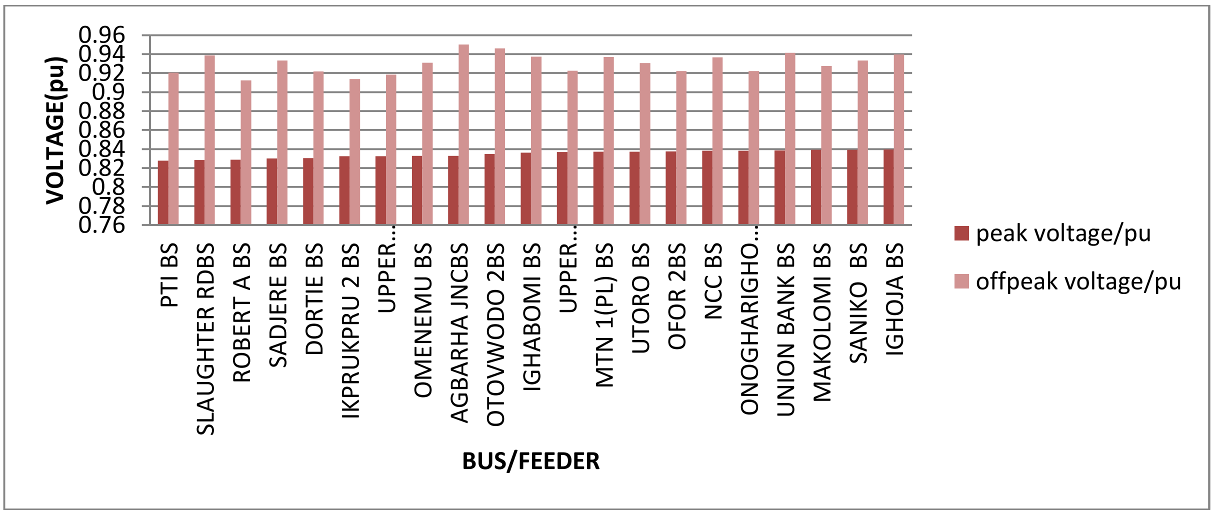

Fig 5: Peak and Off-Peak voltage without SVC (PTI – Ighoja)

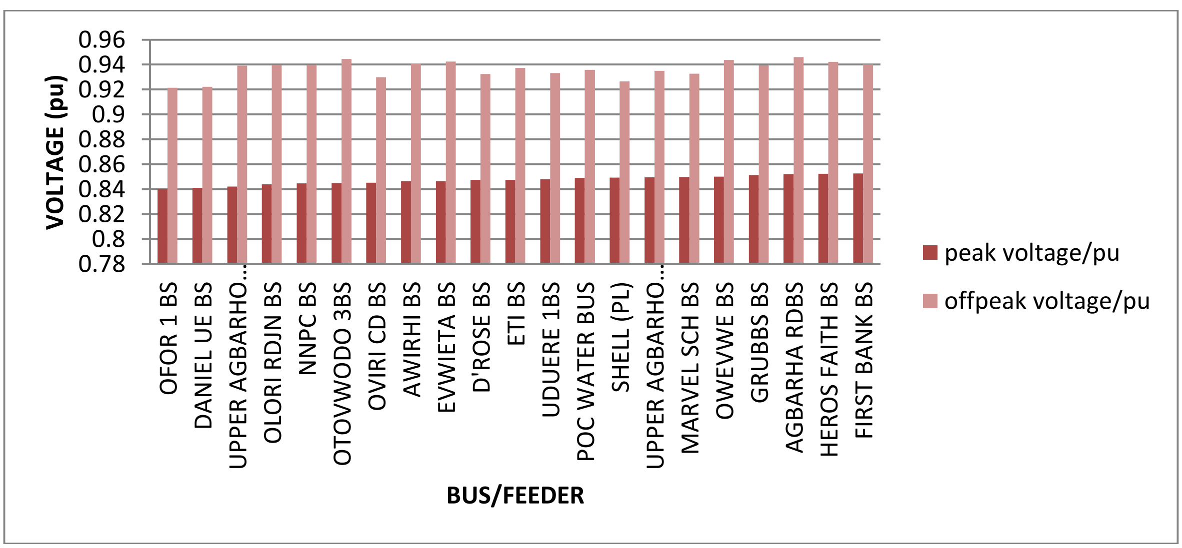

Fig 6: Peak and Off-Peak voltage without SVC (Ofor – First Bank)

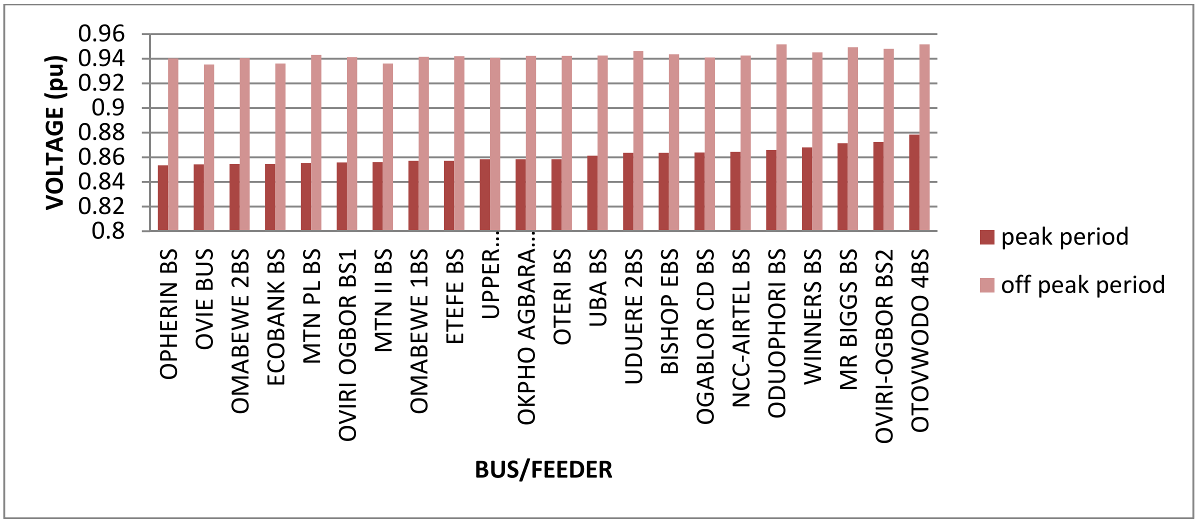

Fig 7: Peak and Off-Peak voltage without SVC (Opherin – Otovwodo 4)

Table 2: Summary of Load Flow for Entire Network.

	Peak	**Off peak**
Voltage Profile	0.7771 – 0.8783pu	0.889 -0.9517pu
Active Load Demand	10.243MW	5.101MW
Reactive Load Demand	6.447Mvar	1.93Mvar
Losses (Real)	1.045MW	0.265MW
Losses (Reactive)	2.007 Mvar	0.425Mvar

5.0 Result Discussion and Conclusion

The result obtained from load flow analysis of Otovwodo 15MVA 33/11/0.415kV injection substation and its associated feeders indicate the following:

1. The load flow analysis carried on the network shows that a total of eighty – five (85) load buses in the network, voltage violation occurred in all eighty – five (85) buses during peak load period with voltage range between Ogele bus-0.7771 pu and Otovwodo IV bus- 0.8783 pu.
2. During off peak period, fifty five (55) recorded voltage violations, while Thirty (30) buses were within the statutory voltage with the voltage range between Ikprukpru 1 bus - 0.889 and Otovwodo IV bus- 0.9517).
3. The highest percentage voltage drop was 22.29% at Ogele Bus for peak and 11.1% at Ikprukpru I bus for off peak.
4. The lowest percentage voltage drop of 12.17% for peak and 4.83% at off peak occurred at Otovwodo IV bus.
5. The load during the peak period is 10.243MW and 6.447Mvar, while that for off peak was 5.101MW and 1.93Mvar.
6. The total loss during peak is 1.045MW, 2.007Mvar and off peak is 0.265MW, 0.425 Mvar.

It can be seen from the load flow report that the 15MVA transformer is over loaded and urgent step needs to be done to either upgrade the power rating or get another transformer as a relief for this one.

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