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Load Flow Analysis of 15MVA, 33/11kV Injection Substation

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ABSTRACT

This study presents the load flow analysis of Ughelli- 15, 15MVA, 33/11kV injection substation, Delta State, Nigeria. It is very essential for a load flow study to be carried out in a power system in other to enable one carry out an effective planning, design, implementation, configuration and control of the system so as to obtain maximal, effective and more reliable system. With load flow analysis the state of power distribution (load)is related or evaluated with generation. The paper presents a computer aided load flow analysis of an existing Ughelli- 15, 15MVA, 33/11kV injection substation using ETAP 12.6 software. From the result of the analysis out of (63) load feeders, (4) feeders were out of service, during peak period and off-peak period voltage violation occurred on (58) feeders, with (1) load feeder within acceptable voltage range at both peak period and off-peak period.

Keywords: *injection Substation, feeders, power, voltage, frequency*

INTRODUCTION

In recent times the Nigeria Government in a view to address the challenges of power supply used the Ministry of Power through an agent of the Ministry known as the Electric Power Sub-sector (EPS), this was aimed at the reform of the power sector in Nigeria which has a population size of over 150 million people, as a result of Nigeria size the EPS finds it very difficult in achieving its core goal and mandate given to the Ministry of Power to actualize the agenda of the Nigerian Government after a national crisis and embarrassment which took place in its power sector the year 2000, when the country was faced with power generating capacity which was bellow 2000MW. From the very onset of the institution of a democratically elected government in Nigeria various elected President such Olusegun Obasanjo and Musa Yar'Adua made different effort in addressing the epileptic power system bedeviling Nigeria including President Goodluck Jonathan during his inaugural speech on 29th May, 2011 he placed the power sector in his transformation agenda. As reliable electricity is the bed rock for technological revolution and development of any nation or country, as the previous democratic government has not been able to address the challenges and provide power to the Nigeria citizenry for not more seventy two hours (Okolobah and Ismail, 2013; www.nercng.org; www.marketresearch.com; Odueme, 2001;www.nigeriatoday.com; Okhueleigbe, 2016).

LOAD MODEL FOR POWER DISTRIBUTION SYSTEM

Loads in electrical power system are modeled as constant impedance (Z), current (I) and power (P). It could be a combination of the three, for each value the real power and reactive power are specified ($P_{spec} + jQ_{spec}$).

Then constant power will be $S_{LK} = P_{spec} + jQ_{spec}$ (1)

At normal voltage in 1.0 per unit real power and reactive power will be written as $p + jQ$

Complex power load(s) could be derived as $S = VI^*$ (2)

$$I^* = \frac{S}{V} = \frac{P_{spec} + jQ_{spec}}{1.0\angle\theta} \quad (3)$$

$$S = V\angle\,\theta_v \left(\frac{P_{spec} + jQ_{spec}}{1.0\angle\theta_v}\right) \quad (4)$$

The system load becomes a linear function of the voltage magnitude

$$S_{LK} = \left|V\right|\left(P_{spec} + jQ_{spec}\right) \quad (5)$$

The $P + jQ$ specified represent the load voltage of 1.0 per unit, from the complex power equation we have

$$S = VI^* = V\left[\frac{V}{Z}\right]^* = \frac{V^2}{Z^*} = \frac{(1.0)^2}{P_{spec} + jQ_{spec}} \quad (6)$$

$$S_{load} = \frac{V^2}{\left[\frac{(1.0)^2}{P_{spec} + jQ_{spec}}\right]} = V^2\left(P_{spec} + jQ_{spec}\right) \quad (7)$$

The load becomes a quadratic function of voltage magnitude

$$S_{LK} = \left|V\right|^2\left(P_{spec} + jQ_{spec}\right) \quad (8)$$

Generator Model

Generators are model as source of real and reactive power (MW, Mvar) output generator has some control features which are

i. Automatic voltage regulator (AVR) – This are used in the control of reactive power output (Q) in other to maintain a specified voltage level of the regulated Bus.

ii. Automatic generation Control (AGC) – This is used in the modification of real power output (P).

The Power Flow Equation

Load flow or Power flow study is the study of interconnected power system with the use of simplified notation such as per unit and one line diagram in the analysis of various alternating current parameters such as voltage, voltage angle, real power and reactive power. This study is very essential in power system so as to be able to understand the particular network and carry out formed decision making as regarding a particular network.

Linear programming is used in software in resolving some problems associated with power system which include short circuit, stability analysis (transient and steady state) in other to arrive at the lowest cost of kilowatt hour. A system with multiple load flow centers load flow activity is very crucial in other determine if the main feeder is able to supply adequate power to the various load center and also determine the losses between load centers and its main source.

Carrying out load flow study you are able to identify a system's capability and control settings in other to obtain maximum output from a particular system.(https://en.wikipedia.org/wiki/Power-flow_study)visited 15th August, 2015).

Reason for Power Flow Equation Model

This are model used in power system in analyzing the power flow which are non-linear system, this method is used in describing the energy flow through the various transmission lines. The problem associated with non-linearity is because the power flows into the load impedances is a function of the square of the applied voltage thus the non-linearity in large network using AC is often not flexible and less accurate, hence the use of DC power flow model is deployed. Analysis in a three phase system is often assumed to be balanced loading of all three phase to the load generation changes, with the frequency also assumed to be constant, thus the use of per-unit system and one line diagram is used for simplicity so as to be able to develop a mathematical model of the generators load buses and transmission lines of a system being worked upon including their electrical impedance and ratings. (https://en.wikipedia.org/wiki/Power-flow_study)visited 15th August, 2015).

Deriving the Power Flow Equations

The use of Y-bus, and applying Kirchhoff's current law at each bus using matrix equation we have

$$\text{YV-}I_{generator} + I_{load} = 0 \quad (9)$$

$$S = VI^* = [V]\ (V^*Y^*) - [V]I^*_{generators} + [V]I^*_{loads} = 0 \quad (10)$$

$$[V]\ (V^*Y^*) - S_{generators} + S_{loads} = 0 \quad (11)$$

The above are known as N-1 complex number equations (where N = the number of buses in the power system)

N-1 complex number equations can be written as 2* (N-1) real number equations as

$$P_k = 0 = V_k \sum_{m=1}^{N-1} [V_m [g_{km} \cos(\delta_k - \delta_m) + b_{km} \sin(\delta_k - \delta_m)]] - P_{GK} + P_{LK} \quad (12)$$

$V_k \sum_{m=1}^{N-1} [V_m [g_{km} \cos(\delta_k - \delta_m) + b_{km} \sin(\delta_k - \delta_m)]]$ Represents Transmission lines, Transformers and Capacitors.

$-P_{Gk}$ Power Generated.

$+P_{Lk}$ Power Consumed by Load.

$$Q_k = 0 = V_k \sum_{m=1}^{N-1} [V_m [g_{km} \sin(\delta_k - \delta_m) + b_{km} \cos(\delta_k - \delta_m)]] - Q_{Gk} + Q_{Lk} \quad (13)$$

$V_k \sum_{m=1}^{N-1} [V_m [g_{km} \sin(\delta_k - \delta_m) + b_{km} \cos(\delta_k - \delta_m)]]$ Represents Transmission lines, Transformers and Capacitors.

$-Q_{Gk}$ Represents Generators.

$+Q_{Lk}$ Represents Load

g_{km} and b_{km} Represents Element s of the Y-Bus

Thus it should be noted that g_{km} and b_{km} are variables of the real and imaginary parts of the Y-Bus.

($Y = G + jB$ or $Y_{km} = g_{km} + jb_{km}$)

There are four parameters used in describing the bus in power flow equation.

1. Voltage magnitude (v)
2. Voltage angle ($\delta\ or\ \theta$)
3. Real power($P = P_{gen} - P_{load}$)
4. Reactive power($Q = Q_{gen} - Q_{load}$)

The main objective of the power flow algorithm is to determine the four values listed above. In any power flow situation two of the values at each bus are known and then we solve for the other two values. In a power flow there are generally three buses they are shown on Table 1.

Table 1 Types of Buses

Type of Bus	Voltage Magnitude (V)	Voltage Angle (δ)	Power Injection ($P = P_{gen} - P_{load}$)	Reactive Power Injection ($Q = Q_{gen} - Q_{load}$)
Slack Bus ($V\delta - Bus$) (only one of these)	Known	Known	Unknown	Unknown
($PV - Bus$) (generator on AVR control)	Known	Unknown	Known	Unknown
($PQ - Bus$) (load or generator not on AVR control)	Unknown	Unknown	Known	Known

Source: Power World Corporation 2014

Non- Linear Equations

Power flow equations are represented with cos ($*$) and sin($*$) which makes such equations non-linear, by this finding a direct solution in resolving non- linear equation is impossible, thus the use of iterative numerical schemes are deployed in determining their solution, hence in power flow equation the use of Newton's method is found to be the technique used in resolving such problems.

A simple scalar equation $f(x)$ can be written in "Taylor Series" as

$$f(x) = f(x_0) + \left[\frac{\partial f}{\partial x}\Big|_{x=x_0}\right](x - x_0) + \frac{1}{2}\left[\frac{\partial^2 f}{\partial x^2}\Big|_{x=x_0}\right](x - x_0)^2 + h.o.t. \quad (14)$$

Approximating scalar functions in Taylor Series is by ignoring all but the first two terms

$$f(x) \approx f(x_0) + \left[\frac{\partial f}{\partial x}\Big|_{x=x_0}\right](x - x_0) \longrightarrow [x - x_0] \approx \left[\frac{\partial f}{\partial x}\Big|_{x=x_0}\right]^{-1}[f(x) - f(x_0)] \quad (15)$$

At this point we are trying to find where $f(x) = 0$, the power flow equation s sums up to be zero.

Thus $x \approx x_0 - \left[\frac{\partial f}{\partial x}\Big|_{x=x_0}\right]^{-1}[f(x_0)]$

(16)

Newton-Rhapson Convergence Characteristics

The general convergence characteristics of the Newton-Rhapson (N-R) algorithm are not easy to be characterized, Newton-Rhapson algorithm often converges quite quickly provided the initial guess is close enough to the solution, however Newton-Rhapson algorithm does not always converges to the closest solution hence some initial guess plain bad.

Extending Scalar to Vectors and Matrices

Newton's method can also be used when trying to find a solution where multiple functions are equal to zero, if $f(x)$ be a n-dimensional function and let x be an n-dimensional vector

$$f(x) = \begin{bmatrix} f_1(x) \\ \cdot \\ \cdot \\ f_n(x) \end{bmatrix} \quad x = \begin{bmatrix} x_1 \\ \cdot \\ \cdot \\ x_n \end{bmatrix}$$

The Newton-step is still defined as

$$x_{k+1} - x_k = \Delta x_k \approx -\left[\frac{\partial f}{\partial x} \mid_{x=x_0}\right]^{-1} f(x_k)$$

But $\frac{\partial f}{\partial x}$ is now a matrix, called the Jacobian

$$\frac{\partial f}{\partial x} = \begin{bmatrix} \frac{df_1}{dx_1} & \frac{df_2}{dx_2} & \cdots \frac{df_1}{dx_n} \\ \frac{df_2}{dx_1} & \frac{df_2}{dx_2} & \vdots \\ \vdots & & \vdots \\ \frac{df_n}{dx_1} & \cdots & \ddots \frac{df_n}{dx_n} \end{bmatrix} \quad (19)$$

Power flow Solutions Varying with Respect to load Changes

The power flow equation could be used in calculating a series of power flow solutions at various load levels, first determine the following

$$\frac{\partial f}{\partial x} = J(\theta, V) \begin{bmatrix} -BV\cos(\theta) & -B\sin(\theta) \\ -BV\sin(\theta) & B\cos(\theta) - 2BV \end{bmatrix} \quad (20)$$

$$X_k = \begin{bmatrix} \theta \\ V \end{bmatrix}; \quad f(x) = \begin{bmatrix} P_l - BV\sin(\theta) \\ Q_l + BV\cos(\theta) - BV^2 \end{bmatrix} \quad (17)$$

For every load level, iterate from an initial guess to a point where the solution converges

$$x \approx x_o - \left[\frac{\partial f}{\partial x} \mid_{x=x_0}\right]^{-1} [f(x_o)] \quad (18)$$

UGHELLI- 15 (U-15), 15MVA, 33/11kV Injection SubstationNetwork Overview

Ughelli- 15, 15MVA, 33/11kV injection substation, also known as (U-15) as its nomeclature name is located beside Transcorp Power Generating Station, KM 20 Ughelli – Patani Express Road, Ughelli, Delta State, Nigeria. It gets its supply from the 33kV transmission line via Transcorp generating Power Limited, which generates at 16kV and it is stepped up to132kV and fed into a 30 MVA, 132/33kV transformer, which in turn feeds the Ughelli-15, 15 MVA, and 33/11kV Injection Substation. The Injection Substation and generating station have common boundary and are both connected with multi-core overhead conductor of 150mm^2 cross sectional

area, while that from Ughelli 15, 15MV A, 33/11kV injection substation to vario us distribution substations which are co nnected also with 150mm^2 multi-core overhead conductor.

Figure 1: Photo View ofU-15, 15MVA, 33/11kV Injection Substation.

SOURCE: Presidential Task force on Power; 10th January, 2011

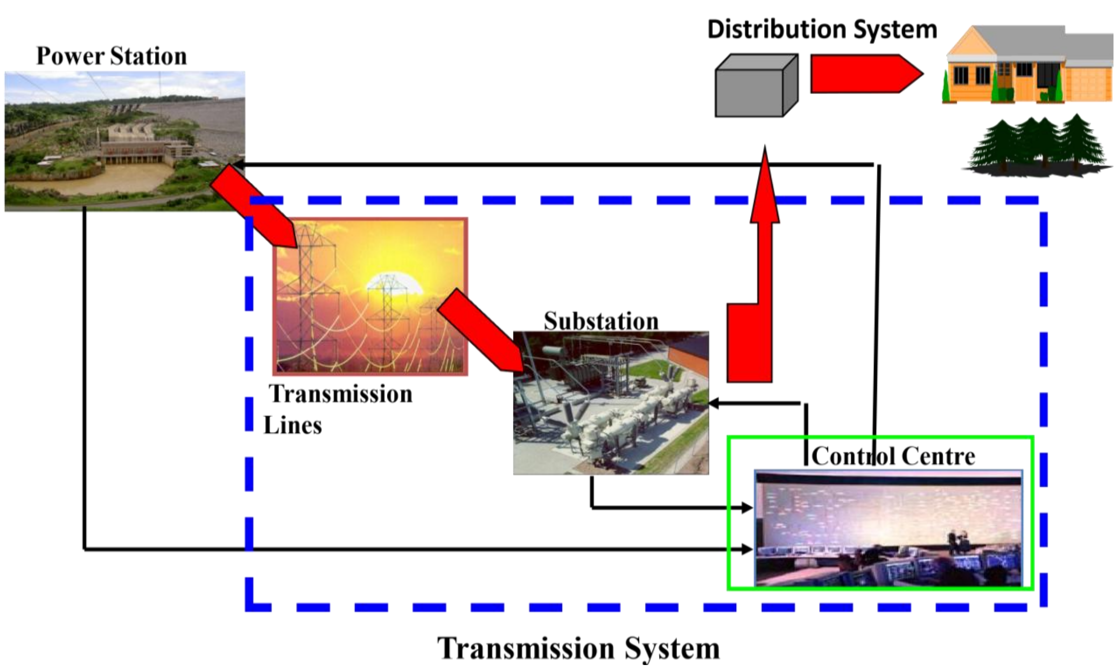

Figure 2: Power System Distribution Layout

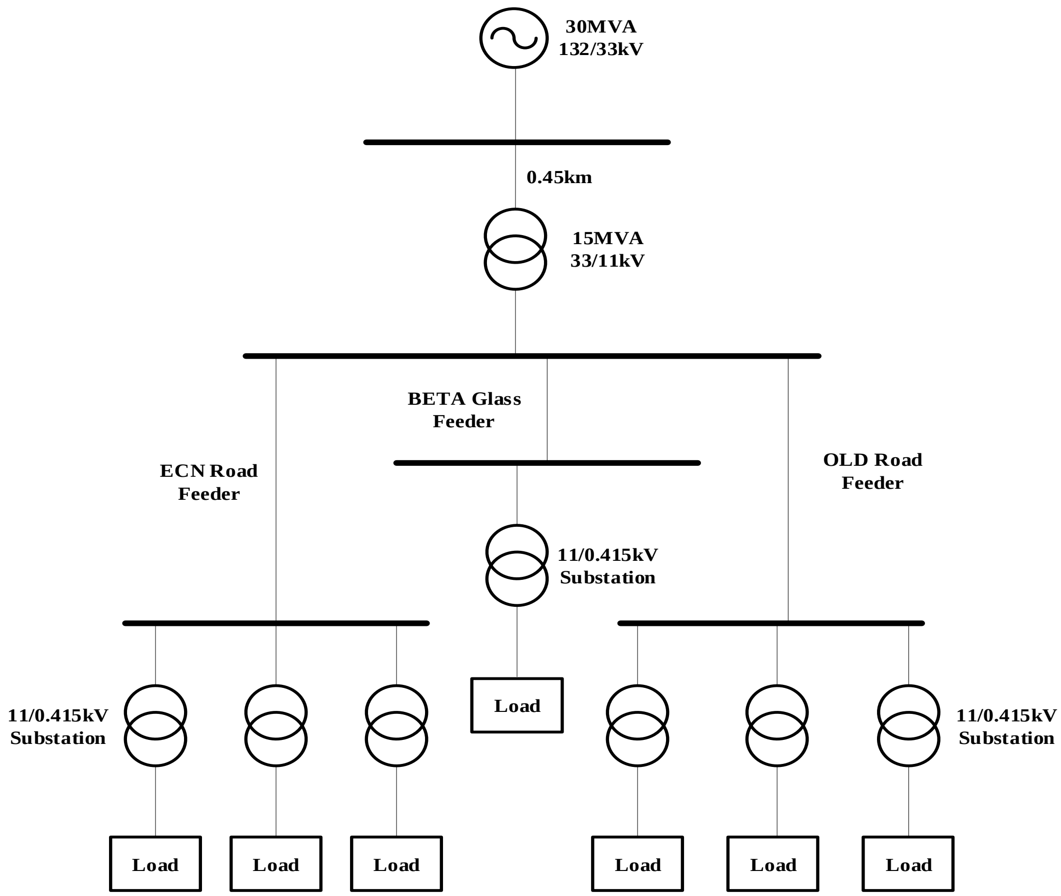

Figure 3: One line Diagram Showing Power Source for Injection Substation.

SIMULATION RESULT AND ANALYSIS

Some of the simulation of the network is presented in table 2. The load flow method used was in Newton-Rephson and it converged at less than 99 iterations.

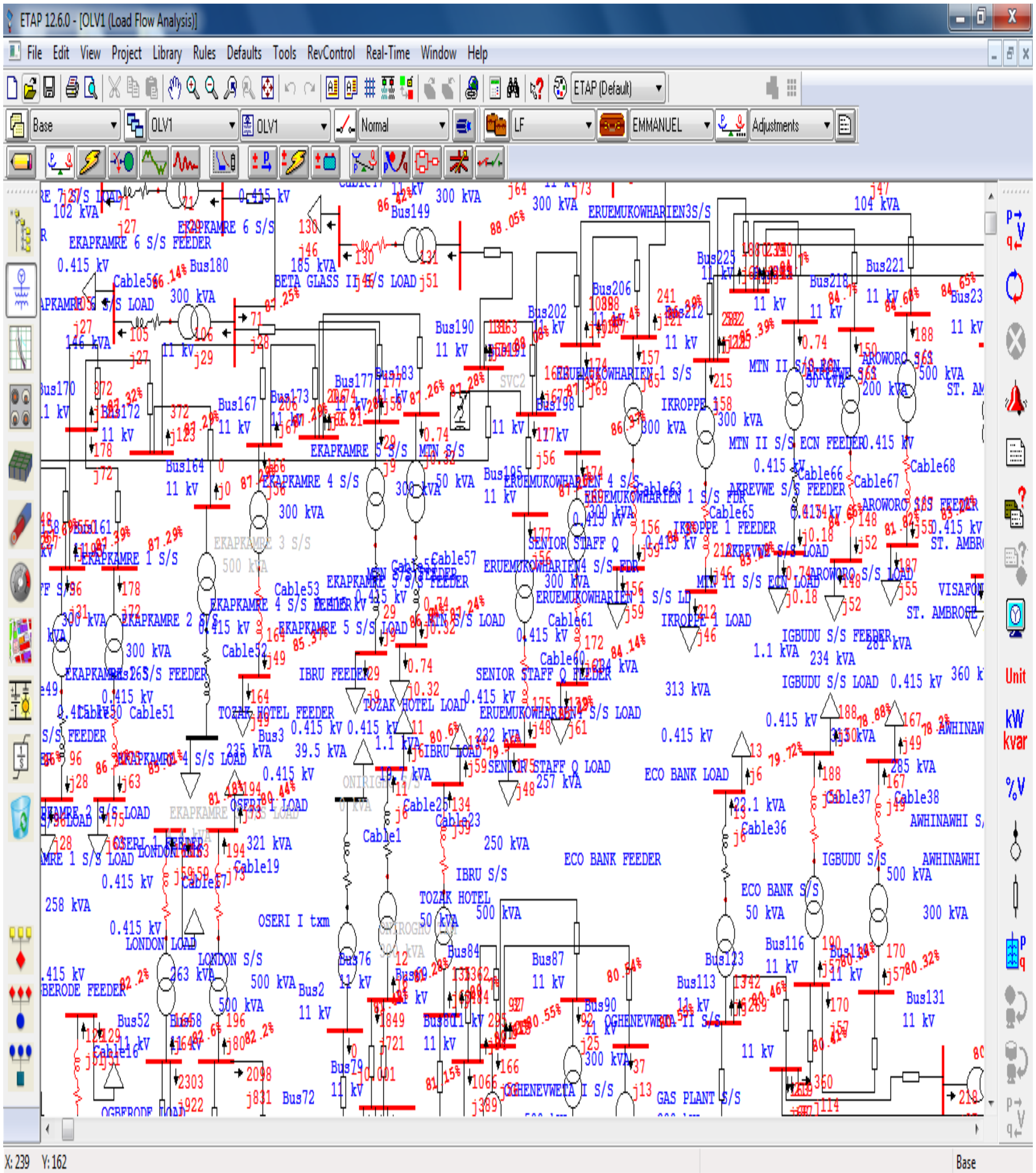

Figure 4: Simulation (RUN) Mode of U-15 Network on ETAP 12.6

Table 2: Load flow Report for entire Network showing Nominal kV, voltage, voltage in per unit, Percentage Voltage Drop for each bus during peak period. (Peak Period Result Summary of U-15)

S/N	BUS ID	Nominal kV	Voltage	Voltage Pu	%Voltage Drop	Remark
1	AIRTEL 1 FEEDER	0.415	87.45	0.8745	12.55	Voltage Drop Outside Acceptable limit
2	AIRTEL 2 FEEDER	0.415	84.91	0.8491	15.09	Voltage Drop Outside Acceptable limit
3	AIRTEL O-FEEDER	0.415	84.01	0.8401	15.99	Voltage Drop Outside Acceptable limit
4	AKREVWE S/S FEEDER	0.415	81.71	0.8171	18.29	Voltage Drop Outside Acceptable limit
5	AROWORO S/S FEEDER	0.415	83.11	0.8311	16.89	Voltage Drop Outside Acceptable limit
6	ARUMALA S/S FEEDER	0.415	78.82	0.7882	21.18	Voltage Drop Outside Acceptable limit
7	ARUMALA II S/S FEEDER	0.415	79.47	0.7947	20.53	Voltage Drop Outside Acceptable limit
8	ATAVERHE FEEDER	0.415	79.37	0.7937	20.63	Voltage Drop Outside Acceptable limit
9	AWHINAWHI S/S FEEDER	0.415	78.11	0.7811	21.89	Voltage Drop Outside Acceptable limit
10	BALAGBA S/S FEEDER	0.415	86.72	0.8672	13.28	Voltage Drop Outside Acceptable limit
11	BETA GLASS 1 FEEDER	0.415	87.3	0.873	12.7	Voltage Drop Outside Acceptable limit
12	BETA GLASS II S/S FEEDER	0.415	86.28	0.8628	13.72	Voltage Drop Outside Acceptable limit
13	BetaG-load FEEDER	0.415	96.26	0.9626	3.74	Voltage Drop Within Acceptable limit
14	ECO BANK FEEDER	0.415	79.63	0.7963	20.37	Voltage Drop Outside Acceptable limit
15	EGOR S/S FEEDER	0.415	80.09	0.8009	19.91	Voltage Drop Outside Acceptable limit

Table 3: Load flow Report for entire Network showing Nominal kV, voltage, voltage in per unit, Percentage Voltage Drop for each bus during Off-Peak period. (Off-Peak Period Result Summary of U-15)

S/N	BUS ID	Nominal kV	Voltage	Voltage pu	% Voltage Drop	Remark
1	AIRTEL 1 FEEDER	0.415	92.98	0.9298	7.02	Voltage Drop Outside Acceptable limit
2	AIRTEL 2 FEEDER	0.415	91.6	0.916	8.4	Voltage Drop Outside Acceptable limit
3	AIRTEL O-R FEEDER	0.415	90.68	0.9068	9.32	Voltage Drop Outside Acceptable limit
4	AKREVWE S/S FEEDER	0.415	89.64	0.8964	10.36	Voltage Drop Outside Acceptable limit
5	AROWORO S/S FEEDER	0.415	90.74	0.9074	9.26	Voltage Drop Outside Acceptable limit
6	ARUMALA S/S FEEDER	0.415	87.68	0.8768	12.32	Voltage Drop Outside Acceptable limit
7	ARUMALA II S/S FEEDER	0.415	88.03	0.8803	11.97	Voltage Drop Outside Acceptable limit
8	ATAVERHE FEEDER	0.415	87.15	0.8715	12.85	Voltage Drop Outside Acceptable limit
9	AWHINAWHI S/S FEEDER	0.415	86.82	0.8682	13.18	Voltage Drop Outside Acceptable limit
10	BALAGBA S/S FEEDER	0.415	92.4	0.924	7.6	Voltage Drop Outside Acceptable limit
11	BETA GLASS 1 FEEDER	0.415	93.14	0.9314	6.86	Voltage Drop Outside Acceptable limit

12	BETA GLASS II S/S FEEDER	0.415	92.34	0.9234	7.66	Voltage Drop Outside Acceptable limit
13	BetaG-load FEEDER	0.415	98.21	0.9821	1.79	Voltage Drop Within Acceptable limit
14	ECO BANK FEEDER	0.415	87.91	0.8791	12.09	Voltage Drop Outside Acceptable limit
15	EGOR S/S FEEDER	0.415	88.1	0.881	11.9	Voltage Drop Outside Acceptable limit

Figure 5: Bus ID Vs Voltage Drop for Peak Period and Off Peak Period of U-15 Load Flow Analysis

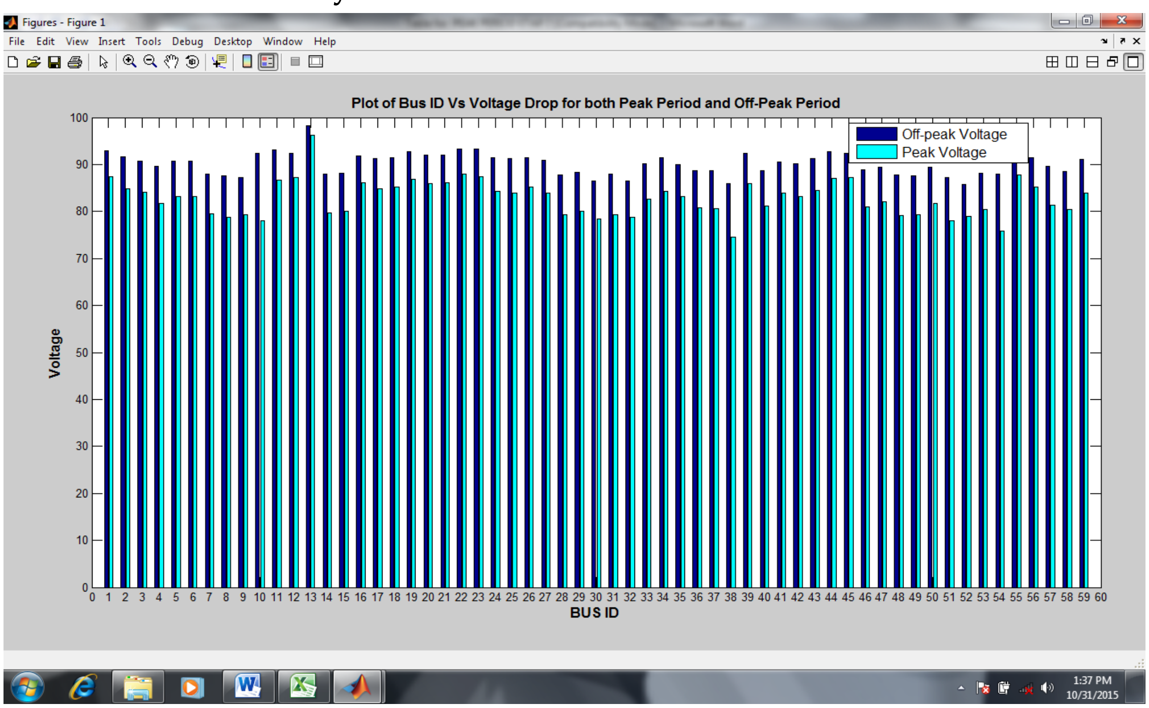

Table 4: Summary of result for peak period and off peak period gotten from ETAP 12.6 software.

S/N.		Peak	Off peak
1	**Voltage Profile**	0.7458 – 0.9626pu	0.8114 -0.9821pu
2	**Active Load Demand**	7.323MW	4.441MW
3	**Reactive Load Demand**	3.8Mvar	1.949Mvar
4	**Losses (Real)**	0.89MW	0.328MW
5	**Losses (Reactive)**	1.578Mvar	0.566Mvar

Validation of Results

Before we embark on the analysis of the results gotten from ETAP 12.6 load flow studies, there was need to ascertain the validity of the results gotten from the software. To do this, actual line voltage measurement were taken at some selected load buses during peak and off peak periods. The measurements were taken from a total of eleven buses (Five from ECN feeder, Five from Old Road feeder and One from Beta Glass Plc feeder). An average of three measurements was taken from each of the selected bus. The average measurements are tabulated and compared with the results from the software. The comparison is presented in Table 5

Table 5: Comparison between Measured Voltages and Results from Software

S/N	Name of Substation	AVERAGE VALUE OF MEASUREMENTS TAKEN				RESULTS FROM SOFTWARE	
		PEAK PERIOD		OFF PEAK PERIOD		PEAK PERIOD	OFF PEAK PERIOD
		Measured Voltage (V)	Voltage (%)	MeasuredVoltage V)	Voltage (%)	Voltage (%)	Voltage (%)
1	EkrerenvwenI	362.63	87.38	377.36	90.93	87.89	93.28
2	Beta glass I	382.73	92.22	382.09	92.07	87.30	93.14
3	EkparemenIV	397.22	95.72	395.66	95.34	85.27	91.53
4	Ekuemukow-harien I	398.31	95.98	376.60	90.75	84.22	91.46
5	Aroworo	363.09	87.49	372.51	89.76	83.11	90.74
6	Beta Glass PLC	371.87	89.61	384.63	92.68	96.26	98.21
7	NNPC	374.81	90.32	374.12	90.15	87.22	92.30
8	Ogberode	339.54	81.82	364.37	87.80	82.09	89.34
9.	GRA	371.93	89.62	347.16	83.65	78.31	86.40
10	Omotor	363.68	87.63	379.78	91.52	78.01	87.14
11	Oghenevweta I	367.37	88.53	338.78	81.63	79.14	87.75

Thus: Voltage Magnitude (%) =
Measured Voltage / 415
(20)

Formula for software result validation,

$$\frac{Actual\ Value - Software\ Value}{Actual\ Value} * 100\% \quad (21)$$

$$\frac{SV - AV}{SV} * 100\% \quad (22)$$

Further analysis of results in Table 5 shows that the percentage errors between the actual measured values and the result from the software lies between -7.50% and 12.25% with the lowest deviation occurring at Oghenevweta I substation and the highest deviation occurring at Ekuemukowharien I substation. These deviations are partly as a result of unbalanced load on the lines and the voltage drop along the short cable connecting the transformers to the 11kV line which was considered while modeling the network. Thus one can say that the software is sufficiently accurate and the results are valid and are true reflection of the network.

RESULT DISCUSSION AND CONCLUSION

From the Load flow analyses of Ughelli-15, 15MVA Injection Substation network. The study shows that the state of the present network was unsatisfactory due to high losses, valuation of voltage regulation in virtually all the buses.

1. During peak period the highest percentage voltage drop was 21.99% at Omotor sub-station bus and the lowest percentage was 3.74% at Beta Glass load feeder bus.
2. During off peak the lowest percentage voltage drop was 1.79% at Beta Glass load feeder bus and highest percentage voltage drop was 13.44% at Igbudu Sub-station bus.
3. The load during peak period is 7.323MW and 3.8Mvar. While for off peak period is 4.441MW and 1.949Mvar.
4. The total loss during peak period is 0.89MW, 1.578Mvar. and 0.328MW, 0.566Mvar. at off peak period.
5. Frequent power outages from both generating stations and transmission lines in Nigeria Power System include frequent tripping of the 33/11kVA lines resulting in too many unplanned outages in the system.
6. Ughelli-15, 15 MVA Injection Substation was studied which comprises of 63 substations comprising of three (3) Feeders, Energy Commission of Nigeria (ECN) feeder (29), Old Road feeder (33) and Beta Glass feeder (1) which is also a point load. Etisalat substation has not been commissioned, Visafone substation was disconnected for non- payment, Onirigho substation has not been commissioned all substation

mentioned above are connected to Old Road feeder, Ekparemre III substation was out of service as a result of bunted coils the said transformer is connected to ECN feeder, the above information given was as at the time of data collection.

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