Power Flow Analysis Using Load Tap – Changing Transformer (LTCT): A Case Study of Nigerian 330kv Transmission Grid System

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Abstract- In order to ensure that electrical power transfer from generator to consumers through the grid system is stable, reliable and economical , it becomes imperative to carry out power flow studies. This paper presents power flow solution incorporating load tap changing transformer (LTCT) for solving the steady-state problems of longitudinal power system using Nigerian 330kV transmission system as a case study . In this work, the adopted numerical technique for solving the power flow problems was the Newton Raphson iterative algorithm. Modified power flow algorithm was implemented by the application of voltage control method using a load tap changing transformer (LTCT). Simulations were done using MATLAB software package .The results obtained from the existing condition of the Nigerian 330 kV transmission Network indicate that the bus voltages at New Heaven (0.929p.u), Gombe (0.886p.u), and Kano(0.880p.u) were below the set of binding limits that is, $\pm 10\%$ tolerance. With the incorporation of LTCT, voltage magnitudes of 0.995p.u, 0.950p.u and 0.996p.u were obtained at New Heaven, Gombe and Kano respectively, while the total system active power loss on the transmission line also reduced by about 5.1%.

Keywords: Power Flow, LTCT, power system, active power loss, voltage magnitude

I. INTRODUCTION

The major important investment decisions begin with reinforcement strategies based on power-flow analysis. In power system operating studies, power - flow analysis is used to ensure that each generator runs at the optimum operating point and that demand will be met without overloading facilities and that maintenance plans can proceed without undermining the security of the system. Power flow studies are of great importance in planning and designing the future expansion of power systems as well as in determining the best operation of existing systems [1] [11]. They are used to ensure that electrical power transfer from generator to consumers through the grid system is stable, reliable and economical. The major goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage condition [2].

Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance.

In a modern-day energy management centre, highly developed optimization methods are used to determine not only the optimal outputs of the generators participating in the dispatch, but also the optimal settings of various control devices, such as the tap settings of load tap –changing transformer (LTCT), outputs of VAR compensating devices, desired settings of phase shifters and so on . In this paper , the application of LTCT to Nigerian grid system is considered with the aim of improving voltage profile and reducing the total system active power losses of the weak buses [3].

II. BRIEF REVIEW OF POWER FLOW METHODS

Power flow study is the steady state solutions of the power system. Generally, power flow calculations are carried out for power system planning, operational planning and in connection with system operation and control. The information obtained from power flow analysis can be used for the studies of normal operating mode, contingency analysis, outage security assessment, as well as optimal dispatching and stability.

Most of the early iterative methods were based on the Y-matrix of the Gauss-Seidel method. It requires minimum computer storage and needs only a small number of iterations for small networks [12].

The shortcoming of this is that, as the size of the network is increased, the number of iterations required increases dramatically for large systems. In some cases, the method does not provide a solution at all. Therefore, the slowly converging behavior of the Gauss-Seidel method and its frequent failure to converge in ill-conditioned situations resulted in the development of the Z-matrix methods. Even though these methods have considerable better converging characteristics, they also have the disadvantage of requiring a significantly larger computer storage memory owing to the fact that the Z-matrix is full, contrary to the Y-matrix, which is sparse [4]. These difficulties encountered in power flow studies led to the development of Newton Raphson iterative method. This method was originally developed by [5] and later by others including [6]. The method is based on the Newton-Raphson algorithm to solve the simultaneous quadratic equations of the power network. Contrary to the Gauss-Seidel algorithm which needs a larger time per iteration,

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Newton-Raphson needs only a few of iterations, and is significantly independent of the network size. Therefore, most of the power flow problems that could not be solved by the Gauss-Seidel method, for example, systems with negative impedances are solved with no difficulties with Newton Raphson technique [10].

III. PROBLEM FORMULATION (POWER FLOW EQUATIONS)

A typical bus of a power system network is as shown in Figure 1. Transmission lines are represented by their equivalent π model where impedance has been converted to per unit admittances on common MVA base. Details of the power flow equations with Newton Raphson iterative algorithm is reported in [7].
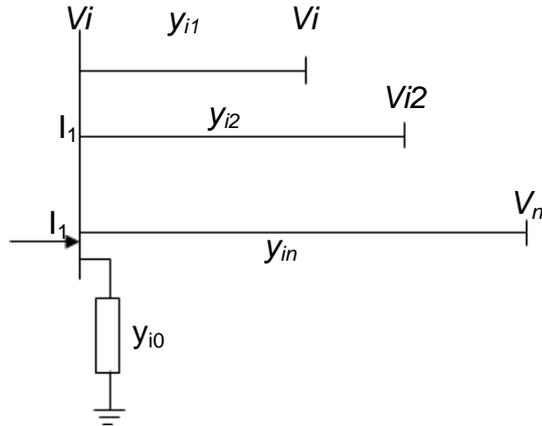

Figure 1:- A typical bus of the power system Source: [7]

The linearized form of the power flow equations is as in equation (1)

The new estimate for bus voltages are

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{5}$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \tag{6}$$

From the above relation, the mathematical formulation of the power flow problem result in a system of algebraic nonlinear equations which must be solved by iterative techniques.

IV. LINE FLOWS AND LOSSES

After the iteration solution of bus voltage, the next step is the computation of line flow and line losses [7] [13] [14] [15].

$$\begin{bmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial|V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial V_n} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial V_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial V_n} \\ \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial V_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial V_n} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} & \frac{\partial Q_n^{(k)}}{\partial V_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial V_n} \end{bmatrix} \begin{bmatrix} \Delta\delta_2^{(k)} \\ \vdots \\ \Delta\delta_n^{(k)} \\ \Delta|V_2^{(k)}| \\ \vdots \\ \Delta|V_n^{(k)}| \end{bmatrix} \tag{1}$$

In the above equation, bus 1 is assumed to be the slack bus. The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta\delta_2^{(k)}$ with the small changes in real and reactive power $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$. The elements of the Jacobian matrix can be written in the form

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta|V| \end{bmatrix} \tag{2}$$

The diagonal and the off-diagonal of J_1, J_2, J_3 and J_4 are also presented in [7].

The terms $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the difference between the scheduled and calculated values, known as the power residuals, given by (3) and (4)

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \tag{3}$$

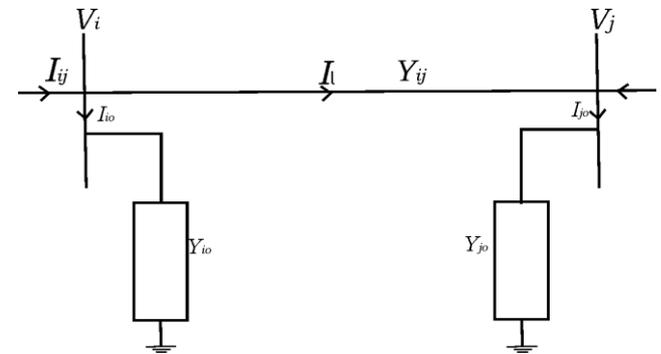$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \tag{4}$$

Figure 2: Transmission line model
Source: [7]

$i \rightarrow j$ is given by

$$I_{ij} = I_i + I_{i0} = y_{ij}(V_i - V_j) + y_{i0}V_i \tag{7}$$

Similarly, the line current I_{ji} measure at bus j and defined positive in the direction $j \rightarrow i$ is given by

$$I_{ji} = -I_i + I_{ji0} = y_{ij}(V_{ji} - V_i) + y_{ji0}V_j \tag{8}$$

The complex power S_{ij} from bus i to j and S_{ji} from bus j to i are

$$S_{ij} = V_i I_{ij}^* \tag{9}$$

$$S_{ji} = V_j I_{ji}^* \tag{10}$$

The power loss in line $i – j$ is the algebraic sum of the power flows determined from equation , i.e.

$$SL_{ij} = S_{ij} + S_{ji} \tag{11}$$

Where $S L_{ij}$ is the total power loss between buses i and j.

V. LOAD - TAP CHANGE TRANSFORMER SETTINGS

Most transformers are equipped with taps on the winding to adjust either the voltage transformation or reactive flow through the transformer. Such transformer are called load tap changing transformer (LTCT) [8] .A transformer tap is a connection point along a transformer winding that allows a certain number of turns to be selected. This implies that, a transformer with a variable turn's ratio is produced, enabling voltage control or regulation of the output. The tap selection is made via a tap changer mechanism.

The off-nominal tap ratio determines the additional transformation relative to the nominal transformation. This value normally ranges from 0.9<V<1.1 corresponds to no additional transformation [8] . At low voltages, the tapping are applied respectively at the sending end while the receiving end voltage was observed. However, power transformers are often fitted with a tap-changing mechanism to allow a degree of voltage magnitude regulation at one of the transformer terminals. This is achieved by injecting a small variable voltage magnitude in phase (added or subtracted) with the voltage magnitude at the output winding. The representation of a LTCT may be achieved by the series connection of the short circuit admittance representing a per- unit transformer and an ideal transformer with taps ratio T : 1 [9].

The following expressions can be shown from Figure 3 .

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} Y_k & -T_k Y_k \\ -T_k Y_k & T_k^2 Y_k \end{bmatrix}\begin{bmatrix} V_k \\ V_m \end{bmatrix} = \begin{bmatrix} Y_{kk} & T_k Y_{km} \\ T_k Y_{mk} & T_k^2 Y_{mm} \end{bmatrix}\begin{bmatrix} V_k \\ V_m \end{bmatrix} \tag{12}$$

Power flow equations at both ends of the transformer were derived, where T_k was allowed to vary within design rating values

$$(T_{k\min} < T_k < T_{k\max}):$$

$$P_k = V_k^2 G_{kk} + T_k V_k V_m \left[G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m) \right] \tag{13}$$

$$Q_k = -V_k^2 B_{kk} + T_k V_k V_m \left[G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m) \right] \tag{14}$$

$$P_m = T_k^2 V_m^2 G_{mm} + T_k V_m V_k \left[G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k) \right] \tag{15}$$

$$Q_m = -T_k^2 V_m^2 B_{mm} + T_k V_m V_k \left[G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k) \right] \tag{16}$$

where

$$Y_{kk} = Y_{mm} = G_{kk} + jB_{kk} = Y_k \tag{17}$$

$$Y_{km} = Y_{mk} = G_{km} + jB_{km} = -Y_k \tag{18}$$

I_k is the current at bus k

I_m is the current at bus m

Y_k is the admittance at bus k

Y_m is the admittance at bus m

V_k is the sending end voltage magnitude at bus k

V_m is the receiving end voltage magnitude at bus m

T_k is the variable tap

θ_k is the phase angle of the voltage at bus k

θ_m is the phase angle of the voltage at bus m

P_k is the active power at bus k

P_m is the active power at bus m
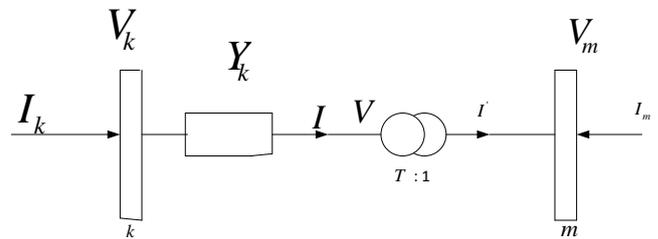
Figure 3 : Simple tap – changing transformer [9]

Q_k - the reactive power at bus k

Q_m -the reactive power at bus m

ΔP_k is the active power mismatch at bus k

ΔP_m is the active power mismatch at bus m

ΔQ_k is the reactive power mismatch at bus k

ΔQ_m is the reactive power mismatch at bus m

The set of linearised power flow equations for the nodal power injections, equations (13) – (16) assuming that the load tap changer (LTC) is controlling nodal voltage magnitude at its Sending end (bus k) , may be written as :

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \end{bmatrix}^{(i)} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial T_k}T_k & \frac{\partial P_k}{\partial V_m}V_m \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial T_k}T_k & \frac{\partial P_m}{\partial V_m}V_m \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial T_k}T_k & \frac{\partial Q_k}{\partial V_m}V_m \\ \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_k}{\partial T_k}T_k & \frac{\partial Q_m}{\partial V_m}V_m \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta T_k}{T_k} \\ \frac{\Delta V_m}{V_m} \end{bmatrix} \tag{19}$$

The tap variable T_k is adjusted, within limits, to constrain the voltage magnitude at bus k at a specified value V_k . For this mode of operation V_k is maintained constant at the target value [3].

At the end of each iteration, i, the tap controller is updated using the following relation :

$$T_k^{(i)} = T_k^{(i-1)} + \left(\frac{\Delta T_k}{T_k}\right)^{(i)} T_1^{(i-1)}$$

(20)

VI. RESULTS AND DISCUSSION

Nigerian 330kV grid system

The single line diagram of the Nigerian 330kV network consists of seven generating stations, twenty-four load stations and thirty-nine transmission lines. The system may be divided into three major sections: - North, South-East and the South-West sections, as shown in Figure 4. The North is connected to the South through one triple circuit lines between Jebba and Osogbo while the West is linked to the East through one transmission line from Osogbo to Benin and one double circuit line from Ikeja to Benin.

maximum power mismatch of 0.000726207 was obtained from the power flow solutions . The power flow solutions converged after the fourth iterations. It can be observed from Table 1 that the voltage magnitude at buses 16 (Gombe) and 22 (Kano) are lower than the acceptable limit
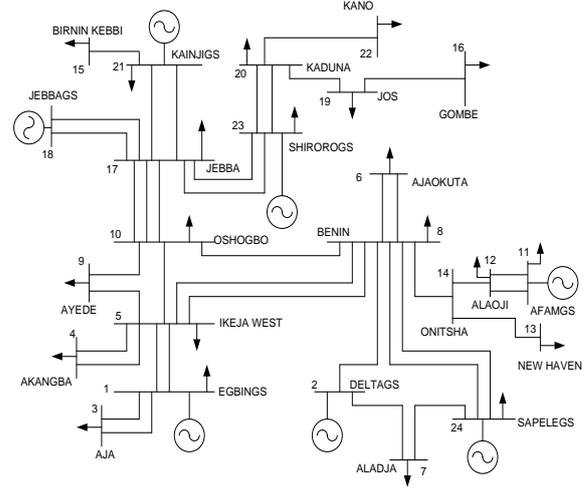

Figure 4: 24-bus 330kV Nigerian transmission system
Source: (National Control Centre, Power Holding Company of Nigerian, Nigeria, 2007)

A. Power Flow Solutions using Newton Raphson Method Without Load Tap Changing Transformer.
Table 1 shows the power flow solutions obtained for 330kV Nigerian 24-bus systems. The

of $\pm 10\%$ ($V_{min} \le V \le V_{max}$ i.e 0.9<1.0<1.1.) for the Nigerian 330kV transmission system [16]. Also the voltage magnitude at bus 14 (New-Haven) is very close to the lower limit and disproportionate power flows in some of the system transmission lines as shown alighted in Table 2.

Table 1: Power flow solutions by Newton Raphson method without load tap changing transformer.

Bus No.	Bus name	Voltage Mag.	Angle Degree	---Load—		---Generation---	
				MW	Mvar	MW	Mvar
1	Egbin	1.050	0.000	68.900	51.700	1490.456	197.004
2	Delta	1.050	-1.141	0.000	0.000	670.000	5.133
3	Aja	1.045	-0.284	274.400	205.800	0.000	0.000
4	Akangba	0.988	-5.644	344.700	258.500	0.000	0.000
5	Ikeja	0.996	-5.193	633.200	474.900	0.000	0.000
6	Ajaokuta	1.054	-6.991	13.800	10.300	0.000	0.000
7	Aladija	1.046	-2.711	96.500	72.400	0.000	0.000
8	Benin	1.034	-6.631	383.300	287.500	0.000	0.000
9	Ayade	0.974	-7.785	275.800	206.800	0.000	0.000
10	Osogbo	1.026	-4.932	201.200	150.900	0.000	0.000
11	Afam	1.050	-17.267	52.500	39.400	431.000	468.262
12	Alaoji	1.033	-17.892	427.000	320.200	0.000	0.000
13	New Heaven	**0.929**	-18.891	177.900	133.400	0.000	0.000
14	Onitsha	0.971	-16.086	184.600	138.400	0.000	0.000
15	Birnin-Kebbi	1.010	-3.972	114.500	85.900	0.000	0.000
16	Gombe	**0.866**	-31.675	130.600	97.900	0.000	0.000
17	Jebba	1.050	-1.614	11.000	8.200	0.000	0.000
18	Jebbag	1.050	-1.354	0.000	0.000	495.000	-59.187
19	Jos	0.948	-24.008	70.300	52.700	0.000	0.000
20	Kaduna	0.999	-16.668	193.000	144.700	0.000	0.000
21	Kainji	1.050	1.547	7.000	5.200	624.700	-114.695
22	Kano	**0.880**	-24.876	199.800	149.900	0.000	0.000
23	Shiroro	1.050	-12.220	320.100	256.100	388.900	559.104
24	Sapele	1.050	-5.122	20.600	15.400	190.300	770.033
	Total			**4200.700**	**3166.200**	**4290.356**	**1825.654**

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VII. LINE FLOW AND LOSSES

The results of the active power, reactive power flow at each bus and the line flow is as presented in Table 2. The total active power loss from the power flow program solutions by Newton Raphson method is 89.683Mw and that of the reactive power loss is 1340.300. In this case, the Load Tap Changing Transformer has not been applied.

Table 2: Line flow and losses of Nigerian 330kV 24-bus transmission system

From Bus	To Bus	Active power flow MW	Reactive power flow Mvar	Complex power flow MVA	Active power loss MW	Reactive power loss Mvar
1	3	137.36	97.59	168.49	0.16	-5.32
1	3	137.36	97.59	168.49	0.16	-5.32
1	**5**	**573.43**	**261.18**	**630.11**	**8.43**	**39.87**
1	**5**	**573.43**	**261.18**	**630.11**	**8.43**	**39.87**
2	**8**	**330.83**	**-0.59**	**330.83**	**4.29**	**-14.03**
2	**7**	**339.17**	**3.61**	**339.19**	**1.25**	**-3.64**
4	5	-72.35	-129.25	215.43	0.33	-4.22
4	5	-72.35	-129.25	215.43	0.33	-4.22
5	8	24.63	-104.06	106.93	0.34	-110.80
5	8	24.63	-104.06	106.93	0.34	-110.80
5	9	113.71	14.37	114.61	0.80	-45.80
5	10	-11.50	-88.60	89.34	0.17	-99.91
6	8	-6.90	-5.15	8.61	0.10	-82.80
6	8	-6.90	-5.15	8.61	0.10	-82.80
7	24	241.42	-65.15	250.05	1.39	-16.80
8	**14**	**425.90**	**109.42**	**439.73**	**10.12**	**21.72**
8	10	-40.15	-35.58	53.58	0.18	-103.36
8	24	-203.97	-89.56	222.76	0.89	-14.71
8	24	-203.97	-89.56	222.76	0.89	-14.71
9	10	-162.89	-146.63	219.17	2.00	-30.04
10	17	-139.36	-62.80	152.86	1.18	-57.15
10	17	-139.36	-62.80	152.86	1.18	-57.15
10	17	-139.36	-62.80	152.86	1.18	-57.15
11	12	189.25	212.74	284.74	0.76	-5.05
11	12	189.25	212.74	284.74	0.76	-5.05
12	14	-50.01	115.39	125.76	1.37	-50.44
13	14	-177.90	-133.40	222.36	1.90	-18.27
15	21	-114.50	-85.90	143.14	1.64	-116.92
16	19	-130.60	-97.90	163.22	3.14	-73.54
17	18	-247.39	28.16	248.99	0.11	-1.04
17	18	-247.39	28.16	248.99	0.11	-1.04
17	**23**	**280.01**	**-63.90**	**287.21**	**6.84**	**-54.35**
17	**23**	**280.01**	**-63.90**	**287.21**	**6.84**	**-54.35**
17	21	-248.94	23.16	250.01	1.85	-21.25
17	21	-248.94	23.16	250.01	1.85	-21.25
19	20	-204.04	-77.06	218.10	3.91	-47.36
20	**22**	**205.98**	**116.52**	**236.65**	**6.18**	**-33.38**
20	**23**	**-303.46**	**-145.46**	**336.52**	**4.11**	**-8.89**
20	**23**	**-303.46**	**-145.46**	**336.52**	**4.11**	**-8.89**
Total					89.68	-1340.30

A. *Power Flow Solutions with Inclusion of Load Tap - Changing Transformer.*

The power flow results obtained for 330kV Nigerian 24-bus system when a Load Tap Change Transformer (LTCT) was applied to the weak busses is as shown in Table 3 . LTCT was used in this work to regulate the voltage magnitude

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where needed, taking into consideration the set of voltage binding limits ,that is $V_{min} \leq V \leq V_{max}$ i.e 0.9<1.0<1.1. In this work, the per unit voltage V was taken as 1.0p.u. However, at bus 13, 16 and 22 the voltage magnitude was discovered to be very low, therefore it was neccessary to apply a load tap changing transformer (LTCT) to this busses at the sending end while the voltage magnitude at the recieving end was observed.   The maximum power mismatch was found to be equal to 0.000271655 and the

power flow solution with the incorporation of LTCT converged after the fouth iteration. It is observed from the power flow solution of Table 3 that the set of voltage magnitudes of busses 13, 16 and 22 have drastically increased after the application of LTCT , consequently, the reactive power generated by the system has decreased from 1825.654 Mvar to 1745.674 Mvar, meaning that the system is generating less reactive power.

Table 3: Power flow solutions by Newton Raphson method with load tap changing transformer.

Bus No.	Bus Name	Voltage Mag.	Angle (Degree)	Load MW	Load Mvar	Generation MW	Generation Mvar
1	Egbin	1.050	0.000	68.900	51.700	1482.958	191.205
2	Delta	1.050	-1.060	0.000	0.000	670.000	-2.289
3	Aja	1.045	-0.284	274.400	205.800	0.000	0.000
4	Akangba	0.988	-5.607	344.700	258.500	0.000	0.000
5	Ikeja	0.996	-5.157	633.200	474.900	0.000	0.000
6	Ajaokuta	1.054	-6.911	13.800	10.300	0.000	0.000
7	Aladija	1.046	-2.629	96.500	72.400	0.000	0.000
8	Benin	1.034	-6.550	383.300	287.500	0.000	0.000
9	Ayade	0.974	-7.684	275.800	206.800	0.000	0.000
10	Osogbo	1.026	-4.777	201.200	150.900	0.000	0.000
11	Afam	1.050	-17.175	52.500	39.400	431.000	461.769
12	Alaoji	1.033	-17.800	427.000	320.200	0.000	0.000
13	New Heaven	0.995	-18.805	177.900	133.400	0.000	0.000
14	Onitsha	0.972	-16.000	184.600	138.400	0.000	0.000
15	Birnin-Kebbi	1.010	-3.757	114.500	85.900	0.000	0.000
16	Gombe	0.950	-31.952	130.600	97.900	0.000	0.000
17	Jebba	1.050	-1.398	11.000	8.200	0.000	0.000
18	Jebbag	1.050	-1.138	0.000	0.000	495.000	89.521
19	Jos	0.958	-24.480	70.300	52.700	0.000	0.000
20	Kaduna	1.001	-17.178	193.000	144.700	0.000	0.000
21	Kainji	1.050	1.763	7.000	5.200	624.700	-196.116
22	Kano	0.996	-15.418	199.800	149.900	0.000	0.000
23	Shiroro	1.050	-11.865	320.100	256.100	388.900	440.911
24	Sapele	1.050	-5.041	20.600	15.400	190.300	760.673
	Total			**4200.700**	**3166.200**	**4282.858**	**1745.674**

B. *Power Flow Solutions Showing Line Flow and Losses With Inclusion of Load Tap Changing Transformer*

The results of the line flow and total active power losses obtained when Load Tap Changing   Transformer was applied to 330kV Nigerian 24-bus system is as shown in Table 4. As mentioned in the previous discussion , the tap ratio of the LTCT determines the additional transformation relative to the nominal transformation. In order to minimize the target objective function , the   tap ratios was

manipulated i.e controlled manually. The tappings was varied in such a way that if the voltage on the primary side as shown in figure 3   is lower than the set of binding limits (that is between 0.9 and 1.1 p.u) , the tap would change so as to increase the primary voltage while maintaining the secondary side voltage. The   same was also applied to the case when the voltage magnitude is higher than the set of binding limits. In this case, the tap will change so as to reduce the voltage to the desired range.

Table 4 : Line Flow and Losses Line Flow and Losses with load tap changing transformer.

From	to	Power at bus & line flow MW	Mvar	MVA	Line loss MW	Mvar	Transformer tap
1	3	137.358	97.585	168.493	0.158	-5.315	
1	3	137.358	97.585	168.493	0.158	-5.315	
1	5	569.676	260.973	626.608	8.336	39.164	
1	5	569.676	260.973	626.608	8.336	39.164	
2	8	330.841	-0.863	330.842	4.288	-14.032	
2	7	339.159	3.612	339.178	1.253	-3.640	
4	5	-172.350	-129.250	215.430	0.327	-4.217	
4	5	-172.350	-129.250	215.430	0.327	-4.217	
5	8	23.681	-103.990	106.652	0.334	-110.865	
5	8	23.681	-103.990	106.652	0.334	-110.865	
5	9	111.036	14.730	112.008	0.764	-46.037	
5	10	-14.269	-88.099	89.247	0.173	-99.886	
6	8	-6.900	-5.150	8.610	0.100	-82.814	
6	8	-6.900	-5.150	8.610	0.100	-82.814	

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7	24	241.406	-65.148	250.042	1.393	-16.796	
8	14	425.814	107.861	439.262	10.092	21.473	
8	10	-41.941	-35.133	54.712	0.190	-103.248	
8	24	-203.964	-88.990	222.532	0.893	-14.730	
8	24	-203.964	-88.990	222.532	0.893	-14.730	
9	10	-165.528	-146.033	220.738	2.037	-29.782	
10	17	-141.779	-62.416	154.910	1.217	-56.862	
10	17	-141.779	-62.416	154.910	1.217	-56.862	
10	17	-141.779	-62.416	154.910	1.217	-56.862	
11	12	189.250	211.985	284.171	0.754	-5.076	
11	12	189.250	211.985	284.171	0.754	-5.076	
12	14	-50.007	113.922	124.414	1.343	-50.670	
13	**14**	**-177.900**	**-131.135**	**221.009**	**1.872**	**-18.556**	**1.070**
15	21	-114.500	-85.900	143.140	1.637	-116.916	
16	**19**	**-130.600**	**-91.173**	**159.276**	**2.854**	**-79.026**	**1.070**
17	18	-247.387	28.464	249.020	0.113	-1.035	
17	18	-247.387	28.464	249.020	0.113	-1.035	
17	23	276.328	-64.078	283.660	6.659	-55.684	
17	23	276.328	-64.078	283.660	6.659	-55.684	
17	21	-248.935	23.182	250.012	1.846	-21.250	
17	21	-248.935	23.182	250.012	1.846	-21.250	
19	20	-203.754	-64.847	213.825	3.733	-49.581	
20	**22**	**-43.204**	**-31.494**	**53.464**	**0.185**	**-88.625**	**0.978**
20	23	-357.284	-128.472	379.680	5.298	-0.087	
20	23	-357.284	-128.472	379.680	5.298	-0.087	
Total loss					**85.10**	**-1412.28**	

The summarry of the results obtained without and with LTCT is as shown in Table 5

Table 5 - **Summary of results**

Case			Bus No	V_I (p.u)	V_F (p.u)	P_{LI} (Mw)	P_{LF} (Mw)
Nigerian	330kV	Grid	1	1.050	1.050	89.683	82.169
Systems			2	1.050	1.050		
			3	1.045	1.045		
			4	0.988	0.988		
			5	0.996	0.996		
			6	1.054	1.054		
			7	1.046	1.046		
			8	1.034	1.034		
			9	0.974	0.974		
			10	1.026	1.026		
			11	1.050	1.050		
			12	1.033	1.033		
			13	**0.929**	**0.995**		
			14	0.971	0.972		
			15	1.010	1.010		
			16	**0.866**	**0.950**		
			17	1.050	1.050		
			18	1.050	1.050		
			19	0.948	0.958		
			20	0.999	1.001		
			21	1.050	1.050		
			22	**0.880**	**0.996**		
			23	1.050	1.050		
			24	1.050	1.050		

where

V_I is the initial voltage magnitude in per unit without the incorporation of LTCT.

V_F is the final voltage magnitude in per unit with the incorporation of LTCT.

P_{LI} is the initial active power loss in Mw obtained when LTCT was yet to be applied to the system .

P_{LF} is the final active power loss in Mw obtained when LTCT was incorporated in the system.

VIII. CONCLUSION

Voltage instability in the Nigerian 330kv grid system is very high due to low generation radial and fragile nature of transmission lines and poor system protection. In this work, the power flow analysis for the Nigerian 330kV grid system was carried out successfully. Through this analysis, the active power and reactive power losses on the line were identified and Load Tap-Changing Transformer (LTCT) was used to regulate the voltage magnitude, taking into consideration the set of the binding limits. The results of the power flow analysis shows a significant reduction in the total system active power loss by 5.1% and an improvement in the voltage magnitude as well.

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