# Line Loss Reduction in Nigeria 330KV Transmission Line

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Abstract- This work analyses the line losses in the Nigeria 330kv, interconnected power system. It devised a dependable solution model and strategy for minimization of power losses on lines in the Nigeria 330kV grid. Unfortunately, electricity is not always used in large demand in a location it is been generated. So, long cables are used to transmit the generated electricity through overhead lines, this transmission does not take place without encountering loses. The load flow analysis was carried out on the existing 58bus with the view of estimating the real and reactive power flow, bus voltages and line power losses in the 330kv network using Newton-Raphson iterative algorithm. The simulation result of the 58buses shows that (6) six buses did not satisfy the statutory voltage limit of 0.95pu to 1.05pu. The bus voltage profile shows that most of the violated buses are in the northern part of Nigeria. The simulation result of the study system line active power loss showed that there was 4.3232 pu line active power loss which is about 432 mw 100 mw base power value. Major system active power losses were witness in the southern part Nigeria. The problem of low voltage was solved by the use of facts device using continuation power flow method, the violated buses were cleared by optimal placement of UPFC along Kaduna – Jos transmission line. The losses were reduced successfully to 32.39% by combine effort of multiple optimal placements of UPFC along Onitsha - Alaoji transmission line.

Indexed Terms- FACTS Device; UPFC; Power Losses; Voltage profile

## I. INTRODUCTION

Electric power losses are wasteful energy caused by external factors or internal factors, and energy dissipated in the power system. Which include losses due to resistance, atmospheric conditions, theft, miscalculations, etc, and losses incurred between sources of supply to load centre (or consumers). In power system, these can lead to more economic operation of the power system. If we can detect how these losses occur, we can take steps to limit and minimize the losses. Consequently Therefore, the existing power generation and transmission can be effectively used without having the need to build new installations and at the same time save cost of losses. Mostly, losses in electrical power system can be identified as those losses caused by internal factors known as technical losses [1] which are mainly energy dissipated in the electrical components like the power transformer, transmission lines, motors, measurement systems, generators, etc and those cause by external factors basically due to human manipulations or errors are called non-technical losses like losses that occur as a result of power theft, billing problems, administrative lapses, metering inaccuracies and unmetered energy [3]. Due to the magnitude of areas the power system serves, the majority of the power systems are dedicated to power transmission. Generally, power system losses increase the operating cost of electric utilities and consequently result in high cost of electricity. Therefore, reduction of system losses is of paramount importance because of the financial, economic and socio-economic values to the utility company, customers and the host country [2]. These generating stations are mostly connected to load centers through very long, fragile and radial transmission lines. Considering the fact that most of the existing Nigeria generating stations were located far from the load centers with partial longitudinal network, there is possibility of experiencing low bus voltages, lines overload, frequency fluctuations and poor system damping in the power network, thereby making the stability of the network to be weak when subjected to fault conditions. In other to ascertain the

impact of the integrated power projects on the existing network, a power or load flow program must be carried out load flow analysis is one the most important aspects of power system planning and operation. The power flow provides us the sinusoidal steady state of the entire power system- voltages, real, reactive powers and line losses [6]. In case of violations and losses on the line power electronic FACTS device with fast response is use to clear the violations and reduce the losses. The use of Flexible Alternating Current Transmission System (FACTS) Controllers with fast responses and no major alterations to the system layout were increasingly replacing electromechanical devices. FACTS devices are power electronic devices or other static controllers incorporated in AC transmission systems to enhance controllability and increase power transfer capability [5].

## II. UNIFIED POWER FLOW CONTROLLER

The UPFC is the most versatile and powerful FACTS device. UPFC is also known as the most comprehensive multivariable flexible ac transmission system (FACTS) controller [7]. The Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. The basic structure of the UPFC consists of two voltage source inverters (VSI); where one converter is connected in parallel to the transmission line while the other is in series with the transmission line.

The UPFC consists of two voltage source converters; series and shunt converter, which are connected to each other with a common dc link.

## III. METHOD

3.1 Modeling of Power Systems with UPFC
Equivalent circuit of UPFC is shown in Figure 1. The synchronous voltage sources represent the fundamental Fourier series component of the switched voltage waveforms at the AC converter terminals of the UPFC [5].
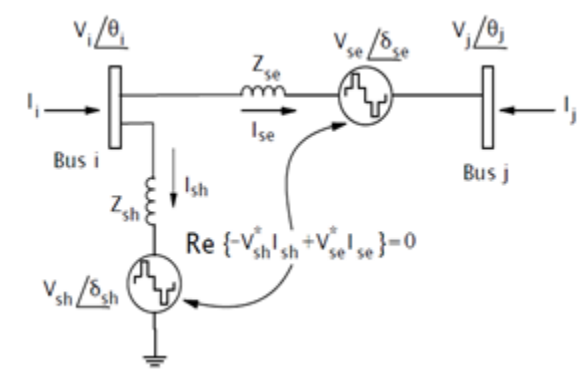


Figure 1 UPFC Equivalent Circuit

$$
\begin{bmatrix}
\Delta P_i \\
\Delta P_j \\
\Delta Q_i \\
\Delta Q_j \\
\Delta P_{ji} \\
\Delta Q_{ji} \\
\Delta P_{bb}
\end{bmatrix}
=
\begin{bmatrix}
\frac{\partial P_i}{\partial \theta_i} & \frac{\partial P_i}{\partial \theta_j} & \frac{\partial P_i}{\partial v_{sh}}v_{sh} & \frac{\partial P_i}{\partial v_j}v_j & \frac{\partial P_i}{\partial \delta_{se}} & \frac{\partial P_i}{\partial v_{se}}v_{se} & \frac{\partial P_i}{\partial v_{sh}} \\
\frac{\partial P_j}{\partial \theta_i} & \frac{\partial P_j}{\partial \theta_j} & 0 & \frac{\partial P_j}{\partial v_j}v_j & \frac{\partial P_j}{\partial \delta_{se}} & \frac{\partial P_j}{\partial v_{se}}v_{se} & 0 \\
\frac{\partial Q_i}{\partial \theta_i} & \frac{\partial Q_i}{\partial \theta_j} & \frac{\partial Q_i}{\partial v_{sh}}v_{sh} & \frac{\partial Q_i}{\partial v_j}v_j & \frac{\partial Q_i}{\partial \delta_{se}} & \frac{\partial Q_i}{\partial v_{se}}v_{se} & \frac{\partial Q_i}{\partial v_{sh}} \\
\frac{\partial Q_j}{\partial \theta_i} & \frac{\partial Q_j}{\partial \theta_j} & 0 & \frac{\partial Q_j}{\partial v_j}v_j & \frac{\partial Q_j}{\partial \delta_{se}} & \frac{\partial Q_j}{\partial v_{se}}v_{se} & 0 \\
\frac{\partial P_{ji}}{\partial \theta_i} & \frac{\partial P_{ji}}{\partial \theta_j} & 0 & \frac{\partial P_{ji}}{\partial v_j}v_j & \frac{\partial P_{ji}}{\partial \delta_{se}} & \frac{\partial P_{ji}}{\partial v_{se}}v_{se} & 0 \\
\frac{\partial Q_{ji}}{\partial \theta_i} & \frac{\partial Q_{ji}}{\partial \theta_j} & 0 & \frac{\partial Q_{ji}}{\partial v_j}v_j & \frac{\partial Q_{ji}}{\partial \delta_{se}} & \frac{\partial Q_{ji}}{\partial v_{se}}v_{se} & 0 \\
\frac{\partial P_{bb}}{\partial \theta_i} & \frac{\partial P_{bb}}{\partial \theta_j} & \frac{\partial P_{bb}}{\partial v_{sh}}v_i & \frac{\partial P_{bb}}{\partial v_j}v_j & \frac{\partial P_{bb}}{\partial \delta_{se}} & \frac{\partial P_{bb}}{\partial v_{se}}v_{se} & \frac{\partial P_{bb}}{\partial v_{sh}}
\end{bmatrix}
\begin{bmatrix}
\Delta \theta_i \\
\Delta \theta_j \\
\frac{\Delta v_i}{v_i} \\
\frac{\Delta v_j}{v_j} \\
\Delta \delta_{se} \\
\frac{\Delta v_{se}}{v_{se}} \\
\Delta \delta_{sh}
\end{bmatrix}
$$

(1)

3.2 Modeling of Power Flow in Transmission Line

An electrical transmission system with n – buses if, the current flowing in bus i-th term is shown in Figure 2.
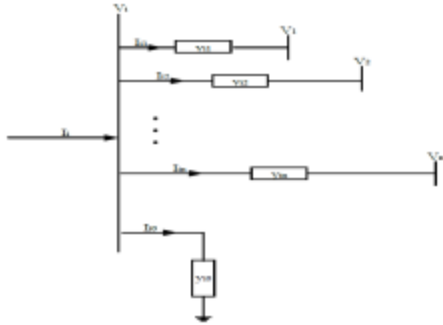
Figure 2 A simplified i-th bus model of a power

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 \cdots Y_{in}V_n \qquad (2)$$

Equation (2) can be expressed as

$$I_i = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j \qquad (3)$$

The expression for the complex power is given in (Gupta, 2011) as

$$S_i = P_i - jQ_i = V_i^* I_i \qquad (4)$$

From Eq. (2) and (3) we have

$$\frac{P_i - jQ_i}{V_i} = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j, \ j \neq i \qquad (5)$$

Solving for $V_i$ in the equation above, we obtain

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i} + \sum_{j=1}^{n} Y_{ij}V_j\right], \quad j \neq i \qquad (6)$$

Also, by decoupling Eq. (5) into real and imaginary parts and expressing the components parts in polar form, we obtain equations

$$P_i = |V_i|^2 G_{ii} + \sum_{j=1}^{n}|Y_{ij}V_jV_{ij}|\cos(\theta_{ij} + \delta_j - \delta_i), \ j \neq I \qquad (7)$$

$$Q_i = |V_i|^2 B_{ii} + \sum_{j=1}^{n}|Y_{ij}V_jV_{ij}|\sin(\theta_{ij} + \delta_j - \delta_i), \ j \neq I \qquad (8)$$

### 3.3 Newton-Raphson Power Flow

The Newton Raphson method formulates and solves iteratively the following load flow equation $\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}\begin{bmatrix} J_1 J_2 \\ J_3 J_4 \end{bmatrix} = \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix}$ Where $\Delta P$ and $\Delta Q$ are bus real power and reactive pwer mismatch vectors between specified value and calculated value, respectively: $\Delta V$

and $\Delta\delta$ represents bus voltage angle and magnitude vectors in an uncremental form: and $J_1$ through $J_4$ are called jacobian matrices.

### 3.4 Modeling of Line Flows and Losses

Once the number of iterations is complete, the computation of line flows and losses is implemented. Thus, Figure 3 is a line diagram of a transmission line between two buses $i$ and j which is used as a model to derive the line flow and losses.
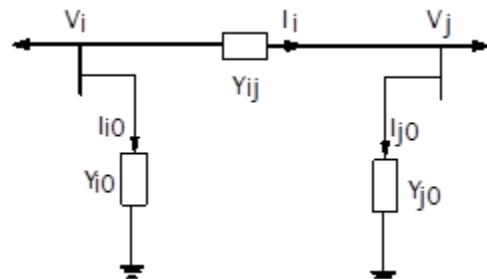


Figure Transmission line model for calculating line losses [8]

The complex power $S_{ij}$ from bus I to j which represents the Line flow and that from j to i, $S_{ij}$, are given as

$$S_{ij} = V_i I_{ij}^* \qquad (9)$$
$$S_{ji} = V_j I_{ji}^* \qquad (10)$$

The power loss $SL_{ij}$ in line i – j is the algebraic sum of the power flows determined from Eq. (9) and (10)

$$SL_{ij} = S_{ij} + S_{ji} \qquad (12)$$

These equations are the mathematical model requirement for simulating load flow and line losses using Newton

### 3.5 Overview of Nigerian Transmission System

The Nigerian national grid is an interconnection of 9,454.8KM length of 330KV and 8,985.28km length of 132KV transmission lines with Twenty-three power stations. The grid interconnects these stations with fifty-eight buses and eighty-seven transmission lines of either dual or single circuit lines and four control centers (one national control center at Oshogbo and three supplementary control centers at Benin, Shiroro and Egbin).
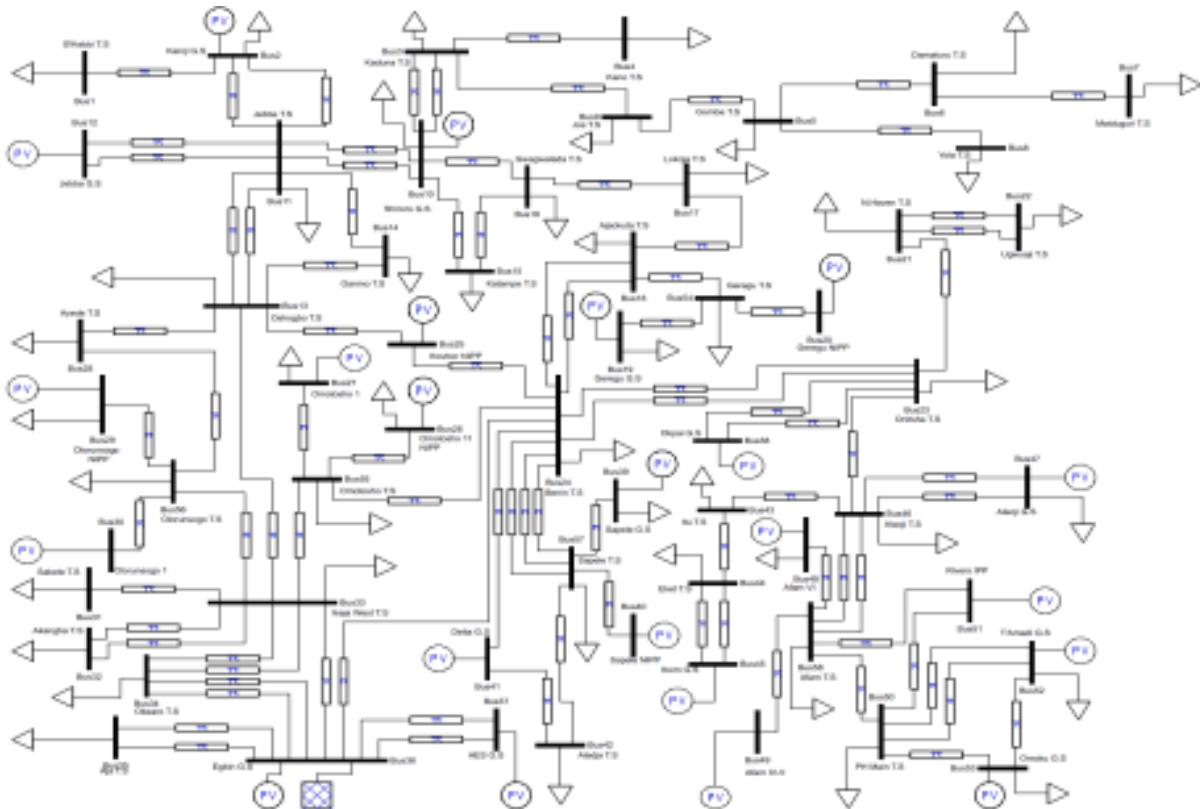
Figure 4: Single Line Diagram of 58 Buses, 330kv Nigeria Transmission Network for Case 1 Study System

IV.    SIMULATION RESULTS

Table 1: Line Flow Simulation Result of 58 Buses, 330 kV Transmission Line Network

| Bus Number | Bus Name | V [p.u.] | phase [rad] | P gen [p.u.] | Q gen [p.u.] | P load [p.u.] | Q load [p.u.] |
|---|---|---|---|---|---|---|---|
| 1 | BirninKebbi | 0.9797 | 0.6710 | - | - | 1.6200 | 1.2200 |
| 2 | Kainji | 0.9700 | -0.5045 | 2.9200 | -4.4960 | 0.8900 | 0.6700 |
| 3 | Kaduna | 0.9880 | -0.8609 | - | - | 1.4300 | 0.9800 |
| 4 | Kano | 0.9352 | -1.0051 | - | - | 1.9400 | 1.4600 |
| 5 | Gombe | 0.8979 | -1.1451 | - | - | 0.6800 | 0.5100 |
| 6 | Damaturu | 0.8942 | -1.1828 | - | - | 0.2400 | 0.1800 |
| 7 | Maiduguri | 0.8845 | -1.2130 | - | - | 0.3100 | 0.2000 |
| 8 | Yola | 0.8898 | -1.1682 | - | - | 0.2600 | 0.2000 |
| 9 | Jos | 0.9331 | -1.0028 | - | - | 0.7200 | 0.5400 |
| 10 | Shiroro | 1.0000 | -0.7766 | 3.0000 | -2.1790 | 1.7000 | 0.9800 |
| 11 | Jebba T/S | 1.0016 | -0.5144 | - | - | 2.6000 | 1.9500 |
| 12 | Jebba G/S | 1.0000 | -0.5097 | 4.0300 | -2.0467 | - | - |
| 13 | Oshogbo | 1.0220 | -0.4437 | - | - | 1.2700 | 0.9500 |
| 14 | Ganmo | 1.0136 | -0.4871 | - | - | 1.0000 | 0.7500 |

| 15 | Katampe | 0.9688 | -0.8546 | - | - | 3.0300 | 2.2700 |
|---|---|---|---|---|---|---|---|
| 16 | Gwagwalada | 0.9810 | -0.8186 | - | - | 2.2000 | 1.6500 |
| 17 | Lokoja | 0.9837 | -0.6683 | - | - | 1.2000 | 0.9000 |
| 18 | Ajaokuta | 0.9857 | -0.6108 | - | - | 1.2000 | 0.9000 |
| 19 | Geregu G/S | 0.9850 | -0.6090 | 3.8500 | 1.4546 | 2.0000 | 1.5000 |
| 20 | Geregu (NIPP) | 0.9850 | -0.6092 | 1.4600 | -0.0045 | - | - |
| 21 | New Haven | 0.9724 | -0.9395 | - | - | 1.9600 | 1.4700 |
| 22 | Ugwaji | 0.9719 | -0.9413 | - | - | 1.7500 | 1.3100 |
| 23 | Onitsha | 0.9741 | -0.8228 | - | - | 1.0000 | 0.7500 |
| 24 | Benin | 0.9959 | -0.4963 | - | - | 1.4400 | 1.0800 |
| 25 | Ihovbor (NIPP) | 1.0000 | -0.4834 | 1.1660 | -1.3929 | - | - |
| 26 | Omotosho (NIPP) | 1.0060 | -0.3375 | 1.1470 | 0.5119 | 0.9000 | 0.4400 |
| 27 | Omotosho I | 1.0000 | -0.3377 | 0.5080 | -0.0283 | 0.3000 | 0.1400 |
| 28 | Ayede | 0.9808 | -0.3097 | - | - | 1.7400 | 1.3100 |
| 29 | Olorunsogo (NIPP) | 0.9730 | -0.1995 | 0.9300 | -0.1499 | 0.7100 | 0.5800 |
| 30 | Olorunsogo I | 0.9700 | -0.1835 | 1.0270 | -0.9704 | - | - |
| 31 | Sakete | 0.9780 | -0.1289 | - | - | 2.0500 | 1.1000 |
| 32 | Akangba | 0.9962 | -0.0905 | - | - | 2.0300 | 1.5200 |
| 33 | Ikeja West | 1.0000 | -0.0861 | - | - | 8.4700 | 6.3500 |
| 34 | Okearo | 1.0147 | -0.0439 | - | - | 1.2000 | 0.9000 |
| 35 | Aja | 1.0313 | -0.0021 | - | - | 1.1500 | 0.8600 |
| 36 | Egbin | 1.0330 | 0.0000 | 41.2292 | 10.0363 | - | - |
| 37 | Aes | 1.0000 | 0.0766 | 2.4520 | -3.4949 | - | - |
| 38 | Okpai | 1.0000 | -0.7857 | 4.6600 | 1.6564 | - | - |
| 39 | Sapele G/S | 0.9850 | -0.4898 | 0.6700 | -0.9584 | 0.4000 | 0.1800 |
| 40 | Sapele (NIPP) | 1.0000 | -0.4799 | 1.1110 | -0.1835 | - | - |
| 41 | Delta | 1.0030 | -0.4790 | 3.4100 | 0.9016 | - | - |
| 42 | Aladja | 0.9922 | -0.4972 | - | - | 2.1000 | 1.5800 |
| 43 | Itu | 0.9830 | -1.5300 | - | - | 1.9900 | 0.9100 |
| 44 | Eket | 0.9879 | -1.5464 | - | - | 2.0000 | 1.4700 |
| 45 | Ibom | 1.0000 | -1.5449 | 0.3050 | 1.6019 | - | - |
| 46 | Alaoji T/S | 0.9834 | -1.4878 | - | - | 2.4000 | 1.0000 |
| 47 | Alaoji G/S | 1.0000 | -1.4885 | 2.5000 | 8.8133 | 2.2700 | 1.7000 |
| 48 | Afam Vi | 1.0000 | -1.5107 | 6.4600 | 8.2675 | 5.3400 | 4.0100 |
| 49 | Afam IV-V | 0.9560 | -1.5100 | 0.5400 | -5.0313 | - | - |
| 50 | Ph Main | 0.9973 | -1.5274 | - | - | 2.8000 | 1.4000 |
| 51 | Rivers (IPP) | 1.0000 | -1.5227 | 0.8000 | 2.7534 | - | - |
| 52 | Trans Amadi | 1.0000 | -1.5274 | 1.0000 | 2.0070 | 0.8000 | 0.2400 |
| 53 | Omoku | 1.0000 | -1.5276 | 0.4480 | 0.3897 | 0.5000 | 0.1000 |
| 54 | Geregu T/S | 0.9849 | -0.6100 | - | - | 2.0000 | 1.5000 |
| 55 | Omotosho T/S | 0.9928 | -0.3420 | - | - | 0.8000 | 0.5000 |

| 56 | Olorunsogo T/S | 0.9804 | -0.2047 | - | - | 0.7100 | 0.5800 |
|----|----------------|--------|---------|---|---|--------|--------|
| 57 | Sapele T/S | 0.9965 | -0.4952 | - | - | 1.0000 | 0.7700 |
| 58 | Afam T/S | 0.9798 | -1.5145 | - | - | 7.2000 | 4.1200 |

The result of the simulation of case1 study system, 58 buses, 330 kV Nigeria transmission network showed that six (6) buses fall off the statutory voltage limit of 0.95 pu to 1.05 pu. These buses are (Kano 0.9352 pu, Gombe 0.8979 pu, Damaturu 0.8942 pu, Maiduguri 0.8845 pu, Yola 0.8898pu and Jos 0.9331 pu).
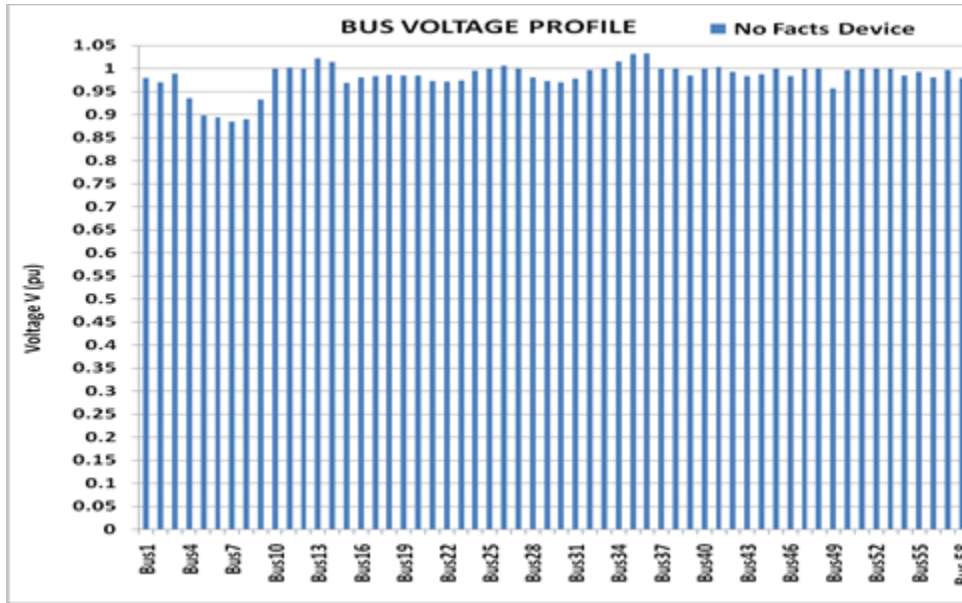


Figure 5Bar Representation of the Simulated Bus Voltages of the System

Table2: Line Flows Simulation Result of 58 Buses, 330 kV Transmission Line Network

| LINE FLOWS | | | | | | |
|------|------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Line | Bus to Bus (Number) | Bus to Bus (Name) | P Flow [p.u.] | Q Flow [p.u.] | P Loss [p.u.] | Q Loss [p.u.] |
| 1 | 1 – 2 | BirninKebbi – Kainji | 1.6200 | 1.2200 | 0.0325 | 2.9933 |
| 2 | 3 – 4 | Kaduna – Kano | 1.9765 | 0.5991 | 0.0365 | 2.0591 |
| 3 | 10 – 11 | Shiroro – Jebba TS | 3.5085 | 1.2846 | 0.1073 | 1.7939 |
| 4 | 10 – 11 | Shiroro – Jebba TS | 3.5085 | 1.2846 | 0.1073 | 1.7939 |
| 5 | 3 – 10 | Kaduna – Shiroro | 2.8447 | 0.4672 | 0.0285 | 0.8054 |
| 6 | 10 – 16 | Shiroro –Gwagwalada | 1.0604 | 0.5391 | 0.0066 | 1.6958 |
| 7 | 3 – 9 | Kaduna – Jos | 2.2828 | 0.5535 | 0.0420 | 0.1049 |
| 8 | 9 – 5 | Jos –Gombe | 1.5208 | 0.1184 | 0.0263 | 0.1957 |
| 9 | 16 – 17 | Gwagwalada – lokoja | 2.9037 | 0.4719 | 0.0573 | 1.6050 |
| 10 | 11 – 14 | Jebba TS –Ganmo | 2.1481 | 0.8483 | 0.0183 | 1.1765 |
| 11 | 13 – 14 | Oshogbo – Ganmo | 3.1829 | 0.0229 | 0.0165 | 0.3989 |
| 12 | 11 – 13 | Jebba TS –Oshogbo | 1.5391 | 1.0655 | 0.0135 | 1.6670 |
| 13 | 5 – 8 | Gombe –Yola | 0.2608 | 0.0650 | 0.0008 | 0.2650 |

| 14 | 11 – 13 | Jebba TS –Oshogbo | 1.5391 | 1.0655 | 0.0135 | 1.6670 |
|----|---------|-------------------|--------|--------|--------|--------|
| 15 | 16 – 15 | Gwagwalada – Katampe | 1.7575 | 0.0214 | 0.0088 | 0.7687 |
| 16 | 10 – 15 | Shiroro – Katampe | 1.2957 | 0.9249 | 0.0145 | 2.4475 |
| 17 | 18 – 17 | Ajaokute –Lokoja | 4.1922 | 0.5559 | 0.0312 | 0.3228 |
| 18 | 53 – 50 | Omoku – PH Main | 0.0037 | 0.3155 | 0.0001 | 0.1426 |
| 19 | 58 – 51 | Afam T/S – Rivers IPP | 0.7098 | 2.3847 | 0.0039 | 0.3251 |
| 20 | 19 – 54 | Geregu G/S  Geregu T/S | 1.8500 | 0.0454 | 0.0002 | 0.0008 |
| 21 | 54 – 20 | Geregu T/S  – Geregu (NIPP) | 1.4599 | 0.0046 | 0.0001 | 0.0002 |
| 22 | 18 – 54 | Ajaokute – Geregu T/S | 1.3095 | 1.5520 | 0.0002 | 0.0012 |
| 23 | 21 – 23 | New Heaven – Onitsha | 3.7104 | 0.7042 | 0.0514 | 2.1783 |
| 24 | 5 – 6 | Gombe – Damaturu | 0.5536 | 0.1309 | 0.0025 | 0.2522 |
| 25 | 21 – 22 | New Heaven – Ugwaji | 0.8752 | 0.3829 | 0.0002 | 1.0379 |
| 26 | 21 – 22 | New Heaven – Ugwaji | 0.8752 | 0.3829 | 0.0002 | 1.0379 |
| 27 | 18 – 24 | Ajaokute – Benin | 2.0414 | 0.9481 | 0.0305 | 2.0817 |
| 28 | 18 – 24 | Ajaokute – Benin | 2.0414 | 0.9481 | 0.0305 | 2.0817 |
| 29 | 25 – 24 | Ihovbor(NIPP) – Benin | 1.7226 | 0.2090 | 0.0028 | 0.2553 |
| 30 | 13 – 25 | Oshogbo –Ihovbor(NIPP) | 0.5598 | 1.2128 | 0.0032 | 2.8147 |
| 31 | 55 – 26 | Omotosho T/S – Omotosho (NIPP) | 0.2461 | 0.9430 | 0.0009 | 0.8711 |
| 32 | 27 – 55 | Omotosho 1 – Omotosho T/S | 0.2080 | 0.1683 | 0.0003 | 0.8708 |
| 33 | 55 – 24 | Omotosho T/S – Benin | 9.7276 | 0.8616 | 0.1760 | 0.9399 |
| 34 | 28 – 13 | Ayede – Oshogbo | 3.6740 | 1.9463 | 0.0654 | 0.7294 |
| 35 | 6 – 7 | Damaturu – Maiduguri | 0.3112 | 0.0588 | 0.0012 | 0.2588 |
| 36 | 29 – 56 | Olorunsogo(NIPP)  – Olorunsogo T/S | 0.2200 | 0.7299 | 0.0005 | 0.6253 |
| 37 | 56 – 30 | Olorunsogo T/S – Olorunsogo 1 | 1.0236 | 0.3716 | 0.0034 | 0.5988 |
| 38 | 28 – 56 | Ayede – Olorunsogo T/S | 5.4140 | 0.6363 | 0.0675 | 0.0617 |
| 39 | 31 – 33 | Sakete – Ikeja West | 2.0500 | 1.1000 | 0.0124 | 0.6578 |
| 40 | 56 – 33 | Olorunsogo T/S – Ikeja West | 4.9484 | 0.3581 | 0.0702 | 0.2469 |
| 41 | 13 – 33 | Oshogbo –Ikeja West | 4.5092 | 0.2261 | 0.1984 | 1.1576 |
| 42 | 55 – 33 | Omotosho T/S – Ikeja West | 10.0739 | 2.0071 | 0.3092 | 2.1886 |
| 43 | 32 – 33 | Akangba – Ikeja West | 1.0150 | 0.7600 | 0.0009 | 0.1922 |
| 44 | 32 – 33 | Akangba – Ikeja West | 1.0150 | 0.7600 | 0.0009 | 0.1922 |
| 45 | 34 – 33 | Okearo – Ikeja West | 8.0612 | 1.8428 | 0.0431 | 0.1625 |
| 46 | 2 – 11 | Kainji – Jebba TS | 0.1887 | 1.6964 | 0.0069 | 0.8315 |
| 47 | 34 – 33 | OkearoIkeja West | 8.0612 | 1.8428 | 0.0431 | 0.1625 |
| 48 | 35 – 36 | Aja – Egbin | 0.5750 | 0.4300 | 0.0002 | 0.1687 |
| 49 | 35 – 36 | Aja – Egbin | 0.5750 | 0.4300 | 0.0002 | 0.1687 |
| 50 | 34 – 36 | Okearo – Egbin | 8.6613 | 2.2928 | 0.0500 | 0.2144 |
| 51 | 34 – 36 | Okearo – Egbin | 8.6613 | 2.2928 | 0.0500 | 0.2144 |
| 52 | 33 – 36 | Ikeja West – Egbin | 16.6373 | 3.4761 | 0.1859 | 1.3701 |
| 53 | 24 – 36 | Benin – Egbin | 7.7806 | 1.2490 | 0.4771 | 1.7638 |
| 54 | 36 – 37 | Egbin – Aes | 1.2123 | 0.4310 | 0.0137 | 2.1784 |

| 55 | 36 – 37 | Egbin – Aes | 1.2123 | 0.4310 | 0.0137 | 2.1784 |
|----|---------|-------------|--------|--------|--------|--------|
| 56 | 24 – 23 | Benin – Onitsha | 7.5734 | 0.1053 | 0.2874 | 0.9643 |
| 57 | 12 – 11 | Jebba GS – Jebba TS | 2.0150 | 1.0233 | 0.0014 | 0.0890 |
| 58 | 24 – 23 | Benin – Onitsha | 7.5734 | 0.1053 | 0.2874 | 0.9643 |
| 59 | 23 – 38 | Opkai – Onitsha | 2.3300 | 0.8282 | 0.0154 | 0.7782 |
| 60 | 23 – 38 | Opkai – Onitsha | 2.3300 | 0.8282 | 0.0154 | 0.7782 |
| 61 | 24 – 57 | Benin – Sapele T/S | 0.0821 | 0.3308 | 0.0000 | 0.5953 |
| 62 | 24 – 57 | Benin – Sapele T/S | 0.0821 | 0.3308 | 0.0000 | 0.5953 |
| 63 | 24 – 57 | Benin – Sapele T/S | 0.0821 | 0.3308 | 0.0000 | 0.5953 |
| 64 | 39 – 57 | Sapele G/S – Sapele T/S | 0.2700 | 1.1384 | 0.0015 | 0.5776 |
| 65 | 57 – 40 | Sapele T/S – Sapele (NIPP) | 1.1087 | 0.3971 | 0.0023 | 0.5805 |
| 66 | 24 – 41 | Benin – Delta | 1.4321 | 0.6171 | 0.0033 | 0.4318 |
| 67 | 41 – 42 | Delta – Aladja | 1.9746 | 0.7164 | 0.0054 | 0.3128 |
| 68 | 12 – 11 | Jebba GS – Jebba TS | 2.0150 | 1.0233 | 0.0014 | 0.0890 |
| 69 | 57 – 42 | Sapele T/S – Aladja | 0.1309 | 0.1402 | 0.0001 | 0.6910 |
| 70 | 43 – 44 | Itu – Eket | 1.7007 | 0.9793 | 0.0048 | 0.3371 |
| 71 | 44 – 45 | Eket – Ibom | 0.1521 | 1.0561 | 0.0004 | 0.2552 |
| 72 | 44 – 45 | Eket – Ibom | 0.1521 | 1.0561 | 0.0004 | 0.2552 |
| 73 | 43 – 46 | Itu – Alaoji T/S | 3.6907 | 0.0693 | 0.0059 | 0.0663 |
| 74 | 23 – 46 | Onitsha – Alaoji T/S | 14.4395 | 2.2188 | 1.1313 | 8.1259 |
| 75 | 46 – 47 | Alaoji T/S – Alaoji G/S | 0.1105 | 3.5912 | 0.0045 | 0.0346 |
| 76 | 46 – 47 | Alaoji T/S – Alaoji G/S | 0.1105 | 3.5912 | 0.0045 | 0.0346 |
| 77 | 58 – 49 | Afam T/S – Afam IV–V | 0.5304 | 5.0680 | 0.0096 | 0.0367 |
| 78 | 52 – 50 | Trans Amadi – PH Main | 0.0980 | 1.4392 | 0.0003 | 0.0360 |
| 79 | 2 – 11 | Kainji – Jebba TS | 0.1887 | 1.6964 | 0.0069 | 0.8315 |
| 80 | 46 – 58 | Alaoji T/S – Afam T/S | 3.7162 | 0.2046 | 0.0075 | 0.0388 |
| 81 | 46 – 58 | Alaoji T/S – Afam T/S | 3.7162 | 0.2065 | 0.0075 | 0.0350 |
| 82 | 58 – 50 | Afam T/S – PH Main | 1.1512 | 2.0579 | 0.0039 | 0.3722 |
| 83 | 51 – 50 | Rivers IPP – PH Main | 1.5059 | 0.6938 | 0.0007 | 0.0578 |
| 84 | 52 – 50 | Trans Amadi – PH Main | 0.0463 | 0.3619 | 0.0001 | 0.0389 |
| 85 | 52 – 53 | Trans Amadi – Omoku | 0.0557 | 0.0342 | 0.0000 | 0.0600 |
| 86 | 48 – 58 | Afam IV – Afam T/S | 1.1200 | 4.2575 | 0.0069 | 0.0030 |
| 87 | 3 – 10 | Kaduna – Shiroro | 2.8447 | 0.4672 | 0.0285 | 0.8054 |

The simulation result of the study system line active power loss showed that there was 4.3232 pu line active power loss which is about 432 mw 100 mw base power value. Major system active power losses were witness in the southern part Nigeria. The lines with active power losses in this research occurred because of the attempts by these lines to evacuate the generated electric power from the south to the northern part of Nigeria where generating plants were lacking.

Table 3: Line Loss Index Order Using Continuation Power Flow

| Item | Line Number | Bus to Bus (Number) | Bus to Bus (Name) | P Loss [p.u.] |
|------|-------------|---------------------|-------------------|---------------|
| 1 | 74 | 23 – 46 | Onitsha – Alaoji T/S | 1.414192 |
| 2 | 53 | 24 – 36 | Benin – Egbin | 0.586005 |
| 3 | 42 | 55 – 33 | Omotosho T/S  Ikeja West | 0.382254 |
| 4 | 56 | 24 – 23 | Benin – Onitsha | 0.355359 |
| 5 | 58 | 24 – 23 | Benin – Onitsha | 0.355359 |
| 6 | 41 | 13 – 33 | Oshogbo –Ikeja West | 0.242838 |
| 7 | 52 | 33 – 36 | Ikeja West  Egbin | 0.225874 |
| 8 | 33 | 55 – 24 | Omotosho T/S – Benin | 0.216129 |
| 9 | 3 | 10 – 11 | Shiroro – Jebba TS | 0.129239 |
| 10 | 4 | 10 – 11 | Shiroro – Jebba TS | 0.129239 |
| 11 | 40 | 56 – 33 | Olorunsogo T/S  Ikeja West | 0.085917 |
| 12 | 7 | 3 – 9 | Kaduna – Jos | 0.083308 |
| 13 | 38 | 28 – 56 | Ayede – Olorunsogo T/S | 0.081813 |
| 14 | 34 | 28 – 13 | Ayede – Oshogbo | 0.07989 |
| 15 | 9 | 16 – 17 | Gwagwalada – lokoja | 0.067813 |
| 16 | 23 | 21 – 23 | New Heaven – Onitsha | 0.062427 |
| 17 | 50 | 34 – 36 | Okearo – Egbin | 0.060708 |
| 18 | 51 | 34 – 36 | Okearo – Egbin | 0.060708 |
| 19 | 8 | 9 – 5 | Jos –Gombe | 0.058233 |

The result of continuation power flow for the ranking of line loadability collapse is shown in table 3. The most vulnerable line to loadability collapse is Onitsha – Alaoji line as this line is the optimal placement for UPFC for line active loss reduction. The optimal placement is chosen as the most vulnerable single line to loadability collapse closest to the voltage violated area, as such Kaduna – Jos line is predicted as the optimal placement of UPFC for voltage profile enhancement.

Table 4 Violated Buses of 58 Bus 330kv Transmission Line System When Facts Devices Are Inserted

| Bus Number | Bus Name | UPFC Voltage V[p.u.] | NO FACT Voltage V[p.u.] |
|------------|----------|----------------------|-------------------------|
| 4 | Kano | 1.0171 | 0.9352 |
| 5 | Gombe | 1.0396 | 0.8979 |
| 6 | Damaturu | 1.0455 | 0.8942 |
| 7 | Maiduguri | 1.0417 | 0.8845 |
| 8 | Yola | 1.0365 | 0.8898 |
| 9 | Jos | 1.0375 | 0.9331 |

Table 5: Total Transmission Line Active Power Loss of the Study System before and After Insertion of Facts Devices.

| | Active Power Loss (pu) | Active Loss Reduction (%) |
|------|------------------------|---------------------------|
| NO FACTS | 4.3232 | – |
| ONE UPFC | 2.9486 | 31.80 |
| TWO UPFC | 2.9230 | 32.39 |

CONCLUSION

The present 58 buses, 330 kV Nigeria transmission network system has been investigated in this research. The research exposed six voltage violated buses (Kano

0.9352 pu, Gombe 0.8979 pu, Damaturu 0.8942 pu, Maiduguri 0.8845 pu, Yola 0.8898pu and Jos 0.9331 pu). Line losses of the 58 buses, 330 kV Nigeria transmission network system has been estimated to be 432 MW which is very high. The voltage bus violations were cleared by optimal placement of UPFC along Kaduna – Jos transmission line. The line losses were successfully reduced to 32. 39% by combine effort of multiple optimal placement of UPFC along Onitsha – Alaoji transmission line for line loss reduction and along Kaduna – Jos transmission line for bus voltage profile improvement.

## REFERENCES

[1] Anumaka, M. C. (2012). Analysis Of Technical Losses In Electrical Power System (Nigerian 330kv Network As A Case Study) www.arpapress.com/Volumes/Vol12Issue2/ IJRRAS_ 12_2_20.pdf

[2] Depazo et al (1967). "An optimization technique for real and reactive power allocation, Proc. IEEE.

[3] Gupta . B. R. (2011). "Power system analysis and design. S. Chand, New Delhi.

[4] Gupta, J. B. (2008). "A course in power systems. S. K. Kataria& Sons, New Delhi.

[5] Hingorani, N. G., Gyugyi, L., & El-Hawary, M. (2000). *Understanding FACTS: concepts and technology of flexible AC transmission systems* (Vol. 1). New York: IEEE press *control*. Springer Science & Business Media.

[6] Omorogiuwa, E. and Ogujor, A . (2012). Determination Of Bus Voltages, Power Losses And Flows In The Nigeria 330kv Integrated Power System. International Journal of Advances In Engineering & Technology.

[7] Singh, S Ram, A., Goel, N. and Kumar, P. (2013). "Transient Stability Enhancement of Multi-Machine System Using FACTS Controllers", International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 2, March 3

[8] Uwaechi P. C, Ezechukwu O. A, Shittu Y. M, and Okolie D. A. (2018).Contingency Analysis Of 330kv Nigeria Network, Journal Of Engineering And Applied Sciences 12 (2018), 103-116