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].

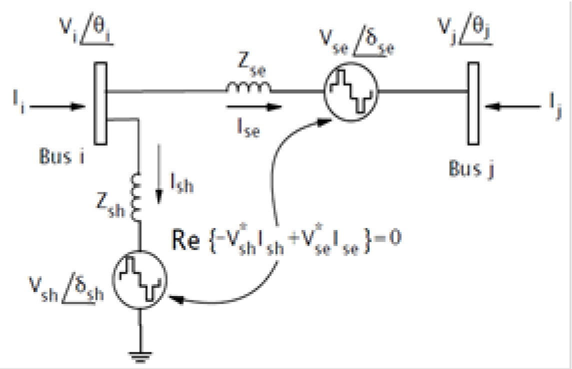

Figure 1 UPFC Equivalent Circuit

$$\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_j}{\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_i}{\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} \quad (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.

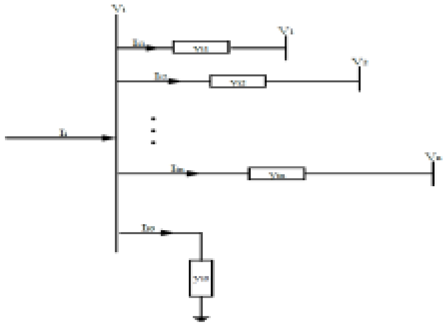

Figure 2 A simplified i-th bus model of a power

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

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

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

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

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 ΔP and ΔQ are bus real power and reactive pwer mismatch vectors between specified value and calculated value, respectively: ΔV 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 jwhich is used as a model to derive the line flow and losses.

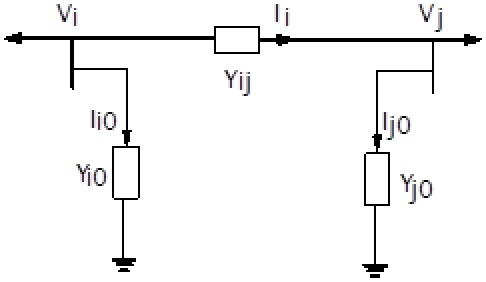

Figure Transmission line model for calculating line losses [8]

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).

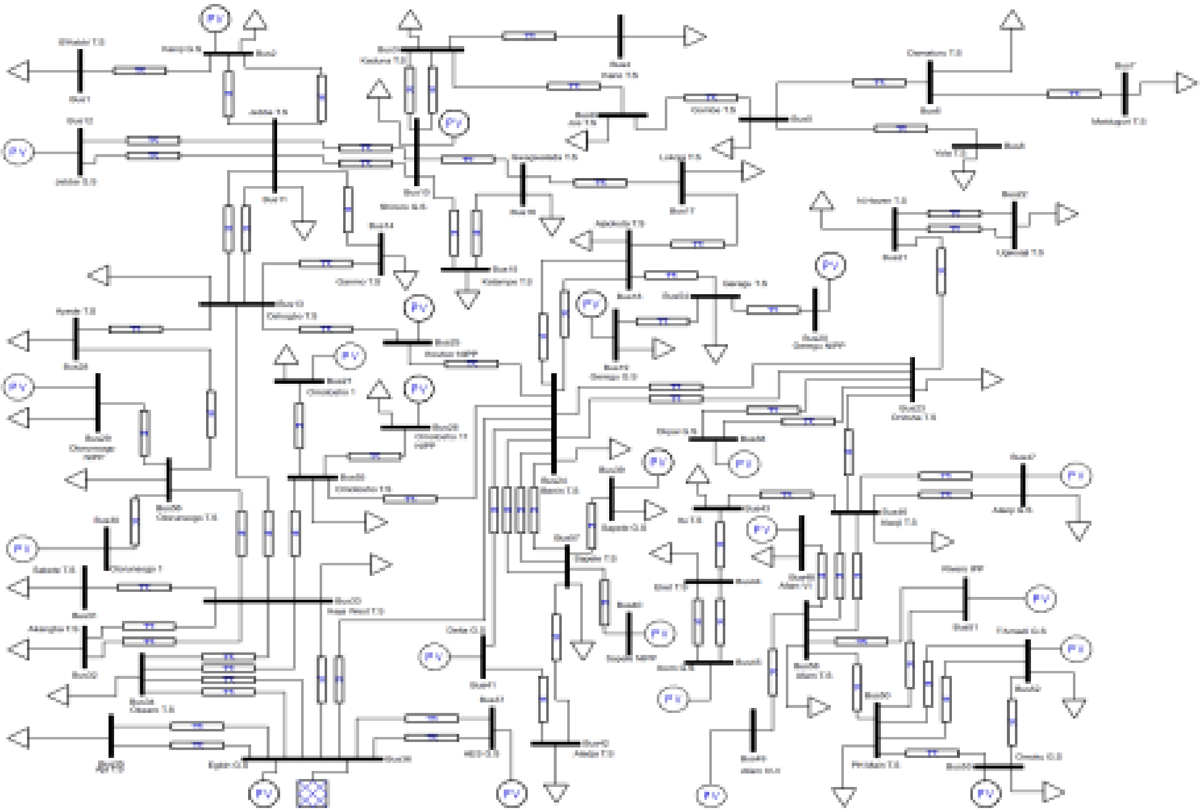

Figure 4: Single Line Diagram of 58 Buses, 330kv Nigeria Transmission Network for Case 1 Study System

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).

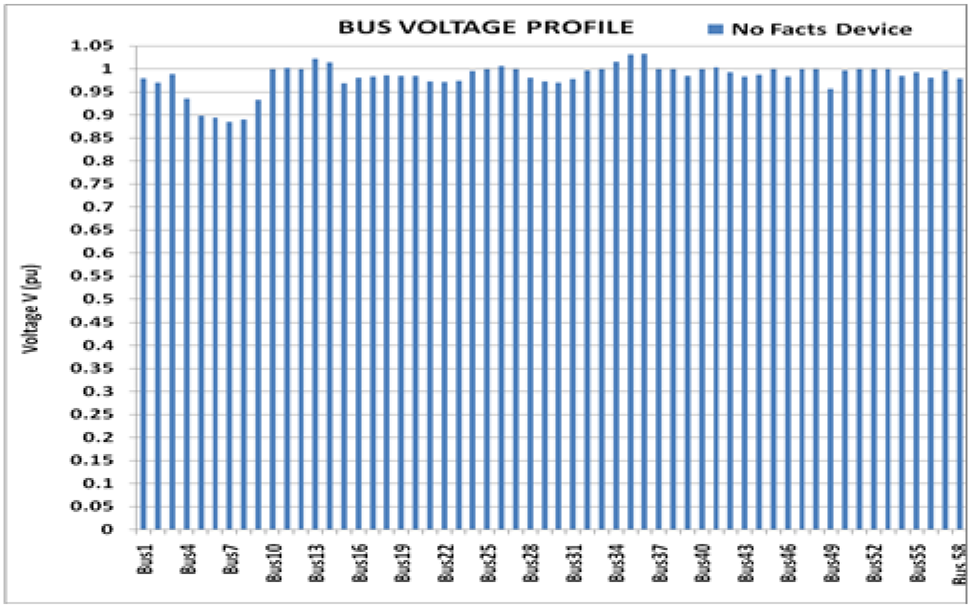

Figure 5Bar Representation of the Simulated Bus Voltages of the System

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

		UPFC	NO FACT
Bus Number	Bus Name	Voltage V[p.u.]	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.

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