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Characterisation and development of simulation model of 58 Bus Nigeria 330kv Transmission Network during UPFC insertion

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Abstract – This Paper on the Characterization and development of simulation model of 58 Bus Nigeria 330Kv Transmission Network during Unified Power Flow Controller(UPFC) insertion is a comprehensive analysis of the 58 Bus Network of Nigeria. It is a research on finding the solutions to the constant voltage violations in the network especially loading and off loads. The Nigeria 330kV transmission was obtained from TCN (master plan data, 2014) and was characterized in pu values using 100 MVA as the base power and 330 kV as the rated and the base voltage. The base impedance for the characterization of the transmission line impedance in pu values was calculated from the base power and the base voltage. A model of power flow equation was developed in order to get the procedure to be used during the simulation. The power flow Newton-Raphson algorithm was also presented because the network involves a large scale of area covering 6702km of 330kv in Nigeria. The simulation of 58 Bus Nigeria 330kv transmissions Network without UPFC and with UPFC FACTSS devices were done following the algorithm shown in fig…This is to ascertain the extent of violations and improvement or corrections obtained after the UPFC insertions. The result obtained showed that the seven(7) violated buses; Kano, Kaduna, Gombe, Damaturu, Maiduguri,Yola and Jos were enhanced with the insertion of UPFC on the Kaduna-Jos Bus.

Keywords – UPFC, FACTS, STATCOM, SSSC, Generation, Transmission, Simulation, Charactersation

I. INTRODUCTION

This Nigerian Transmission grid is made up of interconnected network of 6702 km of 330-kV that spans the country nationwide[1]. The single-line diagram of the Nigerian 330-kV network currently consists of eighty–seven(87) 330 -kV transmission line circuits, twenty –three(23) generating stations, forty – three(43) load stations, fifty-eight(58) buses (sub-stations) fig 1. The system may be divided into three geographical zones- North, South-East, and the South-West[25].

The North is connected to the South through the one-triple circuit lines between Jebba and Oshogbo while the West is linked to the East through one transmission line from Oshogbo to Benin and one double line from Ikeja to Benin. The transmission grid is centrally controlled from the National Control centre (NCC) located at Oshogbo in Osun State, while there is a back-up or Supplementary National Control Centre (SNCC) at Shiroro in Niger State. In addition to these two centres are three Regional Control Centres (RCCs) located at the following substations: Ikeja West (RCC1), Benin (RCC2) and Shiroro (RCC3)[17] from [4].

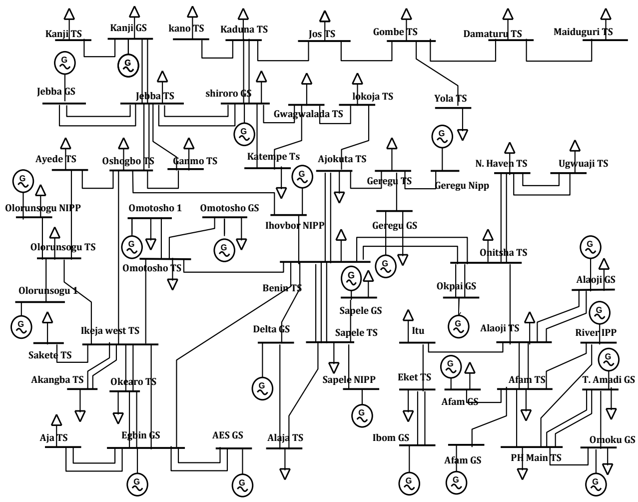

Figure 1: 58 Buses Nigeria 330 kV Transmission Line[16] in [26]

The parameters for the generating station, transmission lines and the load demands at various load centers are listed in table 1, table 2 and table 3 respectively[4],[20] and [23]

Table 1: Generation Data

S/N	Generator Name	Bus No	Operating Gen. Cap (Mw)	Voltage Mag. (P.U.)	Mvar Limits	
					MIN. MW	MAX. MW
1	Kainji	2	292	0.970	16	158
2	Shiroro	10	300	1	12	115
3	Jebba	12	403	1	19	190
4	Gereguru	19	385	0.985	14	140
5	Gereguru (Nipp)	20	146	0.985	9	90
6	Ihovbor (Nipp)	25	116.6	1	7	71
7	Omotosho Ii (Nipp)	26	114.7	I.006	5	52
8	Omotosho I	27	50.8	1	2	21
9	Olorunsogo (Nipp)	29	93	0.973	4	40
10	Olorunsogo I	30	102.7	0.970	8.4	84
11	Egbin	36	513	1.033	0	0
12	Aes	37	245.2	1	20	195
13	Okpai	38	466	1	20	200
14	Sapele	39	67	0.985	2.9	29
15	Sapele (Nipp)	40	111.1	1	5	50
16	Delta	41	341	1.003	12	115
17	Ibom	45	30.5	1	1.2	12
18	Alaoji	47	250	1	12	117
19	Afam Vi	48	646	1	49	486
20	Afam Iv-V	49	54	0.930	2	20
21	Rivers (Ipp)	51	80	1	4	38
22	Trane Amadi	52	100	1	4	39
23	Omoku	53	44.8	1	2	20

Table 2 BUS DATA

SN	Bus Name	Nom Kv	Voltage Mag. P.U.	Actual Voltage Kv	Angle Deg.	Load		Generation	
						Mw	Mvar	Mw	Mvar
1	Birnin Kebbi	330	0.988	326	0	162	122	-	-
2	Kainji	330	0.970	320	0	89	67	292	158
3	Kaduna	330	0.955	315	0	143	98	-	-
4	Kano	330	0.909	300	0	194	146	-	-
5	Gombe	330	0.924	305	0	68	51	-	-
6	Damaturu	330	0.939	310	0	24	18	-	-
7	Maiduguri	330	0.970	320	0	31	20	-	-
8	Yola	330	0.909	300	0	26	20	-	-
9	Jos	330	0.939	310	0	72	54	-	-
10	Shiroro	330	1	330	0	170	98	300	115
11	Jebba T/S	330	0.988	326	0	260	195	-	-

12	Jebba G/S	330	1	330	0	-	-	403	190
13	Oshogbo	330	1	330	0	127	95	-	-
14	Ganmo	330	0.994	328	0	100	75	-	-
15	Katampe	330	1	330	0	303	227	-	-
16	Gwagwalada	330	0.955	315	0	220	165	-	-
17	Lokoja	330	0.970	320	0	120	90	-	-
18	Ajaokuta	330	0.970	320	0	120	90	-	-
19	Geregu G/S	330	1	330	0	200	150	385	140
20	Geregu (Nipp)	330	1	330	0	-	-	146	90
21	New Haven	330	0.988	326	0	196	147	-	-
22	Ugwaji	330	0.994	328	0	175	131	-	-
23	Onitsha	330	0.982	324	0	100	75	-	-
24	Benin	330	0.994	328	0	144	108	-	-
25	Ihovbor (Nipp)	330	1	330	0	-	-	116.6	71
26	Omotosho (Nipp)	330	1.006	332	0	90	44	114.7	52
27	Omotosho I	330	1	330	0	30	14	50.8	21
28	Ayede	330	0.970	320	0	174	131	-	-
29	Olorunsogo (Nipp)	330	0.973	321	0	71	58	93	40
30	Olorunsogo I	330	0.970	320	0	-	-	102.7	84
31	SAKETE	330	0.967	319	0	205	110	-	-
32	Akangba	330	0.948	313	0	203	152	-	-
33	Ikeja West	330	1	330	0	847	635	-	-

34	Okearo	330	0.909	300	0	120	90	-	-
35	Aja	330	1	330	0	115	86	-	-
36	Egbin	330	1.033	341	0	-	-	0	0
37	Aes	330	1	330	0	-	-	245.2	195
38	Okpai	330	1	330	0	-	-	466	200
39	Sapele G/S	330	0.985	325	0	40	18	67	29
40	Sapele (Nipp)	330	1	330	0	-	-	111.1	50
41	Delta	330	1.003	331	0	-	-	341	115
42	Aladja	330	0.939	310	0	210	158	-	-
43	Itu	330	0.955	315	0	199	91	-	-
44	Eket	330	0.909	300	0	200	147	-	-
45	Ibom	330	1	330	0	-	-	30.5	12
46	Alaoji T/S	330	0.985	325	0	240	100	-	-
47	Alaoji G/S	330	1	330	0	227	170	240	117
48	Afam Vi	330	1	330	0	534	401	646	486
49	Afam Iv-V	330	0.930	307	0	-	-	54	20
50	Ph Main	330	0.909	300	0	280	140	-	-
51	Rivers (Ipp)	330	1	330	0	-	-	80	38
52	Trans Amadi	330	1	330	0	80	24	100	39
53	Omoku	330	1	330	0	30	10	44.8	20
54	Geregu T/S	330	1	330	0	200	150	-	-
55	Omotosho T/S	330	1	330	0	80	50	-	-

56	Olorunsogo T/S	330	0.970	320	0	71	58	-	-
57	Sapele T/S	330	0.985	325	0	100	77	-	-
58	Afam T/S	330	0.930	307	0	720	412	-	-

Table 3: Transmission Line Data

Line N0	Bus - Bus	Transmission Line	Length (Km)	R (Pu)	X (Pu)	1/2 B (Pu)
1	1 - 2	Birnin Kebbi - Kainji	310	0.0111019	0.0942241	1.72
2	3 - 4	Kaduna - Kano	230	0.0082369	0.0699082	1.28
3	10 - 11	Shiroro – Jebba TS	244	0.0087383	0.0741635	1.35
4	10 - 11	Shiroro – Jebba TS	244	0.0087383	0.0741635	1.35
5	3 - 10	Kaduna - Shiroro	95	0.0034380	0.0291791	0.53
6	10 - 16	Shiroro – Gwagwalada	144	0.0052820	0.0406200	0.89
7	3 - 9	Kaduna - Jos	197	0.0070193	0.0595739	1.09
8	9 - 5	Jos – Gombe	265	0.0094545	0.0802424	1.47
9	16 - 17	Gwagwalada - lokoja	140	0.0063170	0.0485800	1.06
10	11 - 14	Jebba TS – Ganmo	70	0.0039390	0.0133430	0.61
11	13 - 14	Oshogbo – Ganmo	87	0.0016834	0.0142860	0.26
12	11 - 13	Jebba TS – Oshogbo	157	0.0056226	0.0477199	0.87
13	5 - 8	Gombe – Yola	240	0.0085950	0.0729477	1.33
14	11 - 13	Jebba TS – Oshogbo	157	0.0056226	0.0477199	0.87
15	1 6- 15	Gwagwalada - Katampe	60	0.0026050	0.0200360	0.44
16	10 - 15	Shiroro – Katampe	60	0.0026050	0.0200360	0.44
17	18 - 17	Ajaokute – Lokoja	38	0.0017150	0.0131860	0.29
18	53 - 50	Omoku – PH Main	15	0.0009045	0.0069559	0.15

19	58 - 51	Afam T/S - Rivers IPP	40	0.0009045	0.0069559	0.15
20	19 - 54	Geregu G/S - Geregu T/S	10	0.0000540	0.0005100	0.00
21	54 - 20	Geregu T/S - Geregu (NIPP)	10	0.0000540	0.0005100	0.00
22	18 - 54	Ajaokute – Geregu T/S	65	0.0000540	0.0005100	0.00
23	21 - 23	New Heaven - Onitsha	96	0.0034380	0.0291791	0.53
24	5 - 6	Gombe – Damaturu	160	0.0064460	0.0457110	1.00
25	21 - 22	New Heaven - Ugwaji	6.5	0.0002530	0.0019480	0.04
26	21 - 22	New Heaven - Ugwaji	6.5	0.0002530	0.0019480	0.04
27	18 - 24	Ajaokute – Benin	195	0.0070551	0.0542562	1.18
28	18 - 24	Ajaokute – Benin	195	0.0070551	0.0542562	1.18
29	25 - 24	Ihovbor(NIPP) - Benin	20	0.0008990	0.0076290	0.14
30	13 - 25	Oshogbo – Ihovbor(NIPP)	231	0.0089890	0.0762910	1.39
31	55 - 26	Omotosho T/S - Omotosho (NIPP)	10	0.0028640	0.0243150	0.44
32	27 - 55	Omotosho 1 - Omotosho T/S	10	0.0028640	0.0243150	0.44
33	55 - 24	Omotosho T/S – Benin	110	0.0018264	0.0155014	0.28
34	28 - 13	Ayede – Oshogbo	119	0.0041185	0.0349541	0.64
35	6 - 7	Damaturu - Maiduguri	260	0.0093110	0.0790270	1.44
36	29 - 56	Olorunsogo(NIPP) – Olorunsogo T/S	10	0.0021488	0.0182369	0.33
37	56 - 30	Olorunsogo T/S - Olorunsogo 1	10	0.0021488	0.0182369	0.33
38	28 - 56	Ayede – Olorunsogo T/S	109	0.0021488	0.0182369	0.33
39	31 - 33	Sakete - Ikeja West	70	0.0025069	0.0212764	0.39
40	56 - 33	Olorunsogo T/S - Ikeja West	62	0.0006450	0.0054710	0.10

41	13 - 33	Oshogbo – Ikeja West	235	0.0089532	0.0759871	1.39
42	55 - 33	Omotosho T/S - Ikeja West	160	0.0028640	0.0243150	0.44
43	32 - 33	Akangba - Ikeja West	18	0.0006151	0.0047300	0.10
44	32 - 33	Akangba - Ikeja West	18	0.0006151	0.0047300	0.10
45	34 - 33	Okearo - Ikeja West	32	0.0006450	0.0054710	0.10
46	2 - 11	Kainji – Jebba TS	81	0.0039008	0.0246198	0.45
47	34 - 33	Okearo - Ikeja West	32	0.0006450	0.0054710	0.10
48	35 – 36	Aja - Egbin	14	0.0005014	0.0042553	0.08
49	35 – 36	Aja - Egbin	14	0.0005014	0.0042553	0.08
50	34 - 36	Okearo - Egbin	30	0.0006450	0.0054710	0.10
51	34 - 36	Okearo - Egbin	30	0.0006450	0.0054710	0.10
52	33 - 36	Ikeja West - Egbin	28	0.0027566	0.0234030	0.43
53	24 - 36	Benin – Egbin	218	0.0071625	0.0607897	1.11
54	36 - 37	Egbin - Aes	9	0.0071625	0.0607897	1.11
55	36 - 37	Egbin - Aes	9	0.0071625	0.0607897	1.11
56	24 - 23	Benin – Onitsha	137	0.0049063	0.0416410	0.76
57	12 - 11	Jebba GS - Jebba TS	8	0.0002890	0.0022300	0.05
58	24 - 23	Benin – Onitsha	137	0.0049063	0.0416410	0.76
59	23 - 38	Opkai – Onitsha	56	0.0021708	0.0166942	0.36
60	23 - 38	Opkai – Onitsha	56	0.0021708	0.0166942	0.36
61	24 - 57	Benin – Sapele T/S	40	0.0018090	0.0139118	0.30
62	24 - 57	Benin – Sapele T/S	40	0.0018090	0.0139118	0.30

63	24 - 57	Benin – Sapele T/S	40	0.0018090	0.0139118	0.30
64	39 - 57	Sapele G/S – Sapele T/S	10	0.0018090	0.0139118	0.30
65	57 - 40	Sapele T/S – Sapele (NIPP)	10	0.0018090	0.0139118	0.30
66	24 - 41	Benin – Delta	107	0.0014683	0.0124619	0.23
67	41 - 42	Delta - Aladja	30	0.0011460	0.0097264	0.18
68	12 - 11	Jebba GS - Jebba TS	8	0.0002890	0.0022300	0.05
69	57 - 42	Sapele T/S – Aladja	83	0.0022562	0.0191488	0.35
70	43 - 44	Itu - Eket	38	0.0009045	0.0069559	0.15
71	44 - 45	Eket - Ibom	28	0.0009045	0.0069559	0.15
72	44 - 45	Eket - Ibom	28	0.0009045	0.0069559	0.15
73	43 - 46	Itu – Alaoji T/S	24	0.0009045	0.0069559	0.15
74	23 - 46	Onitsha – Alaoji T/S	24	0.0009045	0.0069559	0.15
75	46 - 47	Alaoji T/S - Alaoji G/S	10	0.0049422	0.0419449	0.77
76	46 - 47	Alaoji T/S - Alaoji G/S	10	0.0049422	0.0419449	0.77
77	58 - 49	Afam T/S - Afam IV–V	10	0.0009045	0.0069559	0.15
78	52 - 50	Trans Amadi – PH Main	4	0.0009045	0.0069559	0.15
79	2 - 11	Kainji – Jebba TS	81	0.0039008	0.0246198	0.45
80	46 - 58	Alaoji T/S – Afam T/S	15	0.0009045	0.0069559	0.15
81	46 - 58	Alaoji T/S – Afam T/S	15	0.0009045	0.0069559	0.15
82	58 - 50	Afam T/S – PH Main	45	0.0009045	0.0069559	0.15
83	51 - 50	Rivers IPP – PH Main	7	0.0009045	0.0069559	0.15
84	52 - 50	Trans Amadi – PH Main	4	0.0009045	0.0069559	0.15

85	52 - 53	Trans Amadi - Omoku	6	0.0009045	0.0069559	0.15
86	48 - 58	Afam IV - Afam T/S	10	0.0009045	0.0069559	0.15
87	3 - 10	Kaduna - Shiroro	95	0.0034380	0.0291791	0.53

II. CHARACTERIZATION OF THE 58 BUS NIGERIA 330KV NETWORK

The Nigeria 330kV transmission was obtained from TCN [10] and was characterized in pu values using 100 MVA as the base power and 330 kV as the rated and the base voltage [27]. The base impedance for the characterization of the transmission line impedance in pu values was calculated from the base power and the base voltage.

III. MODELING OF POWER FLOW IN TRANSMISSION LINE

Consider an electrical transmission system with n – buses if, The current flowing in bus i-th term is given by

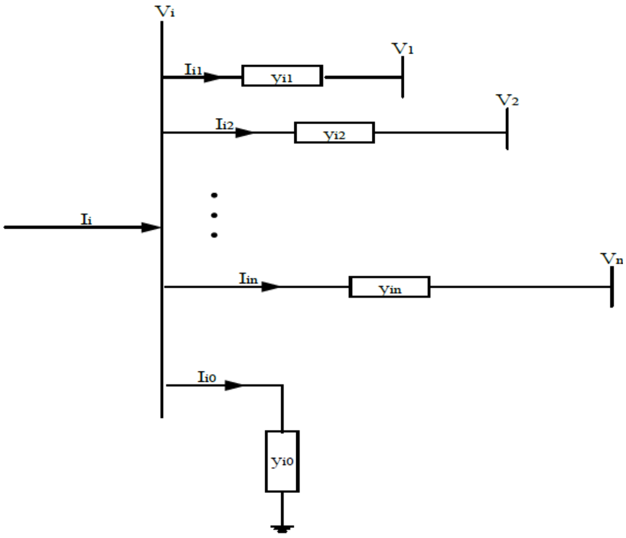

Figure 2: A simplified I – th bus model of a power system[12] and [21]

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 \cdots Y_{in}V_n \qquad (1)$$

Equation (1) can be expressed as

$$I_i = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j \qquad (2)$$

The expression for the complex power is given in [2] and [12] as

$$S_i = P_i - jQ_i = V_i^* I_i \qquad (3)$$

Where S_i = apparent power injected at bus i

P_i = real power injected at bus i

Q_i = reactive power injected at bus i

V_i^* = complex conjugate of bus i power

From equation (.1) and (.2) we

$$\frac{P_i - jQ_i}{V_i} = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j, \quad j \neq i \qquad (.4)$$

Solving for V_i in equation (3.4) we obtain

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

Also, by decoupling equation (3.4) into real and imaginary parts and expressing the components parts in polar form, we obtain equations [22] and [24]

$$P_i = |V_i|^2 G_{ii} + \sum_{j=1}^{n} |Y_{ij}V_jV_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i), j \neq i \qquad (6)$$

$$Q_i = |V_i|^2 B_{ii} + \sum_{j=1}^{n} |Y_{ij}V_jV_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i), j \neq i \qquad (7)$$

Where G_{ii} = self-conductance of bus i

B_{ii} = self susceptance of bus i

Since the voltage at the buses must be maintained within certain specified statutory limit, the voltage bound constraint limit at bus i is then defined by equation (.8):

$$V_{i(min)} \leq V_i \leq V_{i(max)} \qquad (8)$$

Where $V_{i(min)}$ and $V_{i(max)}$ are minimum and maximum values of voltage at bus i.[28]

IV. NEWTON-RAPHSON POWER FLOW

In large-scale power flow studies, the Newton- Raphson [2] has proved most successful owing to its strong convergence characteristics. The power flow Newton-Raphson algorithm is expressed by the following relationship:

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix}\frac{\partial P}{\partial \delta} & v\frac{\partial P}{\partial v} \\ \frac{\partial Q}{\partial \delta} & v\frac{\partial Q}{\partial v}\end{bmatrix}\begin{bmatrix}\Delta \delta \\ \frac{\Delta v}{v}\end{bmatrix} \qquad (9)$$

Where **ΔP** and **ΔQ** are bus active and reactive power mismatches, while δ and **V** are bus magnitude and angle, respectively[8] and [[14].

1. Modeling of line flows and losses

Once the number of iteration is complete, the computation of line flows and losses is implemented. To accomplish this, a different program is developed with the aid of the model derived. Thus, figure 3. is a one- 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.[5] and [19]

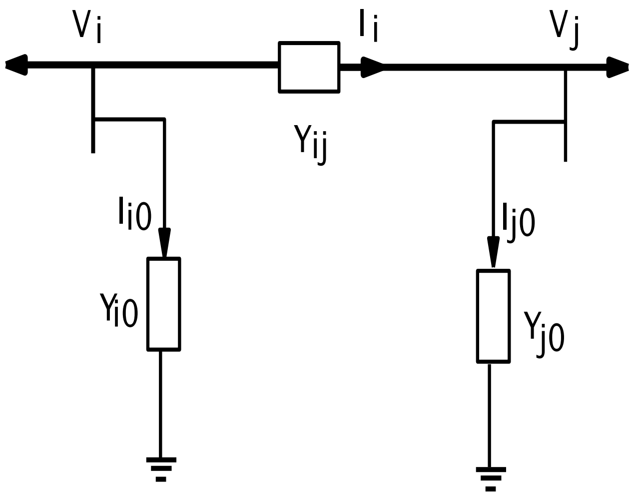

Figure: 3. Transmission line model for calculating line losses[5]

If bus i was to have a higher voltage potential, then applying Kirchhoff's Current Law at bus i and defined in the positive direction of $i \rightarrow j$ gives the line current, I_{ij}, as

$$I_{ij} = I_i + I_{i0} = Y_{ij}\left(V_i + V_j\right) + Y_{i0}V_i \quad (10)$$

Similarly, applying the same KCL at bus j for Iij which is considered positive in the direction j→i, this line current is given as $I_{ji} = -I_j + I_{j0} = Y_{ij}\left(V_j - V_j\right) + Y_{j0}V_j$ (11)

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 [6]

$$S_{ij} = V_i I_{ij}^* \quad (12)$$

$$S_{ji} = V_j I_{ji}^* \quad (13)$$

The power loss $\boldsymbol{S_{Lij}}$ in line i - j is the algebraic sum of the power flows determined from equation (12) and (13)

$$S_{Lij} = S_{ij} + S_{ji}$$
(14)

These equations are the mathematical model requirement for simulating load flow and line losses using Newton-Raphson [3]

V. METHODOLOGY FOR ACHIEVING THE OBJECTIVES

The methodology for achieving the objective of this research is shown in the flow chart in fig 4 and explained in the following sections[8] [11] and[15]

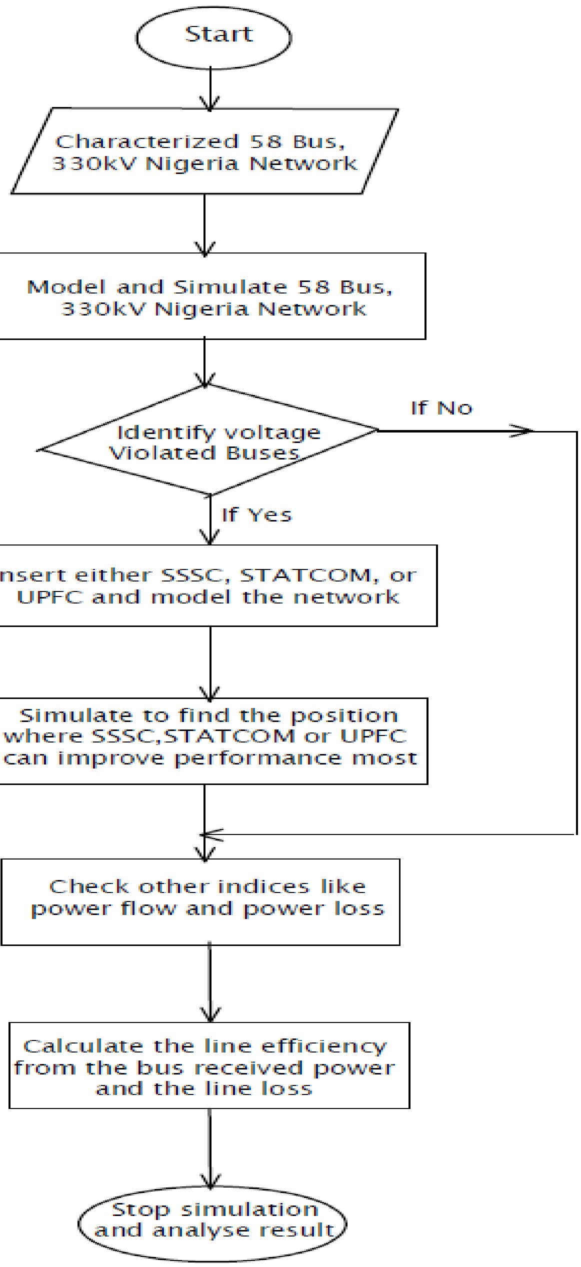

Figure 4: Flow Chart of Research on 58 Buses Nigeria 330 kV Transmission Line [11]

VI.DEVELOPMENT OF SIMULATION MODEL AND THE SIMULATION OF 58 BUS NIGERIA 330KV TRANSMISSION NETWORK.

The 58 bus Nigeria 330 kV transmission line network was modeled in PSAT 2.1.8 and simulated in matlab 2013b

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environment. The PSAT model for the research is shown in fig 5. The simulations of Nigeria 330kV was solved using the power flow equation .6 and equation .8 which is using Newton – Raphson method of load flow solution. Egbin substation was chosen as the slack bus. The solution to the load flow calculation give the output as the bus voltage and phase angle, real reactive power(both sides of each line), line active and reactive loss, and slack power. The voltage violated buses will be sorted from the result of the load flow analysis using the permissive voltage bus limit criteria of 0.95 to 1.05 pu or ±5% of the rated bus voltage. The PSAT uses a subroutine program to solve equation 12 and equation 13 and calculate the powr flow in either direction. This subroutine also uses equation 14 to calculate the line power loss [13]

The efficiency of the 58 bus Nigeria 330 kV transmission line network is calculated using load flow analysis solution, the two line end voltages, the phase angles and the obtained line power loss which is generated from the subroutine program of PSAT. This research writes a subroutine program in matlab 2013b environment to calculate the transmission line efficiency from equation 3.43.

VII.DEVELOPMENT OF SIMULATION MODEL AND THE SIMULATION OF 58 BUS NIGERIA 330KV TRANSMISSION NETWORK DURING UPFC FACTS DEVICE INSERTION

The power flow model for UPFC was derived and written in equation 9 and with this equation the same methods used in section 3.9.2 were used to calculate the bus voltages and phase angles, real and reactive power (both sides of each line), line loss and estimation of efficiency of the transmission line during the UPFC insertion in 58 bus Nigeria 330kv transmission line network[17]. The search for the best position placement of UPFC was done having known the positions of the violated buses.

The method is just to insert the UPFC FACTS device in the line bounded or adjacent to these violated buses. The best position is base on the degree of performance enhancement spread. Also researched on is the effect of variation of the parameters of UPFC FACTS device on the performance enhancement capabilities. This variation simulation was done in the best best position in which the UPFC has the best of performance enhancement. The condition for the simulation 58 bus Nigeria 330kV transmission network when inserted with UPFC is presented in section3.11-3.14

1. Test case 1 (no facts device inserted in the study system)

In this case no facts device is inserted in 58 bus Nigeria 330 kV transmission line fig 5. This test case circuit of fig 5 was configured in PSAT and simulated. The configured test circuit is shown in fig 5.

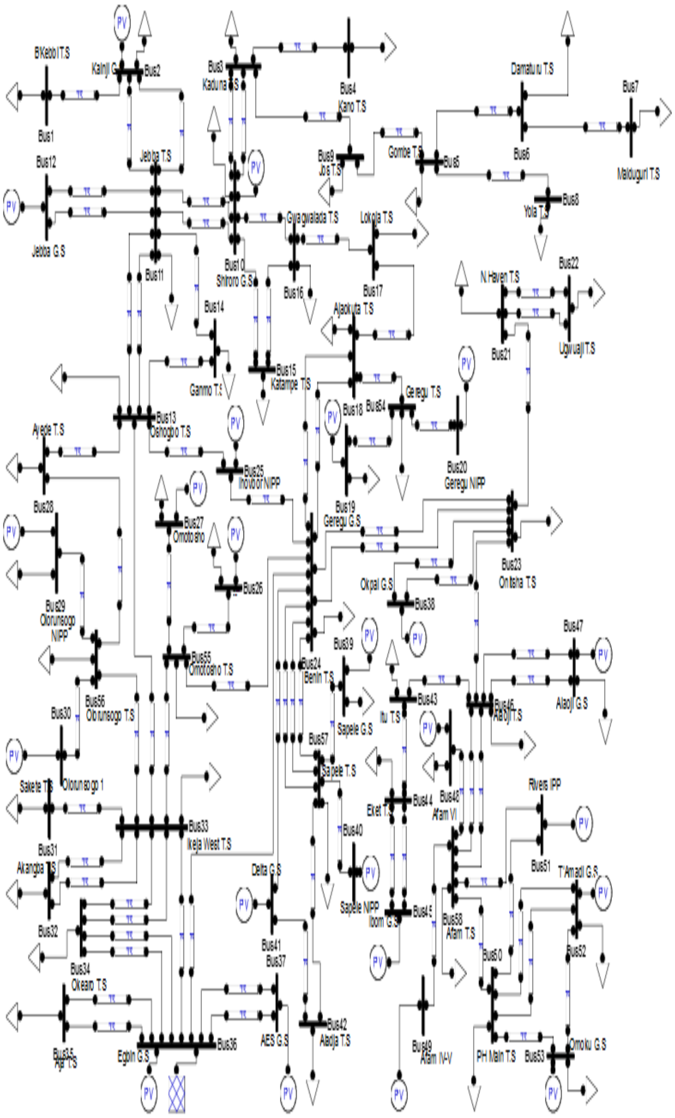

Figure 5: PSAT Model for 58 Bus Nigeria 330 kV Network without FACTS Device

VII. DEVELOPMENT OF SIMULATION MODEL AND THE SIMULATION OF 58 BUS NIGERIA 330KV TRANSMISSION NETWORK DURING UPFC FACTS DEVICE INSERTION

The power flow model for UPFC was derived and written in equation 9 and with this equation the same methods used in the preceding section were used to calculate the bus voltages and phase angles, real and reactive power (both sides of each line), line loss and estimation of efficiency of the transmission line during the UPFC insertion in 58 bus Nigeria 330kv transmission line network [18]]. The search for the best position placement of UPFC was done having known the positions of the

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violated buses. The method is just to insert the UPFC FACTS device in the line bounded or adjacent to these violated buses. The best position is base on the degree of performance enhancement spread.
Also researched on is the effect of variation of the parameters of UPFC FACTS device on the performance enhancement capabilities. This variation simulation was done in the best position in which the UPFC has the best of performance enhancement [18]. The condition for the simulation 58 bus Nigeria 330kV transmission network when inserted with UPFC below

VIII. TEST CASE 3 (UPFC CONNECTED TO NEW HAVEN SUBSTATION)

In this test case, line feeding buses with voltage violations were connected with UPFC. Fig 6 shows one of such connection when UPFC is connected in the branch between bus 3 and bus 9. The simulation and its condition of UPFC are listed section 3.13.1.

1. Simulation conditions for inserted UPFC

1. For position comparison test UPFC was inserted in the following position under these condition

(i) Line between bus 3 – 9, conditions: Compensation = 90% , power = 100MW and shunt current $I_q = 2.75$ pu.

(ii) Line between bus 9 – 5, conditions: Compensation = 80% , power = 100MW and shunt current $I_q = 1.15$ pu.

(iii) Line between bus 5 – 8, conditions: Compensation = 50% , power = 100MW and shunt current $I_q = 0.76$ pu.

(iv) Line between bus 6 – 7, conditions: Compensation = 50% , power = 100MW and shunt current $I_q = 0.69$ pu.

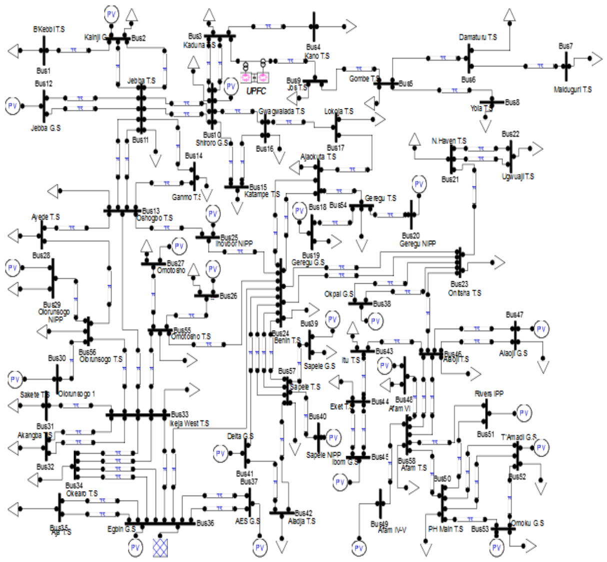

Figure 6: PSAT Model for 58 Bus Nigeria 330 kV Network connected with UPFC

2. When UPFC is inserted between bus 3 and 9 and simulation was done at various compensation conditions

- Compensation = 90% , power = 100MW and shunt current $I_q = 2.00$ pu
- Compensation = 90% , power = 100MW and shunt current $I_q = 2.75$ pu

3. When UPFC is inserted between bus 3 and 9 and simulation was done at various following conditions

- Compensation = 50% , power = 100MW and shunt current $I_q = 2.75$ pu
- Compensation = 70% , power = 100MW and shunt current $I_q = 2.75$ pu
- Compensation = 90% , power = 100MW and shunt current $I_q = 2.75$ pu

2. Simulation Result Presentation

The presentation of the research simulation is as follows. The simulation of 58 buses, 330kV Nigeria transmission line network was simulated; Bus numbers assigned to the buses were tabulated in table 4. Also the simulation transmission line numbers and its bounded buses and corresponding bounded bus names were shown in table 5. The network statistics which showed that the simulated 330 kV transmission network consisted of 58 buses, 87 transmission lines, 23 generators and 46 load centers were shown in table 6. Table 7 showed the solution statistics during simulations.

Simulation results of 58 buses, 330 kV Nigeria transmission line network to study the bus voltage status during no facts and when SSSC, UPFC, and STATCOM were inserted were shown in table 4. through table 10 and also represented diagrammatically in figure 7 through fig 8

Table 4: Simulation Bus Numbers and Names

Bus Number	Bus Name	Bus Number	Bus Name
1	Birnin Kebbi	30	Olorunsogo I
2	Kainji	31	Sakete
3	Kaduna	32	Akangba
4	Kano	33	Ikeja West
5	Gombe	34	Okearo
6	Damaturu	35	Aja
7	Maiduguri	36	Egbin
8	Yola	37	Aes
9	Jos	38	Okpai
10	Shiroro	39	Sapele G/S
11	Jebba T/S	40	Sapele (Nipp)
12	Jebba G/S	41	Delta
13	Oshogbo	42	Aladja

14	Ganmo	43	Itu
15	Katampe	44	Eket
16	Gwagwalada	45	Ibom
17	Lokoja	46	Alaoji T/S
18	Ajaokuta	47	Alaoji G/S
19	Geregu G/S	48	Afam Vi
20	Geregu (Nipp)	49	Afam Iv-V
21	New Haven	50	Ph Main
22	Ugwaji	51	Rivers (Ipp)
23	Onitsha	52	Trans Amadi
24	Benin	53	Omoku
25	Ihovbor (Nipp)	54	Geregu T/S
26	Omotosho (Nipp)	55	Omotosho T/S
27	Omotosho I	56	Olorunsogo T/S
28	Ayede	57	Sapele T/S
29	Olorunsogo (Nipp)	58	Afam T/S

Table -5: Simulation Transmission Line Numbers and Their Bounded Buses

LINE NO	BUS - BUS	TRANSMISSION LINE	LINE NO	BUS - BUS	TRANSMISSION LINE
1	1 - 2	Birnin Kebbi - Kainji	45	34 - 33	Okearo - Ikeja West
2	3 - 4	Kaduna - Kano	46	2 - 11	Kainji – Jebba TS
3	10 - 11	Shiroro – Jebba TS	47	34 - 33	Okearo - Ikeja West
4	10 - 11	Shiroro – Jebba TS	48	35 – 36	Aja - Egbin
5	3 - 10	Kaduna - Shiroro	49	35 – 36	Aja - Egbin
6	10 - 16	Shiroro – Gwagwalada	50	34 - 36	Okearo - Egbin
7	3 - 9	Kaduna - Jos	51	34 - 36	Okearo - Egbin
8	9 - 5	Jos –Gombe	52	33 - 36	Ikeja West - Egbin
9	16 - 17	Gwagwalada - lokoja	53	24 - 36	Benin – Egbin
10	11 - 14	Jebba TS – Ganmo	54	36 - 37	Egbin - Aes
11	13 - 14	Oshogbo – Ganmo	55	36 - 37	Egbin - Aes
12	11 - 13	Jebba TS – Oshogbo	56	24 - 23	Benin – Onitsha
13	5 - 8	Gombe –Yola	57	12 - 11	Jebba GS - Jebba TS
14	11 - 13	Jebba TS – Oshogbo	58	24 - 23	Benin – Onitsha
15	16- 15	Gwagwalada - Katampe	59	23 - 38	Opkai – Onitsha
16	10 - 15	Shiroro – Katampe	60	23 - 38	Opkai – Onitsha
17	18 - 17	Ajaokute – Lokoja	61	24 - 57	Benin – Sapele T/S
18	53 - 50	Omoku –PH Main	62	24 - 57	Benin – Sapele T/S
19	58 - 51	Afam T/S - Rivers IPP	63	24 - 57	Benin – Sapele T/S
20	19 - 54	Geregu G/S - Geregu T/S	64	39 - 57	Sapele G/S – Sapele T/S
21	54 - 20	Geregu T/S - Geregu (NIPP)	65	57 - 40	Sapele T/S – Sapele (NIPP)
22	18 - 54	Ajaokute – Geregu T/S	66	24 - 41	Benin – Delta
23	21 - 23	New Heaven - Onitsha	67	41 - 42	Delta - Aladja
24	5 - 6	Gombe – Damaturu	68	12 - 11	Jebba GS - Jebba TS
25	21 - 22	New Heaven - Ugwaji	69	57 - 42	Sapele T/S – Aladja
26	21 - 22	New Heaven - Ugwaji	70	43 - 44	Itu - Eket
27	18 - 24	Ajaokute – Benin	71	44 - 45	Eket - Ibom
28	18 - 24	Ajaokute – Benin	72	44 - 45	Eket - Ibom
29	25 -	Ihovbor(NIPP) - Benin	73	43 -	Itu – Alaoji T/S

	24			46	
30	13 - 25	Oshogbo – Ihovbor(NIPP)	74	23 - 46	Onitsha – Alaoji T/S
31	55 - 26	Omotosho T/S - Omotosho (NIPP)	75	46 - 47	Alaoji T/S - Alaoji G/S
32	27 - 55	Omotosho 1 - Omotosho T/S	76	46 - 47	Alaoji T/S - Alaoji G/S
33	55 - 24	Omotosho T/S – Benin	77	58 - 49	Afam T/S - Afam IV–V
34	28 - 13	Ayede – Oshogbo	78	52 - 50	Trans Amadi – PH Main
35	6 - 7	Damaturu - Maiduguri	79	2 - 11	Kainji – Jebba TS
36	29 - 56	Olorunsogo(NIPP) – Olorunsogo T/S	80	46 - 58	Alaoji T/S – Afam T/S
37	56 - 30	Olorunsogo T/S - Olorunsogo 1	81	46 - 58	Alaoji T/S – Afam T/S
38	28 - 56	Ayede – Olorunsogo T/S	82	58 - 50	Afam T/S – PH Main
39	31 - 33	Sakete - Ikeja West	83	51 - 50	Rivers IPP – PH Main
40	56 - 33	Olorunsogo T/S - Ikeja West	84	52 - 50	Trans Amadi – PH Main
41	13 - 33	Oshogbo – Ikeja West	85	52 - 53	Trans Amadi - Omoku
42	55 - 33	Omotosho T/S - Ikeja West	86	48 - 58	Afam IV - Afam T/S
43	32 - 33	Akangba - Ikeja West	87	3 - 10	Kaduna - Shiroro
44	32 - 33	Akangba - Ikeja West			

Table -6: Network Statistics

	NETWORK STATISTICS			
Network condition	SSSC	UPFC	STATCOM	No FACTS
Buses	58	58	58	58
Lines	87	87	87	87
Generators	23	23	23	23
Loads	46	46	46	46

Table 7: Solution Statistics

	SOLUTION STATISTICS			
Power Flow Solution Type	Newton - Raphson			
Simulation Condition	SSSSC	UPFC	STATCOM	No FACTS
Number of Iterations:	5	5	5	5
Maximum P mismatch [p.u.]	41.17842	41.17645	41.22503	9.28E-12
Maximum Q mismatch [p.u.]	10.01818	10.01743	10.03604	0.197854
Power rate [MVA]	100	100	100	100

Table 8: Simulation Result of Violated Buses during Insertion of UPFC at Various Lines

		Bus 3 – 9	Bus 9 – 5	Bus 5 – 8	Bus 6 – 7
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	1.004596	0.967104	0.957077	0.95457
5	Gombe	1.043464	1.042598	1.041912	1.025167
6	Damaturu	1.049559	1.048644	1.047919	1.049113
7	Maiduguri	1.045892	1.044947	1.044198	1.044543
8	Yola	1.040417	1.039526	1.037222	1.021574
9	Jos	1.040486	1.042482	1.007956	0.999298

Table -9: Violated Bus Voltage upon the Shunt Current Variation of the Inserted UPFC

		Shunt Current Iq= 2.0 pu	Shunt Current Iq=2.7 Pu
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	0.987067	1.004596
5	Gombe	1.025585	1.043464
6	Damaturu	1.030659	1.049559
7	Maiduguri	1.026368	1.045892

8	Yola	1.022004	1.040417
9	Jos	1.026656	1.040486

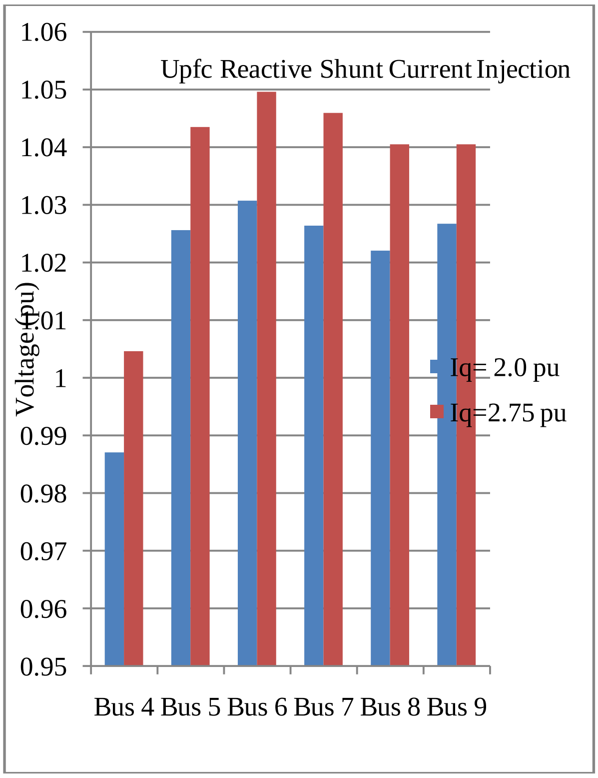

Figure 7: Violated Bus Voltage response upon the Shunt Current Variation of the Inserted UPFC

Table -10: Violated Bus Voltage upon the Compensation Variation of the Inserted UPFC

		Compensation 90%	Compensation 70%	Compensation 50%
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	1.004596	1.003077	1.001384
5	Gombe	1.043464	1.038897	1.032466
6	Damaturu	1.049559	1.044734	1.037935
7	Maiduguri	1.045892	1.040909	1.033886
8	Yola	1.040417	1.035716	1.029092
9	Jos	1.040486	1.036945	1.031968

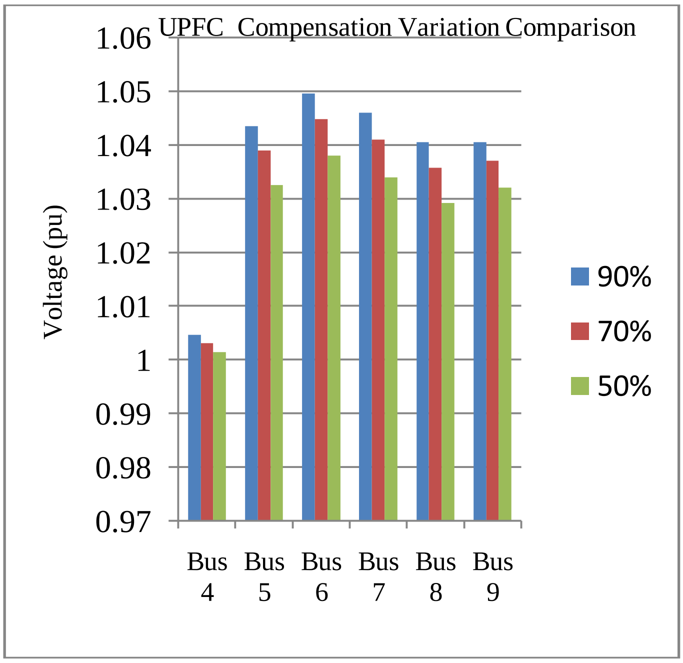

Figure 8: Violated Bus Voltage response upon the Compensation Variation of the Inserted UPFC

VIII. CONCLUSION

The 58 buses, 330 kV Nigeria transmission line network as shown by this research has 7 voltage violated buses. These buses are Kano (0.9180 pu), Gombe (0.7890 pu), Damaturu ().7634 pu), Maiduguri (0.7613 pu), Yola (0.7769 pu) and Jos (0.8756 pu). When these voltage violated buses where enhanced with UPFC inserted in the line between Kaduna – Jos buses, the bus enhancement capabilities of UPFC was the greatest.

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