The Role of Artificial Neural Network (ANN) Based Unified Power Flow Controller (UPFC) in Reduction of Transmission Line Losses: A Case Study of Nigeria 330 kV 58-Bus Network

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Abstract: The Nigeria 330 kV Power transmission network is beset with high losses due to weak transmission lines and greater radial network, resistive as well as losses due to corona. The network consists of 87 transmission lines, 58-buses, 22 generation stations and 36 load buses. To mitigate the losses, power flow was carried out using PSAT to determine the steady state voltage, active power, reactive power, active power loss and reactive power losses which forms input to ANN based UPFC to reduce the active and reactive power losses and also improve voltage profile of the buses. The load flow was based on the singularity of the Jacobian Matrix. The data used was real-time data of the Transmission Company of Nigeria (TCN) Osogbo. The result showed that, the active and reactive power losses without FACTS device was 5.237 MW and 7.03 MW and with UPFC FACTS it was 2.6788 MW and 4.658 MW with ANN based UPFC FACTS 1.2952MW and 1.9150 MW. Also, the active power loss reduction with UPFC FACTS was 48.8% and reactive power loss reduction with UPFC FACTS was 33.8% compared with ANN-based UPFC controller, the active power loss reduction was 75.3% and the reactive power loss reduction was 73%. It is therefore evident that ANN-based UPFC controllers reduced active and reactive power losses greatly and should be integrated into 330 kV network.

Keyword: *Load Flow, ANN Based Unified Power Flow Controller, Power Loss and Reactive Power Loss.*

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I. INTRODUCTION

Transmission lines possess parameters such as resistance, inductance and capacitance. Power transfer along these corridors are limited by those properties. The effective resistance of the transmission line is a function of the current on the line. This is because of the I^2R losses producing heat and accounting for the temperature rise in the conductor. This rise in temperature increases the resistance of the conductor and consequently the losses on the line (Ezechukwu *et al.*, 2022). Okonkwo *et al.*, (2020) in their work placed SSSC in Benin – Egbin transmission line and it was found that optimally, the technical loss of the system under study decreased from 257MW to 163MW which is 36.6% technical loss reduction.

Losses can be reduced by reducing either the resistance or overall impedance of the transmission line. This is possible by selecting a conductor with large cross-sectional area or low resistivity. Another approach is to deploy FACTS devices to control selectively or simultaneously all parameters of the transmission line. FACTS controllers are used to control voltage, impedance, phase angle and power transfer capabilities and ensures that power flows appropriately through the lines in either a simple or complex network.

The electrical grid, which is used to transmit power, includes the combined transmission and distribution network. Effective long-distance electric power transmission requires high voltages (Ezeonye *et al.,* 2024). As a result losses from large currents flow are reduced (Ulasi *et al.*, 2019, Obi *et al.*, 2022). The increment of reactive power demand in distribution system creates manifold challenges especially in loss profile management due to most of the loads consist of reactive leads. This significantly increases the current flow in

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transmission and distribution system which also increases I^2R and I^2X loses in the line. As reported by Bazilah *et al.*, (2017), about 13% of power delivered from generation to load is lost as resistive losses at the distribution level. According to Badran *et al.*, (2017), 70% of total power losses in power system occurs at distribution level while the remaining 30% occurs at transmission and sub-transmission system. By integrating capacitor, custom power devices or FACTs devices into the network, the power losses produced by reactive currents can be reduced. The reduction of total power losses is significant in order to alleviate the sag problem, increase the capacity of line loading as well as reduce the heating effect in cables. The investigation in reducing power low is one of the most common criteria in selecting the possible location of FACTS devices Ejebe *et al.*, (1979).

Siti *et al.*, (2016), worked on optimal sizing of Static Var Compensator (SVC) based on particle swarm optimization for minimization of transmission line losses considering cost function. Particle Swarm Optimization (PSO) is one of the artificial intelligence search approaches which has potential to solve such a problem. In his work, Static Var Compensator (SVC) was deployed. The work was validated by implementing it on the IEEE 26-bus system. The result obtained showed that, the SVC sizing achieved power loss reduction at several loading conditions to the tune of 7.8% in transmission losses.

II. LOAD FLOW STUDY

Load flow studies are done to ensure that electrical power transfer from generators to consumers through the energy transmission network is stable, reliable and economical. It determines if the system voltage remain within specified limits under various contingency conditions and scenarios. They form the backbone of voltage stability studies.

In this paper power loss reduction for the 330KV Transmission System comprising of 58 buses, 22 generators, 87 transmission lines, one slack bus, and 36 load buses will be X-rayed.

The load flow problem consists of the calculation of power flows and voltages of a network for specified terminal or bus conditions. It is necessary to select one bus, called the slack bus, to provide the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained.

The Real and Reactive Power at Any Bus P is Given as;

$$P_P - jQ_P = E_P^* I_P \tag{1}$$

And the current is

$$I_P = \frac{P_P - jQ_P}{E_P^*} \tag{2}$$

Where I_P is positive when flowing into the system.

In the formulation of the network equation, if the shunt elements to ground are included in the parameter matrix then equation (2) is the total current at the bus. On the other hand if the shunt elements are not included in the parameter matrix the total current at bus P is

$$I_P = \frac{P_P - jQ_P}{E_P^*} - Y_P E_P \tag{3}$$

Where Y_P is the total shunt admittance at the bus $Y_P E_P$ is the shunt current flowing from bus P to ground.

- *Line Flow Equation*

After the iterative solution of bus voltages is completed, line flows can be computed. The current at bus P in the line connecting bus P to q is

$$i_{Pq} = (E_P - E_q)Y_{Pq} + E_P \frac{Y_{pq}^1}{2} \tag{4}$$

Where Y_{Pq} = line admittance

Y_{pq}^1= total line charging admittance

$E_P \frac{Y_{pq}}{2}$ = current distribution at bus P due to line charging

The power flow real and reactive is

$$P_{Pq} - jQ_{Pq} = E_p^* i_{pq} \tag{5}$$

$$P_{Pq} - jQ_{Py} = E_p'^*(E_P - E_q)Y_{Pq} + E^* E_p^1 \frac{Y_{pq}^1}{2} \tag{6}$$

Where at bus P the real power flow from bus P to q is P_{Pq} and the reactive is Q_{Pq} similarly, at bus q the power flow from

q to p is

$$P_{qp} - jQ_{qp} = E_q^*(E_q - E_p)Y_{Pq} + E_q^* E_p \frac{Y_{pq}^1}{2} \tag{7}$$

The power loss in line $P - q$ is the algebraic sum of the power flows determined from equations (6) and (7).

III. METHODOLOGY

This research paper will utilize PSAT software for the modeling of the 58- bus power system network for the determination of active power flow and losses. MATLAB 2023a will be utilized for the computation and generation of plots of the power system network. Power flow to determine active power, reactive power, active power loss and reactive power loss without UPFC FACTS and with UPFC FACTS tuned with ANN is carried out, UPFC is designed to control selectively or simultaneously all parameters affecting flow of power in a transmission line. The UPFC consists of STATCOM and direct voltage regulator. All losses including ohmic and corona will be taken into account in this paper.

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➢ *Mathematical Model to Compute the Power Loss in Transmission Lines*

Transmission line losses refer to the reduction in power as electricity travels through power lines. The main types of losses identified are:

- Resistive Losses (I^2R loses)
- Corona losses
- Dielectric losses
- Inductive and capacitive losses
- Radiation losses and skin effect

The major losses are attributed to ohmic and corona losses using the equation below:

(i) $P = I^2R, (w)$ (1)

P = Power in (kW),

I = Current (A),

R = Resistance of line conductor (Ohms)

- Petersons Formula for determination of corona loss:

$$P_c = \frac{21\times10^{-6} f v^2}{(log_{10}{}^{D}/_{r})^2} \times F \frac{kw}{phase}/km \quad (2)$$

P_c = Corona power loss (R$\dot{w}$)

f = System frequency

V = Phase voltage kV ((Rms value)

r = Radius of conductor in metres

D = Spacing between conductors (m)

The total loss on the transmission line becomes:

$$P_{Loss} = P_{ohmic} + P_{corona} (kW)$$

$$P_{Loss} = I^2R + \frac{21\times10^{-6} f v^2}{(log_{10}{}^{D}/_{r})^2} \text{ (kW)}$$

The UPFC schematic used in this work is here presented:

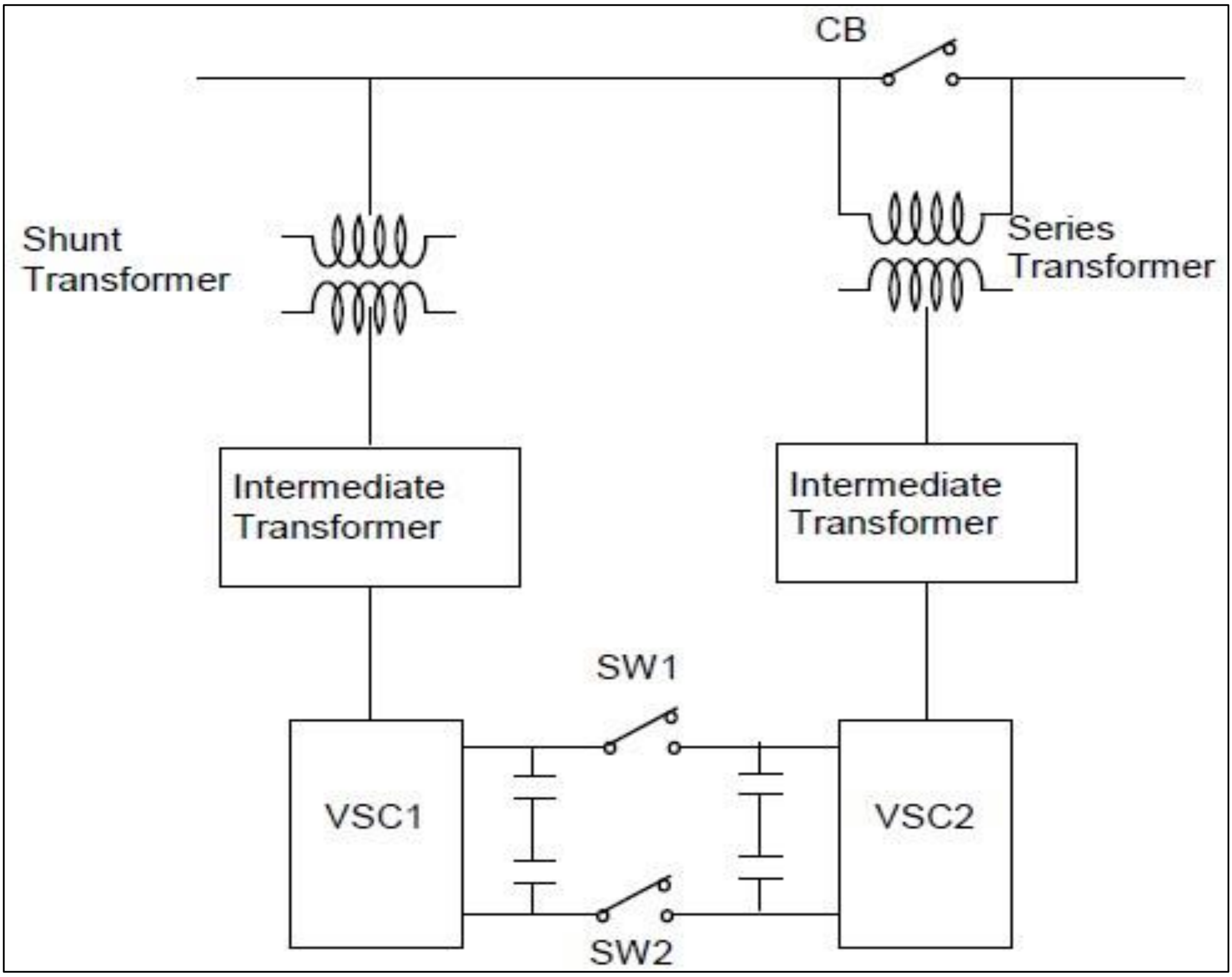

Fig 1 UPFC Schematic

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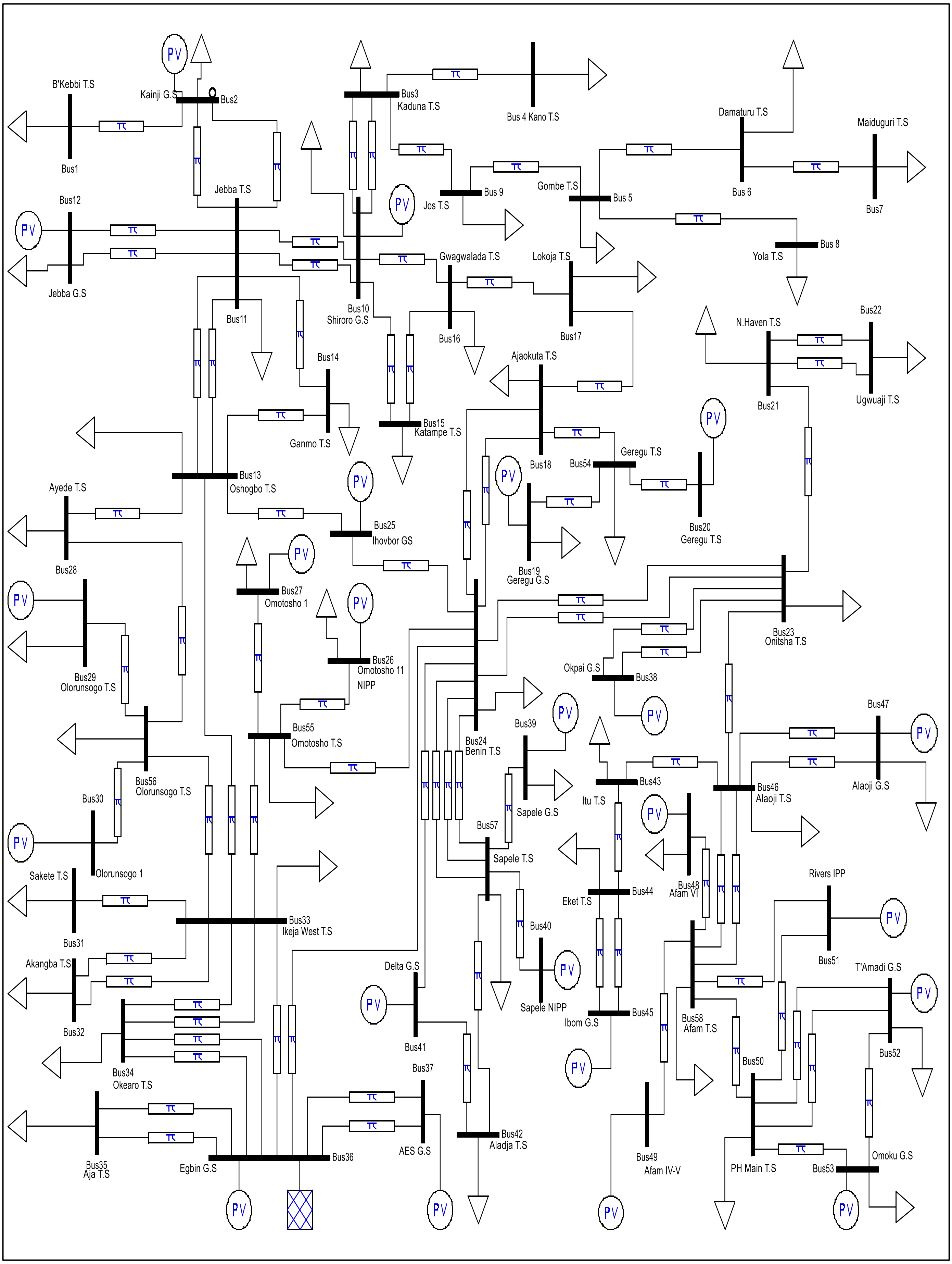

Fig 2 Power System Model of the Nigerian 330 kV Transmission Network In PSAT

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IV. RESULTS AND DISCUSSION

This section shows the power flow results comprising of real and reactive power losses on the five identified weak buses of the 58-bus transmission network and are buses 32, 57, 34, 22 and 55 without FACTS, with UPFC FACTS and ANN.

Table 1 Outcome of the Power Flow Analysis of the System Without FACTS

Bus Number	Real Power (MW)	Reactive power (MVar)	Active power loss (MW)	Reactive power loss (MVar)
1	87.3163	114.4417	4.5947	7.6016
2	95.2701	117.1738	4.1241	7.7922
3	92.5579	93.8096	4.5965	7.1951
4	95.4396	117.4013	4.0927	7.7680
5	98.6571	108.9708	5.0109	7.8875
6	99.4548	92.9262	5.5229	7.0983
7	83.8406	98.3549	5.2621	7.4568
8	82.7775	106.4064	4.1798	7.1535
9	93.9253	118.7252	4.1617	6.0517
10	81.8764	118.9467	5.5545	6.8931
11	90.5081	94.7284	5.8103	7.2926
12	90.6069	119.1178	5.0675	7.0424
13	97.2228	118.7150	4.2183	6.7446
14	89.6971	104.5613	5.6516	7.8743
15	87.8691	114.0084	4.6762	7.6591
16	93.4286	94.2566	4.5879	7.6982
17	94.8252	102.6528	5.4926	6.7451
18	90.4010	117.4721	4.0207	7.1864
19	86.9543	113.7662	4.0969	7.7451
20	82.9999	118.7848	5.3358	7.8670
21	91.7218	109.6722	5.2069	7.3369
22	85.2429	91.0714	5.0522	6.4136
23	80.8891	115.4739	5.4594	7.3077
24	95.0987	118.0198	5.4145	6.1441
25	84.8557	110.3621	5.5628	6.8135
26	88.8480	112.7322	4.5760	7.3339
27	93.7559	112.2940	5.3851	7.8675
28	87.1846	101.7668	5.1133	7.6219
29	94.7268	109.6643	4.7930	6.9691
30	87.8941	95.1356	4.1232	7.5135
31	93.6683	111.1814	5.5604	6.8341
32	94.0809	90.9550	4.6752	7.9436
33	88.8461	98.3077	5.2157	7.9759
34	80.3916	91.3851	5.4825	7.7283
35	86.6172	92.9140	4.2096	6.7778
36	88.4862	114.7037	4.2558	6.9095
37	85.4054	110.8449	5.0991	6.4934
38	83.9411	99.5130	4.9705	7.5688
39	96.4344	118.5067	5.7810	7.7657
40	88.5984	91.0334	5.5979	7.8274
41	97.7554	103.1623	5.4687	7.1166
42	87.8237	101.4468	4.1027	7.1977
43	95.3823	112.9655	4.1458	6.2978
44	87.9358	113.8560	4.1771	7.7994
45	96.1703	95.6062	5.5967	6.9008
46	95.1015	104.6929	5.8860	6.4113
47	87.5479	103.3676	5.3674	7.7993
48	84.3204	109.3894	4.2642	7.5252
49	95.8081	111.2809	5.4454	7.7650
50	98.9861	112.6406	4.2207	6.5699
51	86.5513	98.2808	4.2350	7.3465
52	93.4253	110.3911	5.2814	7.3286
53	88.7729	109.6529	4.6576	6.2456
54	96.6700	94.8784	5.3076	6.8146

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55	95.3771	93.5699	5.4983	6.5506
56	83.3451	104.9509	5.1664	7.4333
57	97.2396	118.7923	5.4801	6.5668
58	99.7974	100.2116	4.4697	7.7924

The bar chart of the power flow analysis of the system was generated and presented in figure 4.2, figure 4.3, figure 4.4 and figure 4.5 for active power, reactive power, active power loss and reactive power loss respectively. The average losses at the busses are shown in Table 2 and the average voltage violations is shown in Table 3.

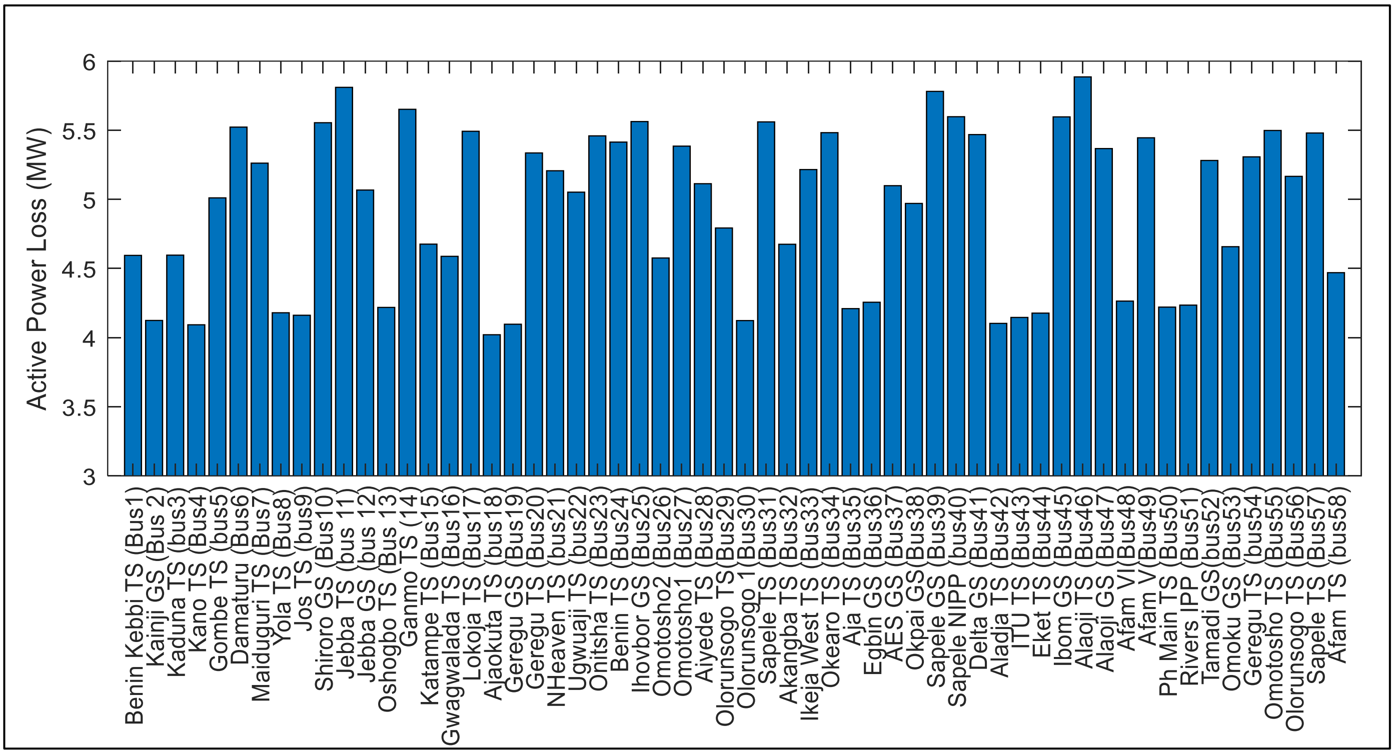

Fig 1 Bar Chart of Active Power Loss of the System in Steady State Situation Without FACTS Using PSAT

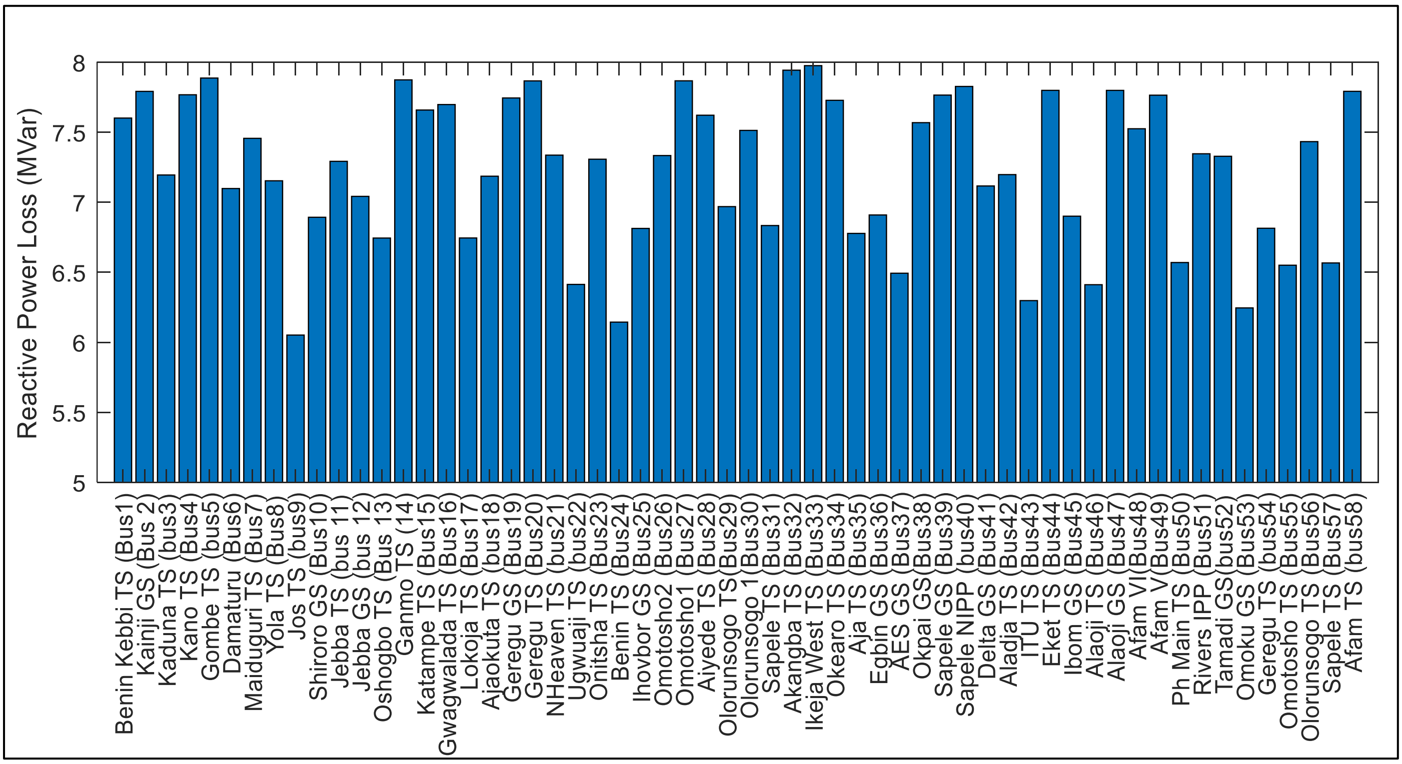

Fig 2 Bar Chart of Reactive Power of the System in Steady State Situation Without FACTS Using PSAT

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Table 2 Outcome of the Power Flow Analysis of the System with ANN Based UPFC FACTS

Bus Number	Real Power (MW)	Reactive power (MVar)	Active power loss (MW)	Reactive power loss (MVar)
1	100.9235	126.3853	2.8487	3.0589
2	100.0782	120.3360	2.8587	4.3055
3	104.2311	120.6881	2.2497	5.4967
4	106.5557	123.1960	2.0489	4.8522
5	107.2292	125.3086	2.5804	4.5604
6	105.3121	126.5445	2.6350	5.5916
7	101.0882	124.0762	3.3074	3.2931
8	106.3177	128.1998	3.9139	5.7242
9	101.2650	127.1836	3.8715	3.3241
10	101.3430	129.6865	2.9158	4.5510
11	100.9859	125.3133	2.4810	3.4295
12	101.4203	123.2515	3.5278	4.6781
13	101.6825	121.0563	3.5187	3.0137
14	101.9625	126.1096	3.4813	5.3000
15	103.1748	127.7880	3.4874	5.5461
16	103.1643	124.2345	2.2118	5.7505
17	102.1756	120.9082	3.3631	5.9609
18	102.5104	122.6647	2.9265	4.5154
19	108.9292	121.5366	2.4243	3.8143
20	107.0322	122.8101	2.1970	3.3023
21	105.5574	124.4009	3.6471	4.5235
22	101.8443	125.2714	2.3500	4.7568
23	102.1203	124.5742	2.3271	5.2887
24	100.7735	128.7537	3.3320	3.2489
25	109.1380	125.1805	3.7888	4.9848
26	107.0672	129.4362	3.0331	4.5509
27	105.5779	126.3771	3.4054	3.5131
28	103.1343	129.5769	2.3072	5.8157
29	101.6620	122.4071	3.9069	4.7714
30	106.2250	126.7612	3.0818	4.3219
31	109.8793	122.8906	3.3595	5.8258
32	101.7043	126.7181	2.0731	4.9677
33	102.5779	126.9514	3.6184	4.3558
34	103.9680	120.6799	3.4972	5.5191
35	100.7399	122.5479	2.2404	4.5979
36	106.8410	122.2404	3.0501	4.6617
37	104.0239	126.6783	2.6517	5.0402
38	109.8284	128.4439	3.0929	4.1016
39	104.0218	123.4446	2.7978	3.7179
40	106.2067	127.8052	2.8302	4.7368
41	101.5437	126.7533	2.3615	5.6007
42	103.8135	120.0672	2.5108	4.2203
43	101.6113	126.0217	2.0411	3.3378
44	107.5811	123.8677	3.8474	4.3315
45	108.7111	129.1599	3.3074	3.9006
46	103.5078	120.0115	3.8652	4.2042
47	106.8554	124.6245	2.3270	5.5001
48	102.9415	124.2435	3.8422	4.2109
49	105.3063	124.6092	3.5893	4.1705
50	108.3242	127.7016	3.1548	4.0813
51	105.9749	123.2247	2.8801	3.4208
52	103.3531	127.8474	2.5152	3.7804
53	102.9923	124.7136	3.5039	3.2604
54	104.5259	120.3576	2.4573	4.2882
55	104.2265	121.7587	2.1284	3.7718
56	103.5961	127.2176	3.5347	3.8927
57	105.5832	124.7349	3.3424	4.2746
58	107.4255	121.5272	3.4304	3.3576

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The bar chart of the power flow analysis of the system was generated and presented in figure 1, figure 2, figure 3 and figure 4 for active power, reactive power, active power loss and reactive power loss respectively.

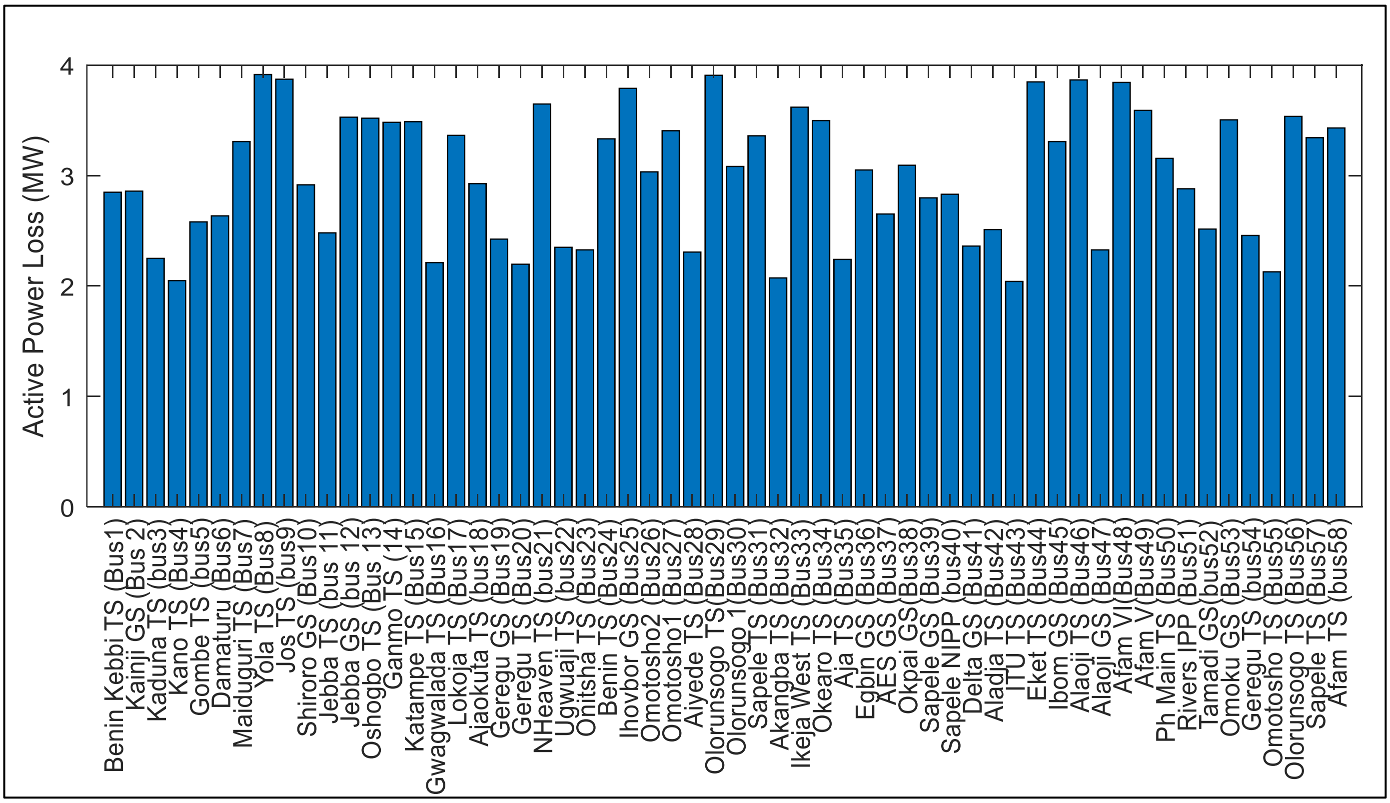

Fig 3 Bar Chart of Active Power Loss of the System with ANN Based UPFC in PSAT

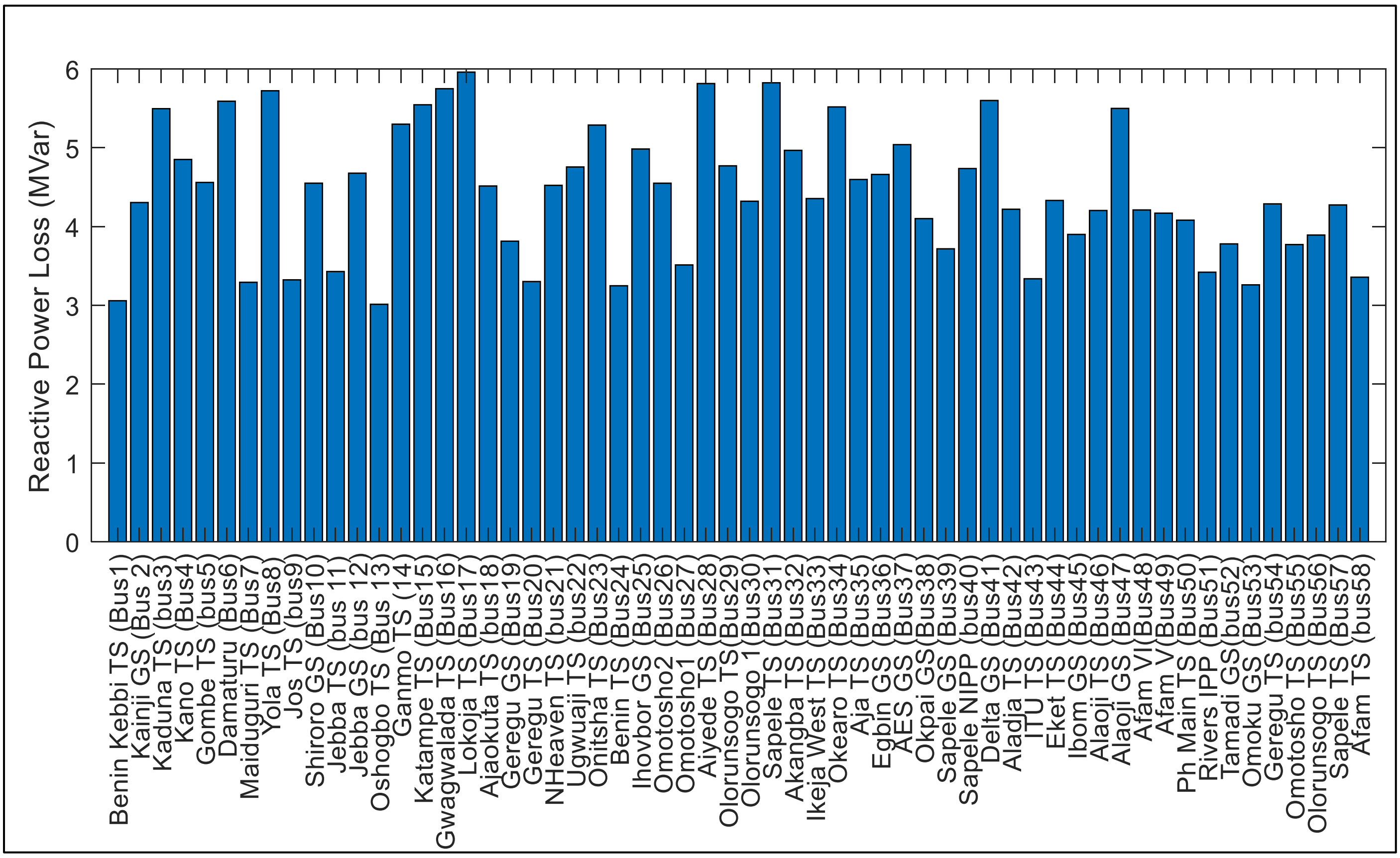

Fig 4 Bar Chart of Reactive Power of the System with ANN Based UPFC in PSAT

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Table 3 Outcome of the Power Flow Analysis of the System with ANN Based UPFC

Bus Number	Real Power (MW)	Reactive power (MVar)	Active power loss (MW)	Reactive power loss (MVar)
1	126.0890	132.5721	0.5147	2.5175
2	129.7221	134.4214	1.7648	2.9904
3	110.5998	132.9401	1.8835	1.3731
4	120.7133	130.7738	1.6564	2.5623
5	111.7415	130.9993	0.5640	1.3916
6	126.0418	132.0348	1.0673	2.9847
7	129.7829	133.7435	1.5565	2.6045
8	111.3389	134.1279	1.5943	1.8485
9	128.7880	133.9498	0.8364	2.4577
10	110.3636	131.5926	0.9036	1.9967
11	123.6768	132.6703	1.5095	2.6180
12	125.6747	130.4498	1.2162	1.7130
13	120.6828	130.5585	1.4356	1.1465
14	127.7072	130.6815	0.8547	2.1820
15	127.9801	133.3933	0.7657	2.8204
16	122.5188	132.4759	1.7445	1.3875
17	112.7574	130.9486	1.6504	1.8647
18	114.3560	132.4750	1.9017	2.4983
19	113.6428	130.7380	0.6618	1.0784
20	110.8364	130.2749	0.7733	2.8926
21	112.1388	134.2536	0.6486	2.5273
22	122.3289	132.8028	1.2346	2.1176
23	128.7932	134.6480	0.7899	1.3677
24	117.0891	133.4833	1.8438	1.9959
25	118.2126	132.9140	0.6486	2.0357
26	129.6870	134.0770	0.5662	2.9885
27	128.9116	134.3951	1.3359	2.7097
28	123.5329	134.9446	1.6587	2.9248
29	129.7660	130.0026	0.9679	2.3579
30	125.3366	134.3272	0.7685	1.8070
31	116.7340	133.0628	1.0084	2.8700
32	123.2476	134.9498	0.8152	1.9590
33	114.8833	132.6384	1.2652	1.4636
34	115.9101	132.3976	1.8595	1.7926
35	123.6036	134.0067	1.4434	2.4102
36	120.5569	131.1392	0.6523	2.1171
37	118.2319	132.4905	1.0863	2.5133
38	122.0528	134.5043	0.5819	2.9910
39	125.0104	132.8733	1.2519	2.9249
40	121.6707	134.2259	1.1476	2.0701
41	121.0359	133.6932	1.9963	2.9277
42	121.6714	132.9299	1.7174	1.2313
43	120.2364	131.2337	1.2285	1.1029
44	111.6519	133.3321	1.8417	1.6087
45	124.3914	130.4174	0.7063	2.1604
46	129.9231	133.1298	1.0850	2.0619
47	117.0907	133.3047	1.8910	2.8024
48	129.4252	133.6488	1.8762	2.0811
49	116.9290	134.4538	1.5704	1.8640
50	127.7309	134.9115	1.4275	2.0853
51	119.0939	133.8451	1.0149	2.4248
52	118.2685	132.9072	1.9040	1.0333
53	114.3546	134.6416	0.6872	2.6018
54	112.5131	132.9005	1.5959	1.2850
55	116.1783	130.0849	1.4697	1.9569
56	124.5221	130.6043	1.7497	1.5137
57	125.6574	134.3136	1.0974	1.7382
58	123.8758	132.4215	1.6247	2.3235

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The bar chart of the power flow analysis of the system was generated and presented in figure 5 and figure 6 for active power, reactive power, active power loss and reactive power loss respectively.

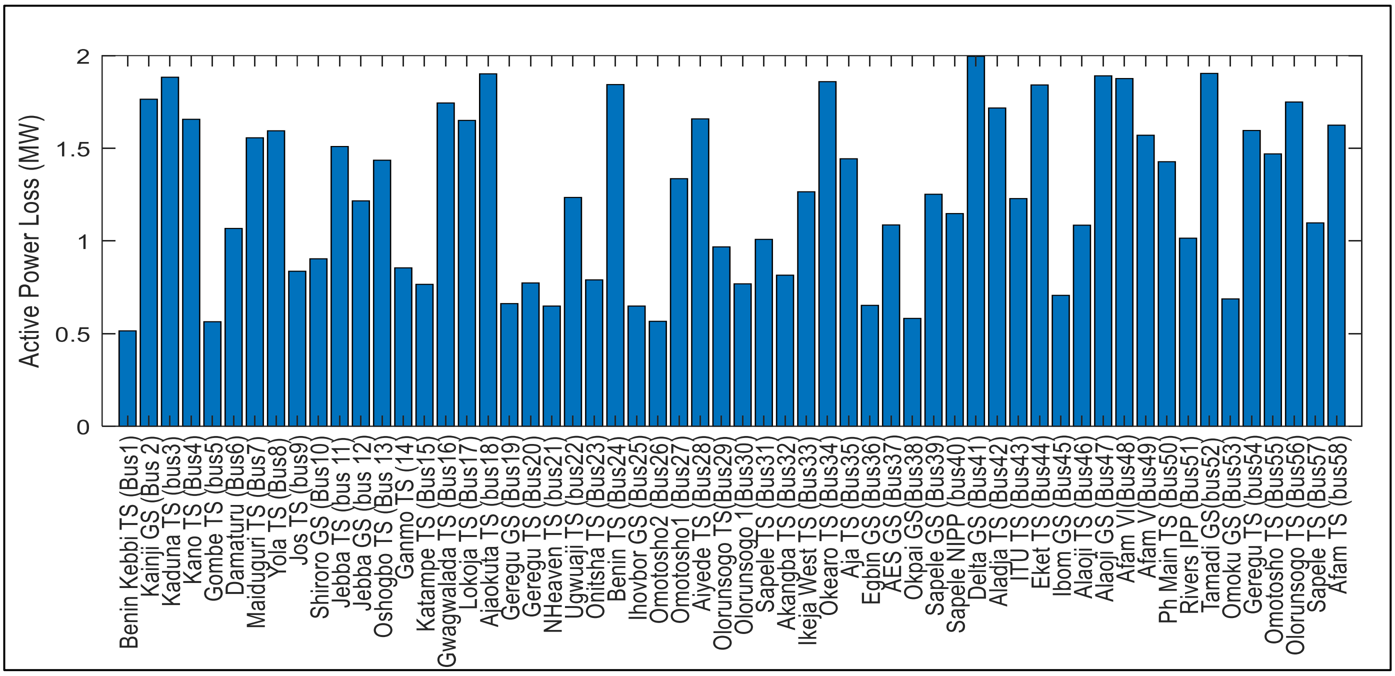

Fig 5 Bar Chart of Active Power Loss of the System with ANN Based UPFC

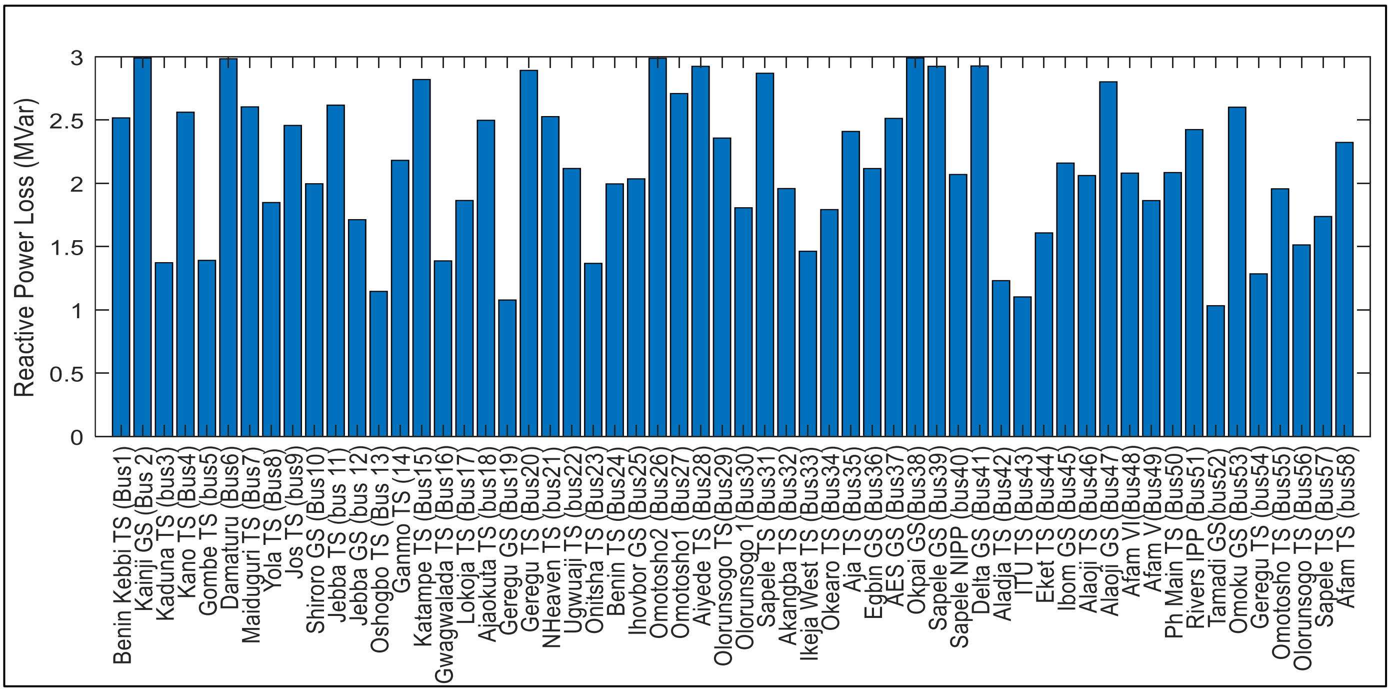

Fig 6 Bar Chart of Reactive Power of the System with ANN Based UPFC

Table 4 Results of Voltage Improvement with Facts and Ann Application on the Five Weak Buses

S/N	BUS LOCATION	BUS NUMBER	BUS VOLTAGE WITHOUT FACTS (KV)	BUS VOLTAGE WITH UPFC (KV)	BUS VOLTAGE WITH ANN (KV)
1	Akangba TS	32	300.3 (0.91pu)	324.69 (0.984pu)	327.91(0.993pu)
2	Sapele NIPP	57	309.59 (0.93pu)	322.97 (0.978pu)	328.47(0.885pu)
3	Okearo Ts	34	300.46 (0.9pu)	322.75 (0.978pu)	326.45(0.989pu)
4	Ugwuaji TS	22	300.35 (0.910pu)	321.53 (0.974pu)	327.270.997pu)
5	Omotosho TS	55	301.19 (0.91pu)	321.31 (0.973pu)	327.990.9939pu)

The introduction of UPFC FACTS and ANN improved the bus voltages from the (base case) steady state values justifying the need to invest in UPFC and ANN in practical power system network.

Table 5 Analysis of Power Losses

S/N	BUS LOCATION	BUS NUMBER	ACTIVE POWER LOSS (MW) WITHOUT FACTS	REACTIVE POWER LOSS (MW) WITHOUT FACT S	ACTIVE POWER LOSS (MW) WITH UPFC FACTS	REACTIVE POWER LOSS (MW) WITH UPFC FACTS	ACTIVE POWER LOSS WITH ANN (MW)	REACTIVE POWER LOSS (MW) WITH ANN
1	Akangba TS	32	4.6752	7.9436	2.0731	4.9677	0.8152	1.9590
2	Sapele NIPP	57	5.4801	6.5668	3.3424	4.2746	1.0974	1.7382
3	Okearo Ts	34	5.4825	7.7283	3.4972	5.5191	1.8595	1.7966
4	Ugwuaji TS	22	5.0522	6.4136	2.35	4.7468	1.2346	2.1176
5	Omotosho TS	55	5.4983	6.5506	2.1284	3.7718	1.4697	1.9569
AVERAGE LOSSES			5.2376MW	7.04MW	2.6788MW	4.658	1.2952	1.9150MW

➢ *Discussion*

The result of this study analyzed the role of ANN based UPFC on the reduction of active and reactive power losses on the Nigeria's 330kV 58-bus network.

V. CONCLUSION

From the power flow analysis of the entire 58-bus network, the active power loss with the introduction of UPFC FACTS was 48.8% and reactive power reduction was 33.8%. With the introduction of ANN based UPFC controller, the active power loss reduction was 75.3% and reactive loss reduction with ANN based controller was 73%.

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