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EFFECT OF UNIFIED POWER FLOW CONTROLLER (UPFC) INTEGRATION TO POWER TRANSFER ON THE NIGERIA 330 KV POWER NETWORK DURING LINE CONTINGENCY

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Abstract*: This paper involves analysis and simulations on the 48-bus 330 kV Nigeria's power network system under line failure contingency. The study used NEPLAN software for the simulation and MATLAB m-file for plotting of the charts in various cases. It is aimed to examine the voltage profile, load flow and available transfer capability of transmission grid system under base case conditions and transmission line contingency situation using the method of repeated power flow based on Newton Raphson. The unified power flow controller, UPFC is placed in the network for the enhancement of voltage profile, power flow and ATC. From the results obtained, integration of UPFC in the ATC least five locations had increased the values of the elements. When the network is operating without UPFC controller, the system had voltage profile of 293.12 kV with real and reactive of 742.93 MW and 1127.80 MVar respectively. However, when the network is operating with UPFC FACTS, the network had voltage profile of 309.23 kV with real and reactive of 783.76 MW and 1189.80 MVar respectively. From the deduced results, as UPFC FACTS increased power transfer during line failure, these FACTS should be installed in the specified locations of the Nigeria 330 kV network for the improvement of voltage profile, real and reactive power and ATC of the power system network.

***Keywords:* Active Power, Available Transfer Capability (ATC), Flexible AC Transmission System (FACTS), MATLAB, NEPLAN, Power Flow, Reactive Power, Unified Power Flow Controller (UPFC), Voltage Profile.**

I. INTRODUCTION

Power network is a complex system comprising several interconnected machineries for the purpose of power generation, transmission and distribution [1, 2]. Due to the complex nature of this system, failure of any equipment or line result in system reduced reliability which mostly leads to outage of part of the power network [3, 4]. Due to downtime of the system during this equipment failure [5], emergency or redundancy generating system is to be installed in the network in order for additional power to be injected to the grid for sustained operation of the system for improved power system security [6, 7]. The assessment of the effects of contingency of power flows on the transmission line, bus voltages, and the stability of the remaining system (post-contingency) is an essential technique for evaluating the impact of outages on the security of the power system during planning and operation [8]. Power system contingency refers to disturbances like outage of transmission element or generator failures, which could result in abrupt and significant changes to the configuration and status (parameters) of the system [9]. A unified power flow controller (UPFC) is the type of flexible AC transmission system

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(FACTS) that composed of two voltage source converters (VSCs) that are connected by a common DC link as shown in Fig. 1 [10]. This connection allows real power to flow in both directions between the two outputs, shunt and series FACTS [11].

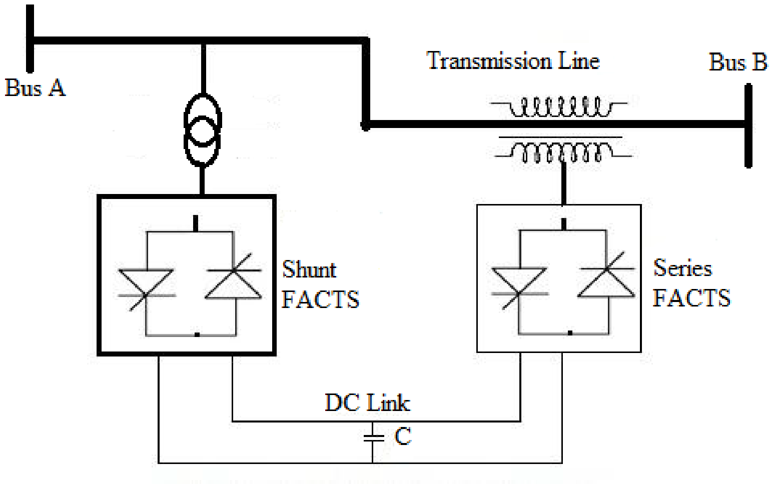

Fig. 1: Schematic model of UPFC [12]

[13] used three FACTS devices; the thyristor-controlled series compensator (TCSC), unified power flow controller (UPFC), and interline power flow controller (IPFC) to improve the transfer capabilities of Nigeria's power network. In order to improve dynamic stability of Nigeria's power network, [14] used two series FACTS devices; the static synchronous series compensator (SSSC) and the TCSC. [15] implemented the static VAR compensator (SVC) and TCSC models into the Newton Raphson power flow equations to improve the available transfer capability (ATC) of a deregulated power network. [16] used IEEE-14 bus system to improve ATC with the aid of shunt and series FACTS. The ideal site for the installation of FACTS devices is established using both real and reactive power loss, sensitivity index, and MATLAB software. The optimal placement of the TCSC in the power system can be achieved using an optimization technique, as the TCSC is very useful in magnifying the ATC of the transmission network by adjusting its reactance as stated by [17].

From the reviewed literatures, the researchers used different methods for ATC determination and enhancement. This ranges from improving power transfer using SSSC, and TCSC controller. However, this work is carried out on a 48 bus 330 kV transmission grid system by utilizing UPFC for improvement of power transfer during line contingency. The bus voltages from load flow analysis are calculated for ATC determination using repeated power flow by utilizing Newton Raphson (RPFN-R) method. The system modeling is carried out with the aid of NEPLAN software.

II. METHODOLOGY

This research paper centers on utilization of NEPLAN software for the modeling of the 48-bus power system network for onward determination and improvement of the voltage profile, power flow and available transfer capability (ATC) of the network on event of line failure using unified FACTS. The software utilized includes. MATLAB is used for the computation of ATC and generation of plots of the power system network.

When UPFC FACTS is installed in a transmission network, the reactance of the line can be adjusted. Normally the adjustment range is 0.5X to 1.5X, where X is the reactance of the original line. The formulation of ATC can be expressed as Equations (1) to (9) as stated in [18 - 21].

$$P_{Gi} - P_{Di} - Q_{Di} = 0 \tag{1}$$

Subject to:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |U_i||U_j|\left(G_{ij-FACTS}\cos\delta_{ij} + B_{ij-FACTS}\sin\delta_{ij}\right) = 0 \tag{2}$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |U_i||U_j|\left(G_{ij-FACTS}\sin\delta_{ij} - B_{ij-FACTS}\cos\delta_{ij}\right) = 0 \tag{3}$$

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$$|U_i|_{min} \le |U_i| \le |U_i|_{max} \quad (4)$$

$$|S_{ij}| \le |S_{ij}|_{max} \quad (5)$$

$$-0.5X \le X_{FACTS} \le 0.5X \quad (6)$$

$$|\delta_{Gi}(t) - \delta_{Gi}(t)| \le \delta_{Gmax} \quad (7)$$

Where:

$G_{ij-FACTS}$, $B_{ij-FACTS}$: real and imaginary part of the ijth element of bus admittance matrix when UPFC FACTS is installed.

X_{FACTS}: reactance of the UPFC FACTS

X: original reactance of the line where UPFC FACTS is installed

$$ATC = \sum_{i \in sink} P_L^i(\lambda_{max}) - \sum_{i \in sink} P_L^{i0} \quad (8)$$

The ATC value between two points is given as

$$ATC = TTC - TRM - (CBM + ETC) \quad (9)$$

Where TTC is total transfer capability, TRM is transmission reliability margin, CBM is capacity benefit margin and ETC is existing transmission commitment including customer services between the same two points.

The UPFC FACTS were placed on the five least locations as shown in Fig. 2, before the calculation of the ATC after insertion of the UPFC FACTS.

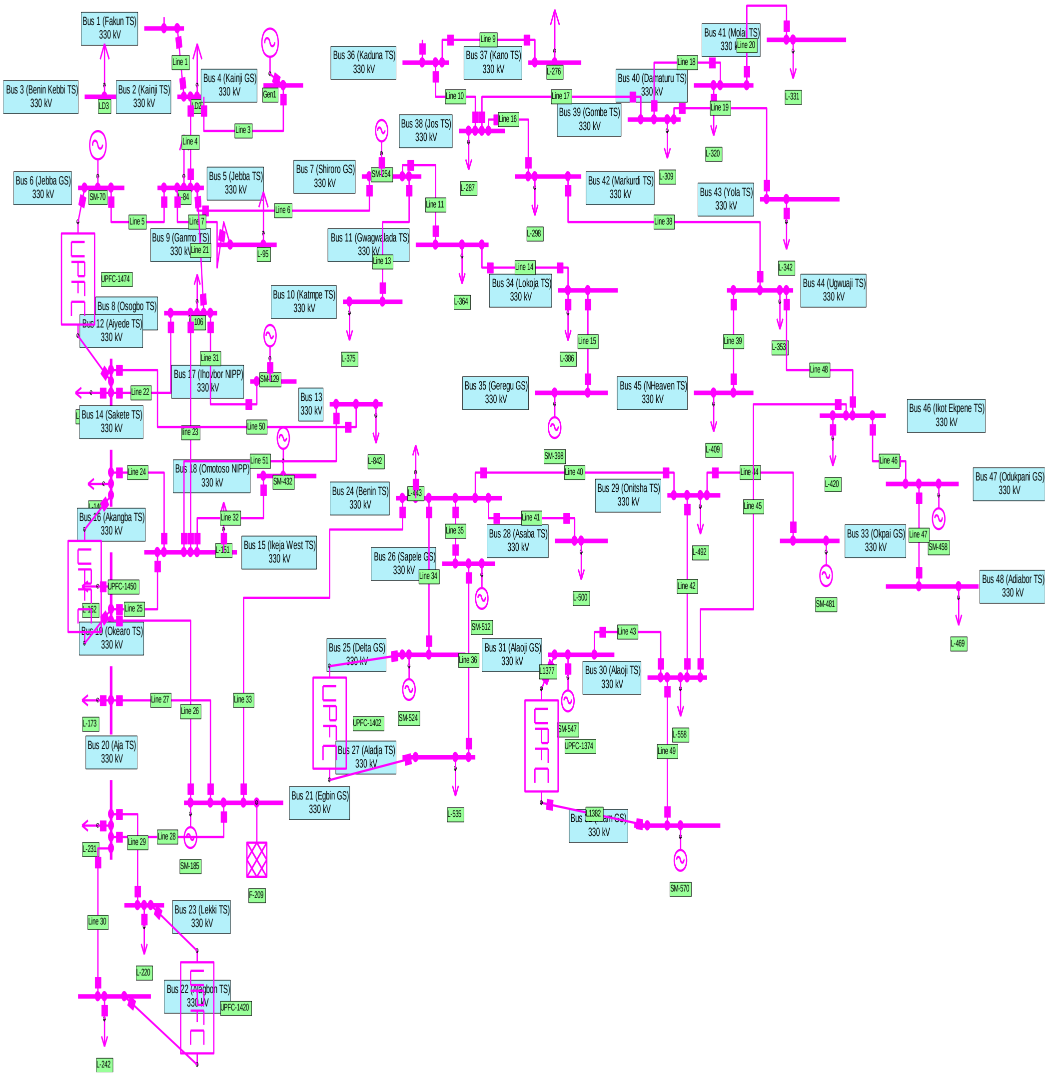

Fig. 2: Network model of 48-bus 330 kV transmission system

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III. RESULT

This section shows the voltage profile results, power flow results comprising of real and reactive power and the ATC values for the 48-bus network. The contingency considered were line offs of the transmission line between Kainji GS and Kainji TS, Shiroro GS and Kaduna TS, Katampe TS and Gwagwalada TS, Osogbo TS to Aiyede TS, Delta GS and Aladja TS and Onitsha TS to New Heaven TS. The modeling of the 48 bus Nigeria 330 kV network in NEPLAN is shown in Figure 2 while the values of the voltage profile, real power, reactive power and ATC of the power system without FACTS and with contingency (line off) is shown in Table 1. The values of the voltage profile, real power, reactive power and ATC of the power system with UPFC FACTS and with line off is shown in Table 2.

Table 1: Power system parameters with values of the system without FACTS and with contingency

Bus location	Voltage profile (kV)	Active power (MW)	Reactive Power (MVar)	ATC
1	292.18	20.00	27.17	22.29
2	292.35	21.61	28.02	20.35
3	290.57	7.83	19.10	11.40
4	292.07	21.74	26.62	17.76
5	291.98	16.77	26.16	14.34
6	290.15	7.31	16.99	26.70
7	289.98	10.51	16.18	17.26
8	291.40	15.26	23.24	21.51
9	293.12	22.52	31.84	14.41
10	290.81	22.65	20.30	22.94
11	291.72	8.37	24.86	16.31
12	290.37	22.75	18.13	23.96
13	292.34	22.52	27.95	24.65
14	290.49	14.17	18.71	25.80
15	291.43	19.74	23.39	19.98
16	292.14	8.10	26.98	12.81
17	292.86	13.05	30.55	15.65
18	293.11	21.78	31.82	29.02
19	291.58	19.60	24.15	14.15
20	290.06	22.56	16.55	27.32
21	290.10	17.19	16.74	21.70
22	290.50	6.22	18.76	30.65
23	292.67	20.61	29.62	12.70
24	290.49	22.11	18.70	19.83
25	292.57	17.59	29.13	13.26
26	290.45	18.99	18.50	29.98
27	293.00	18.73	31.27	11.26
28	290.84	12.52	20.48	26.32
29	290.27	17.18	17.63	27.15
30	290.48	8.61	18.64	28.16
31	291.84	18.08	25.44	12.82
32	291.30	6.15	22.78	18.99
33	290.85	10.48	20.51	16.25
34	292.64	6.40	29.44	26.81
35	291.72	7.30	24.86	19.61
36	291.59	20.15	24.20	28.98
37	292.96	17.88	31.04	14.73
38	290.61	11.20	19.29	16.33
39	292.36	22.39	28.06	14.02
40	292.35	6.20	28.00	13.83
41	290.96	13.35	21.05	28.17
42	291.66	12.34	24.54	22.51
43	289.82	19.13	15.38	21.92
44	289.74	19.65	14.97	14.01

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45	291.52	8.89	23.85	27.85
46	292.44	14.25	28.47	23.33
47	293.01	13.47	31.36	18.03
48	290.02	17.02	16.38	21.20

Table 2: Power system parameters with values of the system with UPFC and with contingency from NEPLAN

Bus location	Voltage profile (kV)	Active power (MW)	Reactive Power (MVar)	ATC
1	308.24	21.10	28.67	23.52
2	308.42	22.80	29.56	21.47
3	306.54	8.26	20.15	12.03
4	308.13	22.94	28.08	18.74
5	308.03	17.69	27.60	15.13
6	306.10	7.71	17.93	28.17
7	305.92	11.09	17.07	18.21
8	307.41	16.10	24.52	22.69
9	309.23	23.76	33.59	15.20
10	306.79	23.90	21.42	24.20
11	307.76	8.83	26.23	17.21
12	306.34	24.01	19.13	25.28
13	308.41	23.76	29.49	26.00
14	306.46	14.95	19.74	27.22
15	307.44	20.83	24.67	21.08
16	308.20	8.54	28.46	13.51
17	308.96	13.76	32.23	16.51
18	309.23	22.98	33.58	30.62
19	307.61	20.68	25.48	14.93
20	306.00	23.80	17.46	28.82
21	306.04	18.13	17.67	22.89
22	306.47	6.56	19.79	32.33
23	308.76	21.74	31.25	13.40
24	306.46	23.32	19.73	20.91
25	308.66	18.56	30.73	13.99
26	306.41	20.03	19.52	31.63
27	309.11	19.76	32.99	11.88
28	306.83	13.21	21.61	27.77
29	306.23	18.13	18.59	28.64
30	306.44	9.09	19.66	29.70
31	307.88	19.07	26.83	13.53
32	307.32	6.49	24.03	20.03
33	306.84	11.06	21.64	17.15
34	308.72	6.75	31.05	28.29
35	307.76	7.71	26.23	20.68
36	307.62	21.26	25.53	30.57
37	309.06	18.86	32.75	15.54
38	306.58	11.81	20.35	17.23
39	308.43	23.63	29.61	14.79
40	308.42	6.54	29.54	14.59
41	306.95	14.08	22.21	29.72
42	307.69	13.01	25.89	23.74
43	305.75	20.18	16.22	23.13
44	305.67	20.73	15.79	14.78
45	307.54	9.38	25.16	29.38
46	308.52	15.03	30.04	24.62
47	309.13	14.21	33.08	19.02
48	305.97	17.95	17.28	22.37

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The voltage profile in base case is shown in Fig. 3.

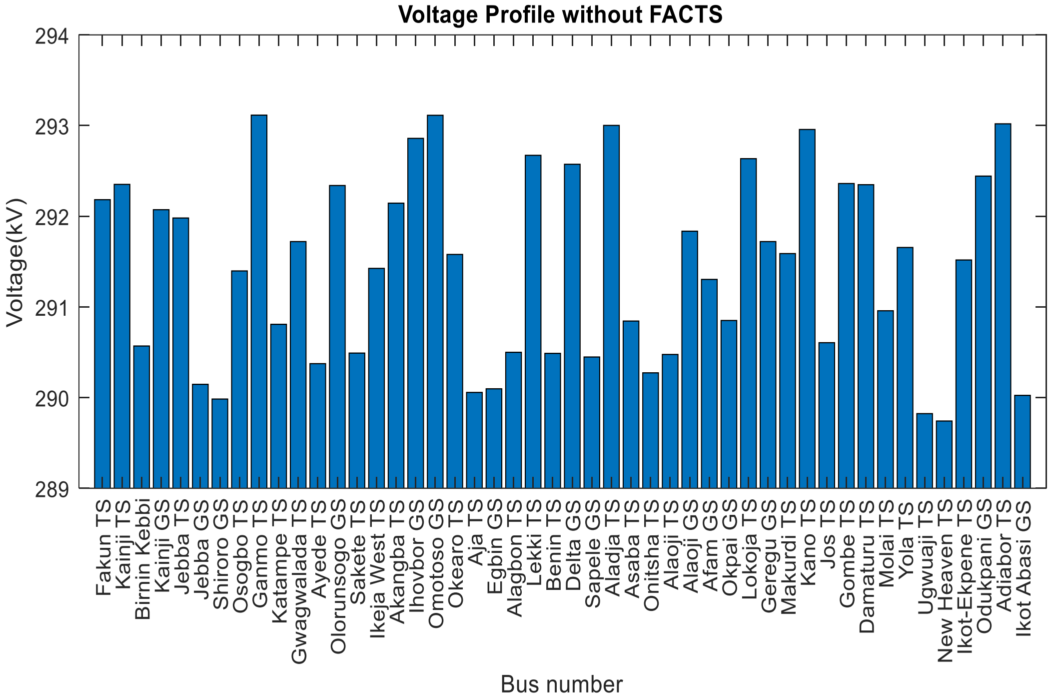

Fig. 3: Voltage profile without FACTS

From the voltage of the power system network displayed in Fig. 3, the highest voltage of the system during contingency is 293 kV. This shows that there is abnormality in voltage due to the contingency. The voltage profile with UPFC is shown in Fig. 4.

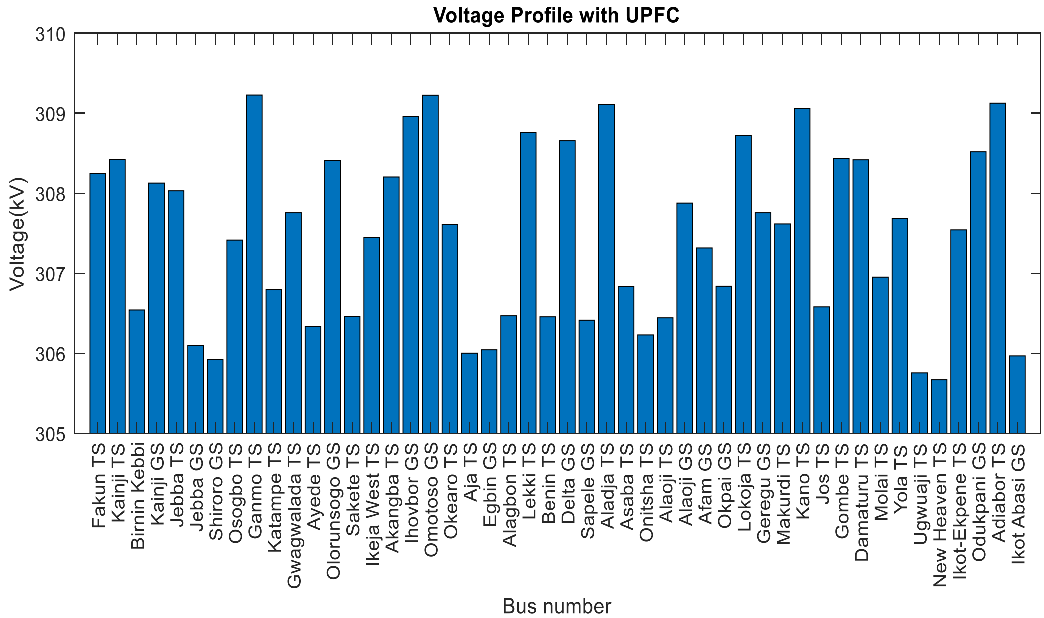

Fig. 4: Voltage profile with UPFC

The voltage profile improvement with UPFC shown in Fig. 4 has the maximum voltage value of 309.2 kV. This also shows that there was voltage improvement when compared to the power system without FACTS. The base case real power chart is shown in Fig. 5.

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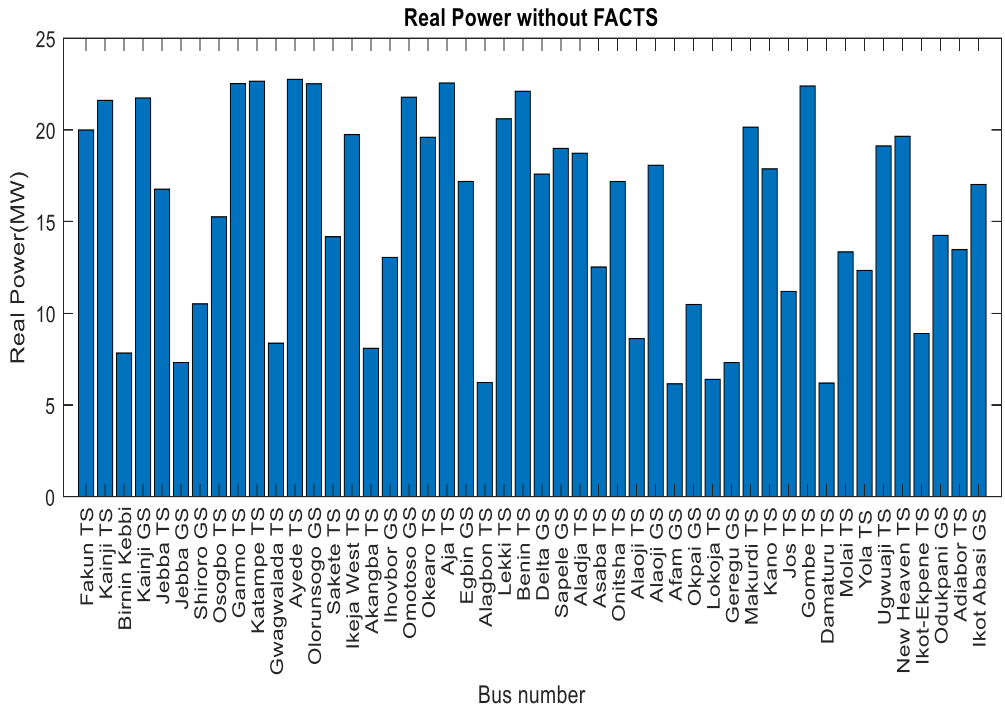

Fig. 5: Real power without FACTS

From Fig. 5, the real power flow shows that the highest power on the system is recorded at 22.7 MW for Ayede TS. The result of UPFC introduction on active power is shown in Fig. 6.

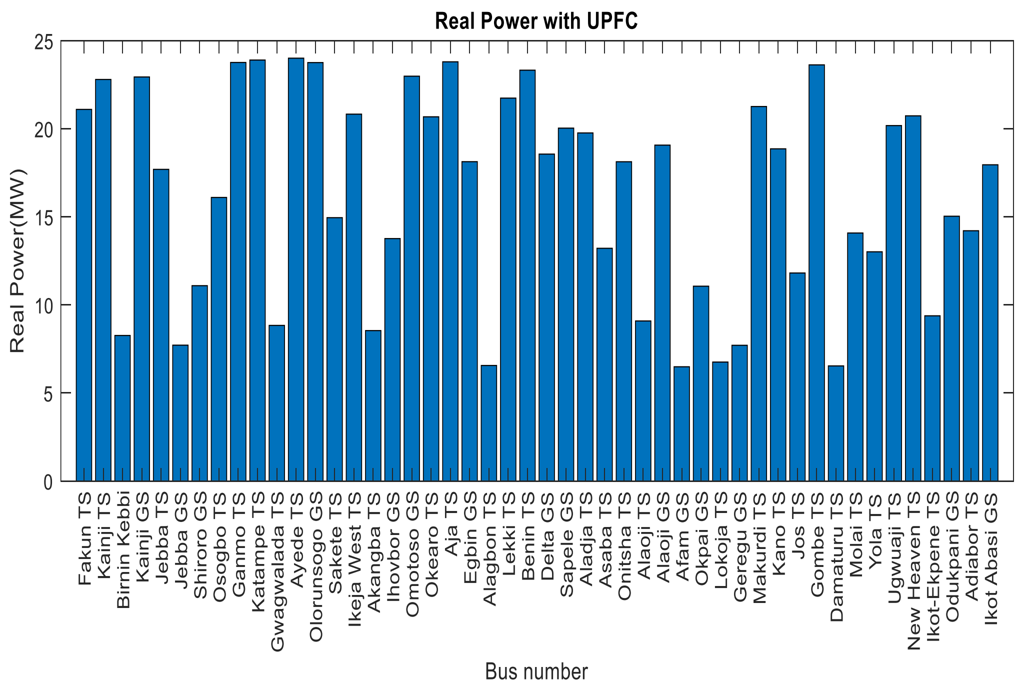

Fig. 6: Real power of the system network with UPFC

When UPFC controller is integrated in the network, the active power increase further to 24 MW. The outcome of reactive power without FACTS is shown in Fig. 7.

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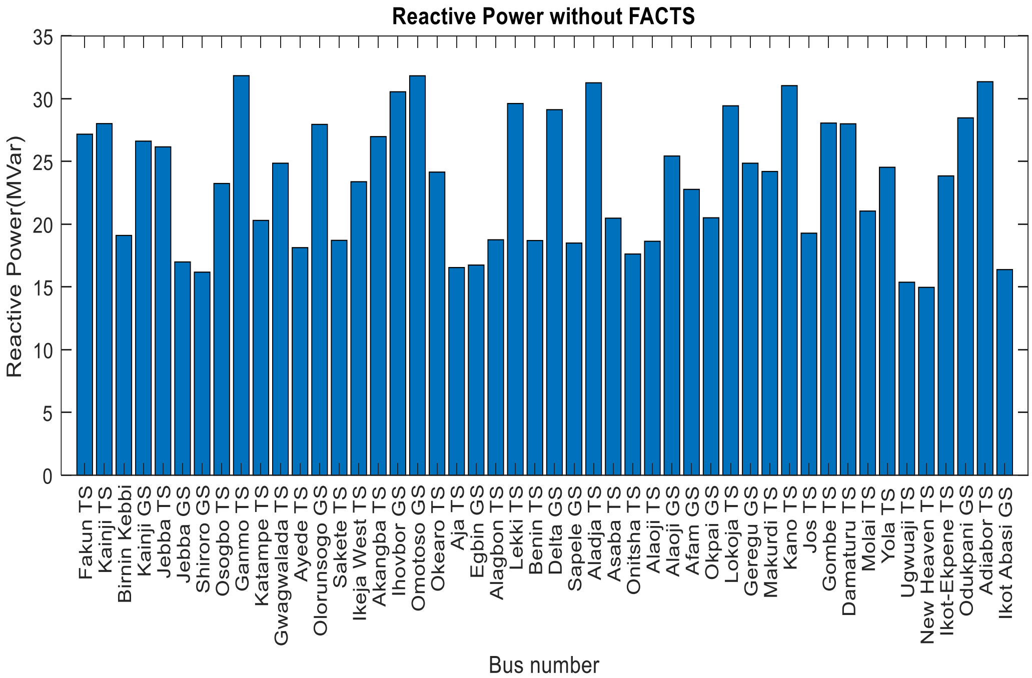

Fig. 7: Reactive power of the network without FACTS

From the chart of Fig. 7, it is seen that the highest reactive power is recorded as 31.8 MVar for Ganmo TS. When UPFC is introduced, the result is as shown in Fig. 8.

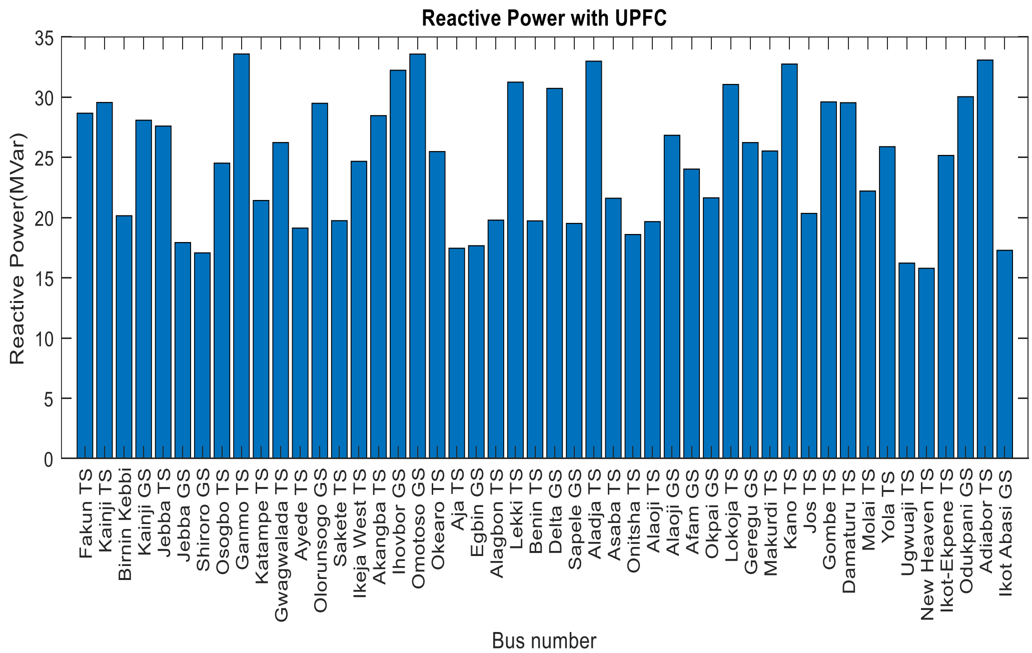

Fig. 8: Reactive power of the network with UPFC FACTS

From Fig. 8, UPFC application equally increased the reactive power of the network as can be seen from Ganmo transmission station. The outcome of ATC is shown in Fig. 9.

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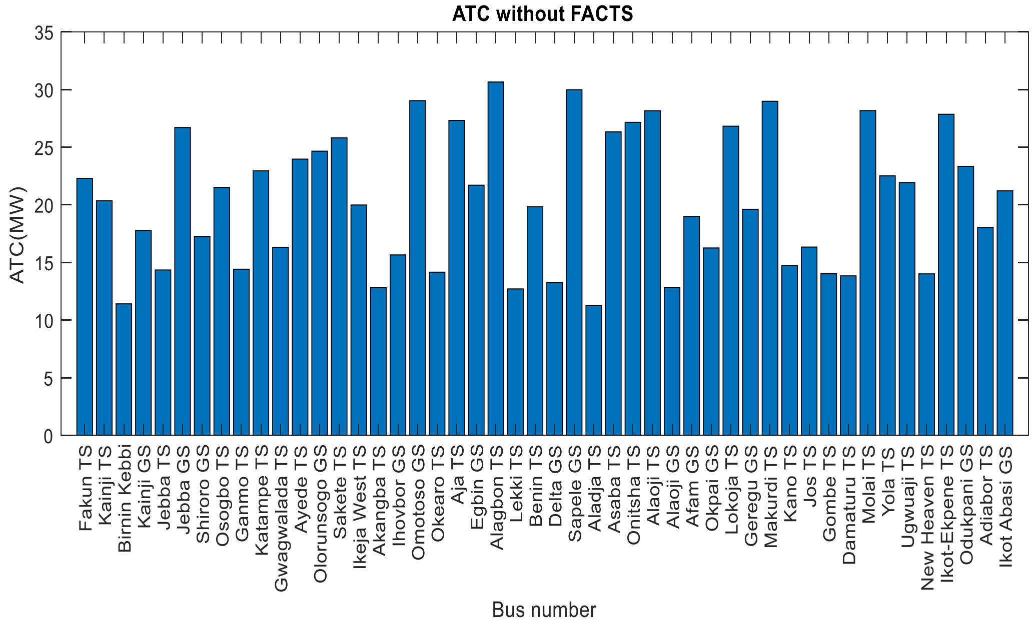

Fig. 9: ATC of the power system network without FACTS

From Fig. 9, it is seen that the values of ATC transferred is between 11 MW and 30 MW when the system operates without any controller during line contingency effect. It is also shown that Alagbon TS has the highest value of ATC (30.6 MW) in the network. The result of UPFC addition is shown in Fig. 10.

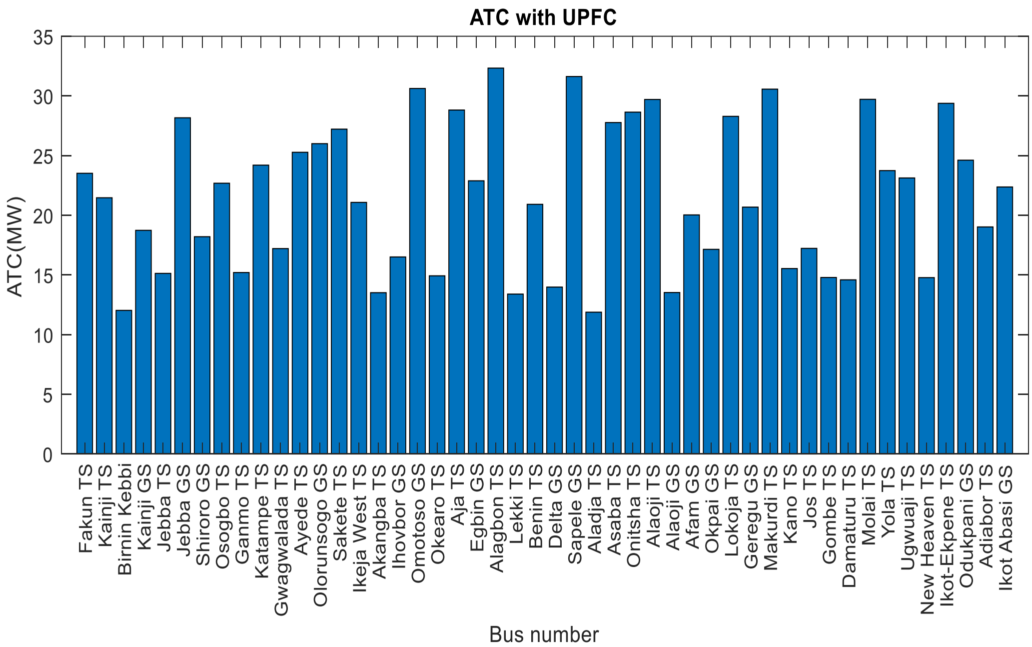

Fig. 10: ATC of the power system with UPFC

From Fig. 10, when UPFC was integrated in the network, ATC also improve greatly as the value for that of Alagbon TS now stood at 32.3 MW.

IV. DISCUSSION

The result of this study analyzed the impact of utilization of UPFC FACTS on the improvement of ATC and power flow on the Nigeria's 330 kV 48 bus power network in the event of line failure.

Table 3: Summary of the power system outcome in NEPLAN with contingency

Parameters	No FACTS	UPFC FACTS
Maximum Voltage (kV)	293.12	309.23
Total Real power (MW)	742.93	783.76
Total Reactive power (MVar)	1127.80	1189.80
Maximum ATC (MW)	30.63	32.33

The summary presented in Table 3 were the outcome from Table 1 and 3 and from Fig. 3 to 10. From Table 4, it is seen that the UPFC had improved the voltage profile with voltage value of 309.23 kV. Real and reactive power stood at 783.76 MW and 1189.8 MVar respectively.

V. CONCLUSION

Power congestion has been the major issue surrounding the power flow of the Nigeria transmission network due to the constant increase in the power demand. This led to the utilization of UPFC FACTS for the improvement of ATC in the power system network. From the outcome of the work, it was found that during the line failure, the introduction additional power source from UPFC improved the voltage profile, ATC, active power flow and reactive power flow as compared to when the system was operating without the FACTS device. Optimally, the use of UPFC system was affirmed to be suitable in the improvement of the Nigeria's power transfer issues and acclaimed to improve the activities of the power system network. It is recommended that the other shunt and series FACTS should be implemented in the power system network with their level of improvement determined and compared with the UPFC FACTS utilized in this work.

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