

# Power Flow Control in the Nigeria 330kV Integrated Power Network using Unified Power Flow Controller (UPFC)

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**Abstract** – This paper studies the impact of unified power flow controller (UPFC) in the Nigeria 330kV integrated power network. The test system consists of seventeen generating stations fifty two buses and sixty four transmission lines. A Matlab program incorporating UPFC in Newton-Raphson power flow program was developed. The power flow study without flexible alternating current transmission systems (FACTS) devices had the total real and reactive power losses to be 53.40MW and 93.300Mvar respectively. However with the introduction of the unified power flow controllers in the weak buses, it gave the real and reactive power losses to be 16.40MW and 22.80Mvar. The new bus voltage values obtained were: (New Haven 0.962pu, 317.46kV; Makurdi 0.997pu, 329.01kV; Damaturu 0.981pu 323.73kV; Gombe 0.992pu 327.36kV; Maiduguri 0.964pu 327.36kV; Jalingo 0.961pu 317.13kV; and Erunkan 0.972pu 320.76kV) and Jos 0.997pu, 329.01KV. Furthermore, UPFC saved (38.8MW+71.80Mvar) for the network.

**Keywords** – FACTS, IPP, NIPP, UPFC.

## I. INTRODUCTION

Nigeria power system is faced usually with the problems of insufficient generation and transmission lines, hence resulting in the overloading and stressing the network beyond their thermal limit, because of the increasing load demand. The resultant effect is having the transmission lines voltages operating outside the allowable limit of + or - 6%, insufficient and inadequate power flow, high line losses, and damping oscillation. In an attempt to solve these challenges, the federal government through Independent Power Producers (IPP) and National Independent Power Projects (NIPP) embarked on building more generating stations and additional transmission lines. The Implication of this attempt, is that the network soon will become complex and will require thorough control of basic parameters. Control parameters such as bus voltages, power flows (active and reactive), phase angles and line currents become very important. Conventionally, these controls were achieved using reactors, capacitor banks and tap changing transformers (phase shifters) to regulate power flows. Due to their slow response to system changes, power electronic based devices became imminent because of their speedy and accurate response to controls. With the integrated power project to solve some of these peculiar problems, government still face some challenges; such as delay in obtaining right of ways in building transmission lines and having generating stations located

very far from load centers. In an attempt to investigate both steady and transient states stability of the existing network, it was found that it is always operated very close to its thermal limit with some bus voltages below the allowable voltage limits of 313.5KV-345.5KV (1). However, Flexible Alternating Current Transmission Systems (FACTS) devices offer a good opportunity in solving some of these issues, rather than making more investment in either building more generating stations or lines. FACTS is defined by Institute of Electrical-Electronic Engineers (IEEE) as “a power electronic based system and order static equipment that provides control of one or more Alternating Current (AC) transmission system parameters to enhance controllability and increase power transfer” (7). The impact of different FACTS controllers on a 5-bus section of the Brazilian network was investigated (2). Different FACTS devices can effectively control power flow (active and reactive) and improve voltage profile (3-10). Unified Power Flow Controller (UPFC) is a combination of both the series and shunt controllers that is used to simultaneously control power (active and reactive) and voltage magnitude and its profile improvement using power electronic converters, such as gate turn on (GTO), IGBT switches and PWM control techniques in an interconnected power system (6, 7 and 8).UPFC is an example of FACTS device used for oscillation damping and improvement of power systems stability and control in a longitudinal network (11). The use of UPFC to determine active and reactive power flows and losses as well as phase angles and bus voltages improvement was studied (12,16). Till date little or nothing has been done in the application of FACTS devices in solving most of the weaknesses inherent in the Nigeria 330kV integrated network from literature review. Unified power flow controller (UPFC), is used to study both the steady-state and dynamic performance of a power network, to relief power congestion and minimize losses at a very fast and accurate speed (13). It is the most used FACTS controller on power grids (7). Figure 1 shows schematic of the 330KV integrated power network of both existing transmission lines and those still under construction. Figure 1 shows current status of the proposed integrated power sector for both existing and the integrated 330KV network in the Nigeria power system.

Currently, the Nigeria Electricity Network comprises of 11,000KM Transmission lines (330 and 132KV), 24,000KM of sub-transmission lines (33KV), 19,000KM of distribution lines (11KV) and 22,500 substations (15).

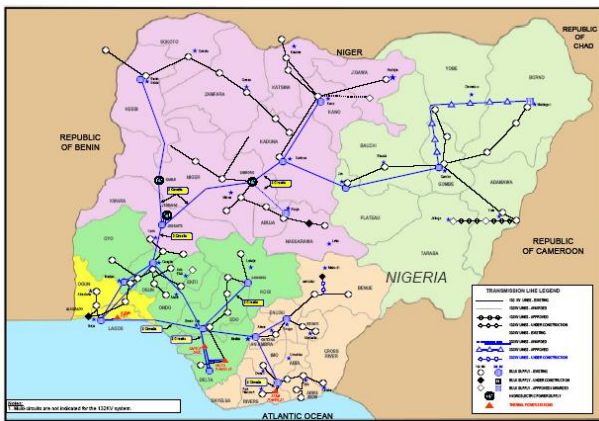


Fig.1 Schematic of the proposed 330kV integrated transmission network.

The Nigerian Power Generation sector can be detailed into the following sub-sectors: Existing Federal Government of Nigeria (FGN) Power Generation facilities, Independent Power Projects and National Integrated Power Projects. The independent power projects (IPP) are the non-funded federal government investment in the Nigerian power industry. They include the AES (Lagos State), Shell-Afam (Rivers State), Agip-Okpai (Delta State), ASG-Ibom (Akwa-Ibom State), RSG-Trans Amadi (Rivers State), and RSG-Omoku (Rivers State). The National Integrated Power Projects (NIPP) is funded and owned by the three tiers of government. Upon completion, these stations will

be controlled and operated through operation and maintenance contracts before there is full privatization by the government. These stations include Calabar (Cross River), Egbema (Imo State), Ihorvbor (Edo State), Gbaran (Bayelsa state), Sapele (Delta State), Omoku (Rivers State), Alaoji (Abia State), Olorunshogo-Phase 2 (Ogun State), Omotosho Phase 2 (Ondo State) and Geregu-Phase 2 (Kogi State). Table 1 give a basic description of Nigeria 330kV proposed integrated 330kV transmission Line network.

Table 1: Basic Description of Nigeria 330kV Integrated Proposed 330KV Line

Capacity of 330/132kV (MVA)	10,894
Number of 330kV substation	28
Total number of 330kV circuits	62
Length of 330kV lines (KM)	9,454.8
Number of control centers	4
Number of transmission lines	65
Number of buses	57
Number of generating stations	17

Table 2 shows both completed power generating and existing stations currently in use with their available and installed capacities and those still under construction. Table 3 shows all the buses and their associated numbers used for the modeling for the study. The transmission line parameter for the proposed 330KV integrated network is shown in appendix A.

Table 2: Generating Stations That Are Currently in Operation in Nigeria

S/N	Station	State	Turbine	Installed Capacity	Available Capacity
1	Kainji	Niger	Hydro	760	259
2	Jebba	Niger	Hydro	504	402
3	Shiroro	Niger	Hydro	600	408
4	Egbin	Lagos	Steam	1320	900
5*	Trans-Amadi	Rivers	Gas	100	7.3
6*	A.E.S (Egbin)	Lagos	Gas	250	233.8
7	Sapele	Delta	Gas	1020	170
8*	Ibom	Akwa-Ibom	Gas	155	25.3
9	Okpai	Delta	Gas	900	223
10	Afam I-V	Rivers	Gas	726	60
11*	Afam VI (Shell)	Rivers	Gas	650	550
12	Delta	Delta	Gas	912	281
13	Geregu	Kogi	Gas	414	120
14*	Omoku	Rivers	Gas	150	28
15*	Omotosho	Ondo	Gas	304	88.3
16*	Olorunshogo phase I	Ogun	Gas	100	54.3
17*	Olorunshogo phase II	Ogun	Gas	200	114.5
18*	Okpai (Agip)	delta	Gas	480	480
19**	Calabar	Cross River	Gas	563	Nil
**20	Ihorvbor	Edo	Gas	451	Nil
**21	Sapele	Delta	Gas	451	Nil
**22	Gbaran	Bayelsa	Gas	225	Nil
**23	Alaoji	Abia	Hydro	961	Nil
**24	Egbema	Imo	Gas	338	Nil

Note: Generating stations marked\* are the completed and functional NIPP and IPP Stations already in the Grid while the ones marked \*\* are still under construction

Table 3: Buses For both Existing and Integrated 330kV Power Project

S/N	Buses	S/N	Buses	S/N	Buses
1	Shiroro	21	New haven south	41	Yola
2	Afam	22	Makurdi	42	Gwagwalada
3	Ikot-Ekpene	23	B-kebbi	43	Sakete
4	Port-Harcourt	24	Kainji	44	Ikot-Abasi
5	Aiyede	25	Oshogbo	45	Jalingo
6	Ikeja west	26	Onitsha	46	Kaduna
7	Papalanto	27	Benin north	47	Jebba GS
8	Aja	28	Omotosho	48	Kano
9	Egbin PS	29	Eyaen	49	Katampe
10	Ajaokuta	30	Calabar	50	Okpai
11	Benin	31	Alagbon	51	Jebba
12	Geregu	32	Damaturu	52	AES
13	Lokoja	33	Gombe		
14	Akangba	34	Maiduguri		
15	Sapele	35	Egbema		
16	Aladja	36	Omoku		
17	Delta PS	37	Owerri		
18	Alaoji	38	Erunkan		
19	Aliade	39	Ganmo		
20	New have	40	Jos		

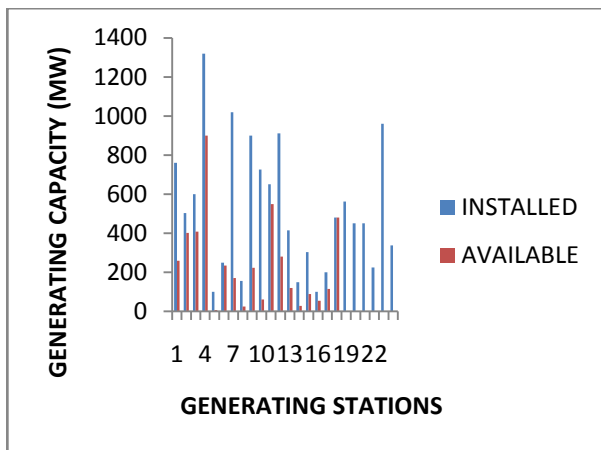


Fig.2. Installed and Available Capacities against the corresponding Generating Station.

This shows plot of the current status of the available and installed capacities of the various generating stations in the Nigeria 330KV integrated power network. This shows that the available capacity is a small compare to the installed capacity of each generating stations. Table 3 shows the bus numbers and names.

### III. METHODOLOGY

The Nigeria 330kV integrated power network consisting of 52 buses, 64 transmission lines, seventeen (17) generating stations and 4 control centers is used for this study. The transmission lines and bus data, generations and transformers data for this work were obtained from Power Holding Company of Nigeria (PHCN) from October 2008-November 2011 (15). Modified Newton-Raphson (N-R) power flow algorithm using UPFC is used in the MATLAB 7.5B environment (14). Upon incorporation of

this device into the N-R load flow algorithm, the following parameters were controlled; weak bus voltage values, phase angles, active and reactive power flow and transmission line losses in the network. This procedure is shown in equations 1-15.

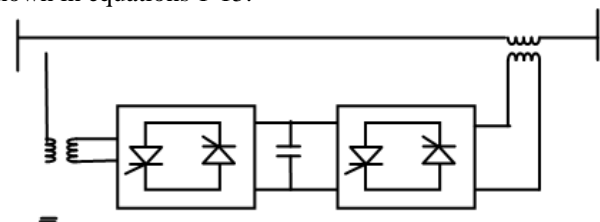


Fig.3. Schematic Representation of Unified Power Flow Controller (UPFC)

Where:

VSC1 = Shunt controller connected to the A.C transmission line through a shunt transformer

VSC2 = Series controller connected to the A.C transmission line through a series transformer

$V_{DC}$  = Common D.C link for the transfer of power when necessary

$\theta_{VP}$  = Phase voltage angle of the portion of transmission line where the controller is connected

$\theta_{SR}$  = Phase angle of the series controller

$\theta_{IP}$  = Phase current angle of the portion of transmission line where the controller is connected

$V_A$  = Bus voltage at node A

$V_B$  = Bus voltage at node B

#### 3.1. Active Power Control

The required active power by the series controller is drawn by the shunt controller from the AC network and then supplied by the common D.C link. The voltage magnitude of the series controller and its phase angles then provides voltage regulation and this is used to control power flow in a network. Table 4 illustrates these conditions.

Table 4: Active Power Control as a Function of  $\theta_{SR}$ ,  $\theta_{VP}$  and  $\theta_{IP}$

Condition	In phase	Result
$\theta_{SR}$	$\theta_{VP}$	It regulates no active power flow
	In quadrature	
$\theta_{SR}$	$\theta_{VP}$	It regulates active power flow and acts as phase shifter but draws no reactive power from the AC network
$\theta_{SR}$	$\theta_{IP}$	It controls active power flow and acts as a variable series impedance compensators

If however  $\theta_{SR}$  takes neither of these values (i.e. either not in phase or in quadrature with  $\theta_{VP}$  and  $\theta_{IP}$ ) It performs both the functions of a phase shifter and a series impedance compensators, thus controlling both active and reactive power flow in the power network.

### 3.2 Reactive Power Control Generation

Shunt controller generates/absorbs reactive power in order to provide independent voltage magnitude regulation at its point of connection with the A.C system.

The equations (1) and (2) are used to specify the control requirement using the Newton-Raphson (N-R) algorithm as stated in the modified UPFC power flow model using N-R algorithm.

Limit for the Shunt Controller

$$V_{SH(MIN)} \leq V_{SH} \leq V_{SH(MAX)}$$

Limit for the Series Controller

$$V_{SR(MIN)} \leq V_{SR} \leq V_{SR(MAX)}$$

## IV. MODIFIED UPFC POWER FLOW MODEL USING NEWTON-RAPHSON ALGORITHM

The UPFC consist of a shunt and series connected voltage source controllers represented respectively as  $V_{SH}$  and  $V_{SR}$  and an active power constraint linking these two voltage sources. Also it is assumed that the active power loss in the controllers is negligible. The two sources ensure active power exchange with the external A.C source. Expressing these statements mathematically, the shunt and series controllers' voltages as well as their power flow yields equations (1-15)

$$V_{SH} = |V_{SH}|(\cos\theta_{SH} - j\sin\theta_{SH}) \quad (1)$$

$$V_{SR} = |V_{SR}|(\cos\theta_{SR} - j\sin\theta_{SR}) \quad (2)$$

$$Re[-V_{SH}I_{SH}^* + -V_{SR}I_{SR}^*] = 0 \quad (3)$$

The impedance of the controllers are given as  $Z_{SH}$  and  $Z_{SR}$  respectively.

Based on the equivalent circuit of figure 1.0, the active and reactive power obtained at the two nodes when incorporated into the Newton-Raphson load flow algorithm is given in equations (4-6)

At Node A

$$P_A = |V_A|^2 G_{AA} + |V_A||V_B|[G_{AB}(\cos(\theta_A - \theta_B)) + (B_{AB}\sin(\theta_A - \theta_B)) + |V_A||V_{SH}][G_{AB}\cos(\theta_A - \theta_{SH}) + (B_{AB}\sin(\theta_A - \theta_{SH}))] + |V_A||V_{SR}][G_{A0}\cos(\theta_A - \theta_{SR}) + (B_{A0}\sin(\theta_A - \theta_{SR}))] \quad (4)$$

$$Q_A = -|V_A|^2 B_{AA} + |V_A||V_B|[G_{AB}(\sin(\theta_A - \theta_B)) - (B_{AB}\cos(\theta_A - \theta_B)) + |V_A||V_{SH}][G_{AB}\sin(\theta_A - \theta_{SH}) - (B_{AB}\cos(\theta_A - \theta_{SH}))] + |V_A||V_{SR}][G_{A0}\sin(\theta_A - \theta_{SR}) - (B_{A0}\cos(\theta_A - \theta_{SR}))] \quad (5)$$

At Node B

$$P_B = |V_B|^2 G_{BB} + |V_A||V_B|[G_{AB}(\cos(\theta_B - \theta_A)) + (B_{AB}\sin(\theta_B - \theta_A)) + |V_A||V_{SH}][G_{BB}\cos(\theta_B - \theta_{SH}) + (B_{BB}\sin(\theta_B - \theta_{SH}))] \quad (6)$$

$$Q_B = -|V_B|^2 B_{BB} + |V_A||V_B|[G_{AB}(\sin(\theta_B - \theta_A)) - (B_{AB}\cos(\theta_B - \theta_A)) + |V_B||V_{SH}][G_{AB}\sin(\theta_B - \theta_{SH}) - (B_{BB}\cos(\theta_B - \theta_{SH}))] \quad (7)$$

The complex power equation derived for the active and reactive power for both connectors shown below in equations (8, 9 and 12).

For The Series Converter

$$S_{SR} = P_{SR} + jQ_{SR} = V_{SR}I_B^* - V_{SR}I_B^* \quad (8)$$

$$S_{SR} = V_{SR}[Y_{AB}V_A^* + Y_{BB}^*V_B^* + Y_{BB}V_{SR}^*] \quad (9)$$

$$P_{SR} = |V_{SR}|^2 G_{BB} + |V_A||V_{SR}][G_{AB}(\cos(\theta_{SR} - \theta_A)) + (B_{AB}\sin(\theta_{SR} - \theta_A)) + |V_B||V_{SH}][G_{BB}\cos(\theta_{SR} - \theta_B) - (B_{BB}\sin(\theta_{SR} - \theta_B))] \quad (10)$$

$$Q_{SR} = |V_{SR}|^2 B_{BB} + |V_A||V_{SR}][G_{AB}(\sin(\theta_{SR} - \theta_A)) + (B_{AB}\cos(\theta_{SR} - \theta_A)) + |V_B||V_{SH}][G_{BB}\sin(\theta_{SR} - \theta_B) - (B_{BB}\cos(\theta_{SR}\theta_B))] \quad (11)$$

For The Shunt Converter

$$S_{SH} = P_{SH} + jQ_{SH} = V_{SH}I_{SH}^* = V_{SH}Y_{SH}^*[V_{SH}^* - V_A^*] \quad (12)$$

$$P_{SH} = -|V_{SH}|^2 G_{A0} + |V_A||V_{SH}][G_{A0}(\cos(\theta_{SH} - \theta_A)) + (B_{A0}\sin(\theta_{SH} - \theta_A)) \quad (13)$$

$$Q_{SH} = |V_{SH}|^2 B_{A0} + |V_A||V_{SH}][G_{A0}(\sin(\theta_{SH} - \theta_A)) - (B_{A0}\cos(\theta_{SH} - \theta_A)) \quad (14)$$

$$\begin{bmatrix} \Delta P_A \\ \Delta P_B \\ \Delta Q_A \\ \Delta Q_B \\ \Delta P_{AB} \\ \Delta Q_{AB} \\ \Delta P_{mm} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_A}{\partial \theta_A} & \frac{\partial P_A}{\partial \theta_B} & \frac{\partial P_A}{\partial |V_{SR}|} & \frac{\partial P_A}{\partial V_B} & \frac{\partial P_A}{\partial |V_{SH}|} & \frac{\partial P_A}{\partial \theta_{SR}} \\ \frac{\partial P_B}{\partial \theta_A} & \frac{\partial P_B}{\partial \theta_B} & \frac{\partial P_B}{\partial |V_{SR}|} & \frac{\partial P_B}{\partial V_B} & \frac{\partial P_B}{\partial |V_{SH}|} & \frac{\partial P_B}{\partial \theta_{SR}} \\ \frac{\partial Q_A}{\partial \theta_A} & \frac{\partial Q_A}{\partial \theta_B} & \frac{\partial Q_A}{\partial |V_{SR}|} & \frac{\partial Q_A}{\partial V_B} & \frac{\partial Q_A}{\partial |V_{SH}|} & \frac{\partial Q_A}{\partial \theta_{SR}} \\ \frac{\partial Q_B}{\partial \theta_A} & \frac{\partial Q_B}{\partial \theta_B} & \frac{\partial Q_B}{\partial |V_{SR}|} & \frac{\partial Q_B}{\partial V_B} & \frac{\partial Q_B}{\partial |V_{SH}|} & \frac{\partial Q_B}{\partial \theta_{SR}} \\ \frac{\partial P_{AB}}{\partial \theta_A} & \frac{\partial P_{AB}}{\partial \theta_B} & \frac{\partial P_{AB}}{\partial |V_{SR}|} & \frac{\partial P_{AB}}{\partial V_B} & \frac{\partial P_{AB}}{\partial |V_{SH}|} & \frac{\partial P_{AB}}{\partial \theta_{SR}} \\ \frac{\partial Q_{AB}}{\partial \theta_A} & \frac{\partial Q_{AB}}{\partial \theta_B} & \frac{\partial Q_{AB}}{\partial |V_{SR}|} & \frac{\partial Q_{AB}}{\partial V_B} & \frac{\partial Q_{AB}}{\partial |V_{SH}|} & \frac{\partial Q_{AB}}{\partial \theta_{SR}} \\ \frac{\partial P_{mm}}{\partial \theta_A} & \frac{\partial P_{mm}}{\partial \theta_B} & \frac{\partial P_{mm}}{\partial |V_{SR}|} & \frac{\partial P_{mm}}{\partial V_B} & \frac{\partial P_{mm}}{\partial |V_{SH}|} & \frac{\partial P_{mm}}{\partial \theta_{SR}} \end{bmatrix} \begin{bmatrix} \Delta \theta_A \\ \Delta \theta_B \\ \Delta |V_{SR}| \\ \Delta V_B \\ \Delta \theta_{SH} \\ \Delta |V_{SH}| \\ \Delta \theta_{SR} \end{bmatrix} \quad (15)$$

$$\frac{\partial Q_A}{\partial |V_{SR}|}, \frac{\partial Q_A}{\partial |V_{SR}|}, \frac{\partial Q_B}{\partial |V_{SR}|}, \frac{\partial P_{AB}}{\partial |V_{SR}|}, \frac{\partial Q_{AB}}{\partial |V_{SR}|}, \frac{\partial P_B}{\partial \theta_{SR}}, \frac{\partial Q_B}{\partial \theta_{SR}}, \frac{\partial Q_{AB}}{\partial \theta_{SR}},$$

and  $P_{mm}$  is power mismatch.

$$\Delta P_m = P_m^{reg} - P_m^{cal} \quad (16)$$

#### 4.1. Modified UPFC Power Flow Model Using Newton-Raphson Algorithm

Step 1: Enter system data

Step 2: Specify the mode of operation of the UPFC (whether in shunt or series mode)

Step 3: Test bus and specify bus type

Step 4: Set tolerance limits

Step 5: Form y-bus matrix equation

Step 6: Compute active and reactive power in the terminals where UPFC is connected using equations 4-6

Step 7: Compute active and reactive power of both series and shunt devices of the UPFC using equation 7-14.

Step 8: Evaluate the modified jacobian matrix and solve the linearized equation using equation 15

Step 9: Compute power mismatch using equation 16

Step 10: Update nodal voltage

## V. RESULTS

A Matlab program incorporating UPFC in the N-R power flow algorithm was developed to control power flow (active and reactive) as well as voltage magnitudes profile and phase angles of the device in the 330KV integrated transmission line network. Table 5 gives the results obtained for the branch power loss summary and flows, while table 5.0 shows the improved bus voltages values on location of the devices on Jos, Erunkan, New Haven, Makurdi, Damaturu, Gombe and Maiduguri buses of the network.

Table 5: Buses Voltages and Phase Angles For The Integrated 330kv Power System

Bus number	Bus name	Voltage	Angle (Degrees)
1	Shiroro	1.041	-23.12
2	Afam	1.038	-18.23
3	Ikot-Ekpene	1.042	-26.02
4	Port-Harcourt	1.023	-19.24
5	Aiyede	1.038	-12.42

6	Ikeja west	1.002	-33.41
7	Papalanto	1.043	-21.23
8	Aja	1.023	-13.22
9	Egbin PS	1.04	-18.18
10	Ajaokuta	0.986	-08.25
11	Benin	1.032	-12.45
12	Geregu	1.043	-16.23
13	Lokoja	1.022	-11.21
14	Akangba	1.021	21.05
15	Sapele	1.029	-15.11
16	Aladja	1.001	-23.24
17	Delta PS	1.045	-13.26
18	Alaoji	1.034	-12.43
19	Aliade	1.037	-18.23
20	New Haven	1.052	-34.48
21	New Haven South	0.962	-32.41
22	Makurdi	0.997	-15.26
23	B-kebbi	0.985	17.12
24	Kainji	1.012	-21.32
25	Oshogbo	1.044	-15.26
26	Onitsha	1.021	-19.32
27	Benin north	1.042	-14.24
28	Omotosho	1.051	-15.23
29	Eyaen	1.023	-16.24
30	Calabar	1.035	12.23
31	Alagbon	0.995	-36.21
32	Damaturu	0.981	-14.49
33	Gombe	0.992	-22.15
34	Maiduguri	0.964	-8.03
35	Egbema	1.032	-23.21
36	Omoku	1.045	-31.18
37	Owerri	1.023	-9.21
38	Erunkan	0.962	-34.26
39	Ganmo	0.983	-12.12
40	Jos	0.997	-13.14
41	Yola	1.021	-16.26
42	Gwagwalada	0.998	-24.12
43	Sakete	0.983	-38.09
44	Ikot-Abasi	1.024	-23.17
45	Jalingo	0.961	-24.15
46	Kaduna	0.992	-18.31
47	Jebba GS	1.023	-23.31
48	Kano	0.994	-29.35
49	Katampe	1.001	-18.23
50	Okpai	1.034	-32.41
51	Jebba	1.045	-17.37
52	AES	1.023	-32.24

Figure 4 shows a plot of the improved bus voltage values on incorporation of UPFC in the network, while

table 6.0 make comparison of the integrated network with and without FACTS (UPFC) devices. Both Power savings and transmission loss reduction is shown also.

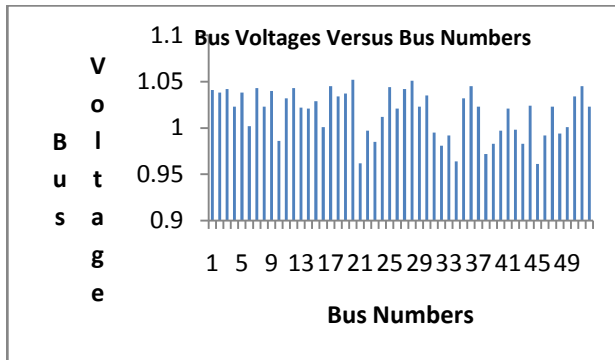


Fig.4

Table 6: gives a summary of the total power losses with and without UPFC Devices.

	Total Transmission Line Losses Without any FACTS Device (13)	Total Transmission Line Losses With UPFC Device	Power Savings by UPFC
Active Power Losses	53.40MW	14.60MW	38.80MW
Reactive Power Losses	93.300Mvar	21.50Mvar	71.80MVar

Branch Losses Summary with Placement of UPFC using the Modified N-R Algorithm

Connected Bus		Line Flows With FACTS Devices (UPFC)				Line Loss With FACTS Devices (UPFC)	
From	To	Sending End		Receiving End		Losses	
		$P_{send}(pu)$	$Q_{send}(pu)$	$P_{received}(pu)$	$Q_{received}(pu)$	Real power loss (pu)	Reactive power loss (pu)
49	1	-0.1779	-0.0737	0.1780	0.0742	0.0001	0.0004
14	6	-0.1937	-0.1200	0.1938	0.1201	0.0001	0.0001
2	18	-0.0556	-0.0383	0.0556	0.0384	0.0000	0.0001
2	3	0.0038	0.0017	-0.0039	-0.0018	-0.0001	-0.0001
2	4	-0.0063	0.0003	0.0064	-0.0003	0.0001	0.0000
16	17	0.0512	-0.0566	-0.0516	0.0563	-0.0004	-0.0003
5	25	-0.1621	-0.1012	0.1625	0.1012	0.0004	0.0000
5	6	-0.0186	-0.0119	0.0186	0.0121	0.0000	0.0002
5	7	-0.0283	-0.0182	0.0285	0.0183	0.0002	0.0001
8	9	-0.0999	-0.0619	0.0997	0.0624	-0.0002	0.0005
8	31	-0.0186	-0.0119	0.0185	0.0121	-0.0001	0.0002
10	11	-0.0215	-0.0134	0.0211	0.0136	-0.0004	0.0002
10	12	0.0239	0.0162	-0.0236	-0.0162	0.0003	0.0000
10	13	-0.0289	-0.0180	0.0289	0.0182	0.0000	0.0002
16	15	-0.1315	0.0163	0.1316	-0.0161	0.0001	0.0002
18	26	-0.2461	-0.1781	0.2463	0.1781	0.0002	0.0000
18	3	0.0457	0.0294	-0.0459	-0.0291	-0.0002	0.0003
18	37	-0.0153	-0.0116	0.0152	0.0117	-0.0001	0.0001
19	21	-0.0026	-0.0050	0.0029	0.0051	0.0003	-0.0001
19	22	0.0031	0.0046	-0.0026	-0.0045	0.0005	-0.0001
23	24	-0.0885	-0.0543	0.0884	0.0548	-0.0001	0.0005
11	6	0.0159	0.0114	-0.0158	-0.0113	0.0001	0.0001
11	15	-0.0257	0.0595	0.0258	-0.0593	0.0001	0.0002
11	17	-0.0611	0.0549	0.0612	-0.0546	0.0001	0.0003
11	25	0.0108	0.0843	-0.0109	0.0843	-0.0001	0.0001
11	26	0.0250	0.0184	-0.0250	-0.0184	0.0000	0.0000
11	27	0.0389	0.0294	-0.0389	0.0294	0.0000	0.0000
11	9	0.0921	0.0779	-0.0925	-0.0779	-0.0004	0.0000
11	28	0.0476	0.0343	-0.0475	-0.0341	0.0001	0.0002
27	29	0.0308	0.0192	-0.0308	-0.0190	0.0000	0.0002
30	3	0.0283	0.0182	-0.0286	-0.0182	-0.0003	0.0000
32	33	0.0364	0.0240	-0.0364	-0.0239	0.0000	0.0001
32	34	0.0485	0.0349	-0.0485	-0.0347	0.0000	0.0002
35	37	0.0181	0.0132	-0.0179	-0.0135	0.0002	-0.0003
35	36	0.0112	0.0088	-0.0111	-0.0089	0.0001	-0.0001

9	6	0.3148	0.1549	-0.3145	-0.1544	0.0003	0.0004
9	38	0.2605	0.1596	-0.2601	-0.1594	0.0004	0.0002
38	6	-0.2612	0.1595	0.2616	-0.1591	0.0004	0.0004
39	25	0.2668	-0.4061	-0.2666	0.4063	0.0002	0.0002
39	51	-0.2678	0.4009	0.2681	-0.4010	0.0003	0.0001
33	40	0.0674	0.1201	-0.0673	-0.1203	0.0001	-0.0002
33	41	0.0790	-0.1002	-0.0792	0.1006	0.0002	0.0004
42	49	-0.0115	-0.0072	0.0118	0.0075	0.0000	0.0003
42	13	0.0289	0.0181	-0.0289	-0.0182	0.0000	-0.0001
42	1	-0.0175	-0.0109	0.0177	0.0110	0.0002	0.0001
6	25	-0.0180	0.0254	0.0181	-0.0249	0.0000	0.0005
6	28	-0.0474	-0.0340	0.0475	0.0342	0.0001	0.0002
6	7	0.0285	0.0184	-0.0283	-0.0182	0.0002	0.0003
6	43	0.0364	0.0202	-0.0365	-0.0205	-0.0001	-0.0003
44	3	0.0461	0.0332	-0.0464	-0.0335	0.0003	0.0003
3	21	0.0496	0.0310	-0.0494	-0.0317	0.0003	0.0007
45	41	0.0881	-0.1138	-0.0884	0.1149	0.0003	0.0011
51	25	0.2638	-0.3355	-0.2594	0.3448	0.0044	0.0093
47	51	-0.1669	0.6067	0.1674	-0.6055	0.0005	0.0012
51	24	-0.4846	0.0706	0.4877	-0.0702	0.0031	0.0004
51	1	-0.1733	-0.2643	0.1738	0.2646	0.0005	0.0003
40	46	-0.0029	-0.0054	0.0032	-0.0056	0.0003	0.0002
40	22	-0.0027	-0.0050	0.0026	-0.0054	-0.0001	0.0004
46	1	-0.1509	-0.1180	0.1511	0.1189	0.0020	0.0009
46	48	0.1252	-0.0982	-0.1246	0.0985	0.0006	0.0003
20	26	-0.13468	-0.0859	0.1351	0.0862	0.0004	0.0003
20	21	0.0468	-0.0260	-0.0466	0.0264	0.0002	0.0004
50	26	0.4222	0.0773	-0.4219	-0.0769	0.0003	0.0004
26	37	0.0152	0.0117	-0.0152	-0.0119	0.0001	0.0002
9	52	0.4222	0.0773	-0.4219	-0.0769	0.0003	0.0004
<b>Total Power Loss</b>						<b>0.0164</b>	<b>0.0228</b>

## VI. DISCUSSION

From the results obtained, it is shown that when the Unified Power Flow Controller (UPFC) were connected to the weak buses as identified by (13), there was improvement in their voltage profile and were all within the allowable tolerable voltage limit of 0.95pu; (313.50KV) - 1.05pu; (346.50KV). Reduction in transmission line losses (both active and reactive power) was also observed. The total active and reactive power losses without UPFC device is (53.4MW+93.300Mvar) (13). However, with the incorporation of UPFC into the weak buses: (New Haven 0.921pu, 303.93kv; Makurdi 0.831pu, 274.23kV; Damaturu 0.9341pu 308.252kv; Gombe 0.941pu 310.53kV; Maiduguri 0.943pu 311.19kV; Jalingo 0.936pu 308.88kV; and Erunkan 0.932pu 307.56kV), the improved bus voltage values were as follows: (New Haven 0.962pu, 317.46kV; Makurdi 0.997pu, 329.01kV; Damaturu 0.981pu 323.73kV; Gombe 0.992pu 327.36kV; Maiduguri 0.964pu 327.36kV; Jalingo 0.961pu 317.13kV; and Erunkan 0.972pu 320.76kV). Furthermore, UPFC saved (38.8MW+71.50Mvar). This implies a 72.66% real power loss reduction and 76.6% reactive power loss savings.

## VII. CONCLUSION/RECOMMENDATION

The Transmission line power losses (both active and reactive) and the weak bus voltages of the Nigeria 330KV integrated network were improved using UPFC devices. This was achieved by incorporating UPFC into the N-R load flow algorithm. It was also shown that with the incorporation of UPFC into the network, the problems of obtaining right of ways for building new transmission lines, cost of building more generating stations among others will be greatly reduced. UPFC is not yet incorporated in the Nigeria 330KV network. It is therefore recommended that, UPFC device be applied to the 330KV integrated power transmission grid. This will improve on the power quality and overall system stability and reliability.

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## APPENDIX A

S/N	Transmission Lines Between Buses		Length (Km)	Circuit Type	Line Impedance (PU)		
	From	To			Z	B	Admittance
1	Katampe	Shiroro	144	Double	0.0029 + j 0.0205	0.308	8-j4.808
2	Afam GS	Alaoji	25	Double	0.009 + j0.007	0.104	9.615-j16.129
3	Afam GS	Ikot-Ekpenne	90	Double	0.0155 + j0.0172	0.104	9.615-j16.129
4	Afam GS	Port-Harcourt	45	Double	0.006 + j0.007	0.104	9.615-j16.129
5	Aiyede	Oshogbo	115	Single	0.0291 + j0.0349	0.437	3.205-j2.288
6	Aiyede	Ikeja west	137	Single	0.0341 + j0.0416	0.521	2.695-j19.919
7	Aiyede	Papalanto	60	Single	0.0291 + j0.0349	0.437	3.205-j2.288
8	Aja	Egbin PS	14	Double	0.0155 + j0.0172	0.257	16.129-j9.615
9	Aja	Alagbon	26	Double	0.006+j0.007	0.257	6.494-j3.891
10	Ajaokuta	Benin	195	Single	0.0126+j0.0139	0.208	1.429-j12.180
11	Ajaokuta	Geregu	5	Double	0.0155+j0.0172	0.257	6.494-j3.891
12	Ajaokuta	Lokoja	38	Double	0.0155+j0.0172	0.257	8-j4.808
13	Akangba	Ikeja west	18	Single	0.0155+j0.0172	0.065	32+j19.32

14	Aladja	Sapele	63	Single	0.016+j0.019	0.239	5.284-j51.913
15	Alaoji	Owerri	60	Double	0.006+j0.007	0.308	6.494-j3.891
16	Aladja	Delta PS	32	Single	0.016+j0.019	0.239	5.848-j4.184
17	Alaoji	Onitsha	138	Single	0.035+j0.0419	0.524	2.754-j33.553
18	Alaoji	Ikot-Ekpene	38	Double	0.0155+j0.0172	0.257	6.494-j3.891
19	Aliade	New Haven South	150	Double	0.006+j0.007	0.308	16.129-j9.615
20	Aliade	Makurdi	50	Double	0.0205+j0.0246	0.308	4.545-j3.247
21	B-kebbi	Kainji	310	Single	0.0786+j0.0942	1.178	1.235-j0.478
22	Benin	Ikeja west	280	Double	0.0705+j0.0779	1.162	1.637-j12.626
23	Benin	Sapele	50	Double	0.0126+j0.0139	0.208	3.194-j17.555
24	Benin	Delta PS	107	Single	0.016+j0.019	0.239	5.848-j4.184
25	Benin	Oshogbo	251	Single	0.0636+j0.0763	0.954	1.508-j12.932
26	Benin	Onitsha	137	Single	0.0347+j0.0416	0.521	2.8-j33.771
27	Benin	Benin north	20	Single	0.049+j0.056	0.208	8-j4.808
28	Benin	Egbin PS	218	Single	0.016+j0.019	0.239	5.848-j4.184
29	Benin	Omotosho	120	Single	0.016+j0.019	0.365	3.846-j2.739
30	Benin North	Eyaen	5	Double	0.0126+j0.0139	0.208	8-j4.808
31	Calabar	Ikot-Ekpene	72	Double	0.0126+j0.0139	0.208	6.494-j3.891
32	Damaturu	Gombe	135	Single	0.0786+j0.0942	1.178	1.19-j0.848
33	Damaturu	Maiduguri	140	Single	0.0786+j0.0942	1.178	1.19-j0.848
34	Egbema	Omoku	30	Double	0.0126+j0.0139	0.208	8-j4.808
35	Egbema	Owerri	30	Double	0.0126+j0.0139	0.208	8-j4.808
36	Egbin PS	Ikeja west	62	Single	0.0155+j0.0172	0.257	7.308+j57.14
37	Egbin PS	Erunkan	30	Single	0.016+j0.019	0.239	5.848-j4.184
38	Erunkan	Ikeja west	32	Single	0.016+j0.019	0.239	5.848-j4.184
39	Ganmo	Oshogbo	87	Single	0.016+j0.019	0.239	5.848-j4.184
40	Ganmo	Jebba	70	Single	0.0341+j0.0416	0.239	2.615-j1.919
41	Gombe	Jos	264	Single	0.067+j0.081	1.01	1.923-j16.456
42	Gombe	Yola	217	Single	0.0245+j0.0292	1.01	1.391-j2.999
43	Gwagwalada	Lokoja	140	Double	0.0156+j0.0172	0.257	6.494-j3.891
44	Gwagwalada	Shiroro	114	Double	0.0155+j0.0172	0.257	6.494-j3.891
45	Ikeja west	Oshogbo	252	Single	0.0341+j0.0416	0.521	2.695-j1.919
46	Ikeja west	Omotosho	160	Single	0.024+j0.0292	0.365	2.695-j1.919
47	Ikeja west	Papalanto	30	Single	0.0398+0.0477	0.597	2.695-j1.919
48	Ikeja west	Sakete	70	Single	0.0398+j0.0477	0.521	2.695-j1.919
49	Ikot-Abasi	Ikot Ekpene	75	Double	0.0155+j0.0172	0.257	6.494-j3.891
50	Jebba	Oshogbo	157	Double	0.0398+j0.0477	0.597	0.246-j3.092
51	Jalingo	Yola	132	Single	0.0126+j0.0139	0.208	8-j4.808
52	Jebba	Jebba GS	8	Double	0.002+j0.0022	0.033	3.174-j1.594
53	Jebba	Kainji	81	Double	0.0205+j0.0246	0.308	3.607-j40.328
54	Jebba	Shiroro	244	Single	0.062+j0.0702	0.927	1.559-j13.297
55	Jos	Kaduna	197	Single	0.049+j0.0599	0.927	1.873-J1.337
56	Jos	Makurdi	230	Double	0.002+j0.0022	0.308	4.545-J3.247
57	Kaduna	Kano	230	Single	0.058+j0.0699	0.874	1.657-j14.12
58	Kaduna	Shiroro	96	Single	0.0249+j0.0292	0.364	3.935-j3.379
59	Katampe	Shiroro	144	Double	0.0205+j0.0246	0.308	8-j4.808
60	New Haven	Onitsha	96	Single	0.024+j0.0292	0.365	3.935-j33.79
61	New Haven	New Haven South	5	Double	0.0205+j0.0246	0.308	4.545-J3.247
62	Okpai	Onitsha	80	Double	0.006+j0.007	0.104	16.13-J9.615
63	Onitsha	Owerri	137	Double	0.006+j0.007	0.104	16.13-J9.615
64	Ikot Ekpene	New Haven South	143	Double	0.0205+j0.0246	0.257	6.494-j3.891