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Power Flow Analysis of Longitudinal Electrical Power System Incorporating Generalized Unified Power Flow Controller (GUPFC)

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Abstract: Generalized Unified Power Flow Controller (GUPFC) is a voltage source converter (VSC) based Flexible AC Transmission System (FACTS) controller for shunt and series compensation among the multiline transmission systems of a substation. This research presents the result of the power flow analysis of Nigerian power system incorporating GUPFC modeled in rectangular form to control active and reactive power in transmission lines and reduce the system active power loss without violation of the bus voltage profile. The steady state modeling of GUPFC combined with power system network equations were solved using Newton-Raphson solution method. A MATLAB based program for steady state power flow analysis was developed to solve the resulting equation using Newton-Raphson method. The result of the power flow analysis of Nigerian transmission system indicates disproportionate power flow and high power losses. Application of GUPFC resulted in enhancing active power flow control, reduced system losses and improvement of the system voltage profile.

Keywords: GUPFC Newton-Raphson, FACTS, MATLAB

1. Introduction

In a developing economy like Nigeria demand for electricity is increasing on a daily basis, though the number of generation stations cannot be increased correspondingly. But the generated power must be effectively transmitted as demanded with minimal losses. In interconnected power system networks, it is of great importance to effectively utilize the existing power system infrastructures. This is due to the high cost of construction and other social constrains in constructing new ones. This offers very good opportunities for the application of Flexible Alternating Current Transmission System (FACTS) devices. FACTS devices can enhance transmission system control and increase line loading in some cases up to thermal limits without compromising reliability.

These devices provide a better adaptation to varying operational conditions and improve the usage of existing installation. With growing line length, the opportunity for FACTS devices get more important [1] They can be used as alternative to reduce the flow of heavily loaded lines, resulting in increased line loadability, low system losses, improved network stability and reduced cost of production. The influence of FACTS is achieved through switched or controlled shunt compensation, series compensation, or phase shifting control. The device works electrically as fast current, voltage or impedance controller and allow short reaction times.

GUPFC is one of the recently developed FACTS devices obtained by a combination of series and shunt configuration of voltage source converter (VSC), and is able to extend the concept of power flow control beyond what is achievable by the earlier FACTS devices [2, 3]. Various application into mesh transmission system has been used to demonstrate its capability, however, this device has not been used to solve inherent technical problems of longitudinal power system such as Nigerian transmission system [4, 5]. In a deregulated power system like Nigeria, maximizing profit is the principal aim of investor, but this may not be achievable without proper investment into the important and technical areas of the power system which the GUPFC can be installed. Thus, GUPFC avails the opportunity of proper investment into the system.

The aim of this research is the incorporation of GUPFC into Nigerian power system for power flow analysis, in order to enhance power flow, improved voltage profile and reduced system losses. This was carried out through rectangular modeling of GUPFC and power flow analysis without and with GUPFC incorporated, using bus voltage magnitude, active power flow and active power loss as performance matrices. The power flow analysis of Nigerian power system incorporating GUPFC was carried out with modification of an existing Newton-Raphson MATLAB code to accommodate GUPFC.

2. Methodology

Modeling GUPFC in rectangular form for power flow analysis:- The simplest GUPFC consist of three converters, one connected in shunt and the other two in series with the transmission lines in a back to back configuration, sharing a common dc link. The shunt converter is primarily used to provide real power demands of series converters via common d.c link terminal from the a.c power system. The shunt converter can also generate or absorb reactive power at it's a.c terminal which is independent of the active power transfer to (from) the d.c terminal. Therefore, with proper control it can also fulfill the function of an independent advanced static VAR compensator, providing reactive power compensation and thus executing indirect voltage regulation at the controlled a.c bus. The series converters are used to generate voltage sources at fundamental frequency with variable amplitude and phase angles which are added to the a.c transmission lines in order to control the active and reactive power flow through the lines. Figure 1 shows typical three converters GUPFC [1, 2, 6, 7, 8].

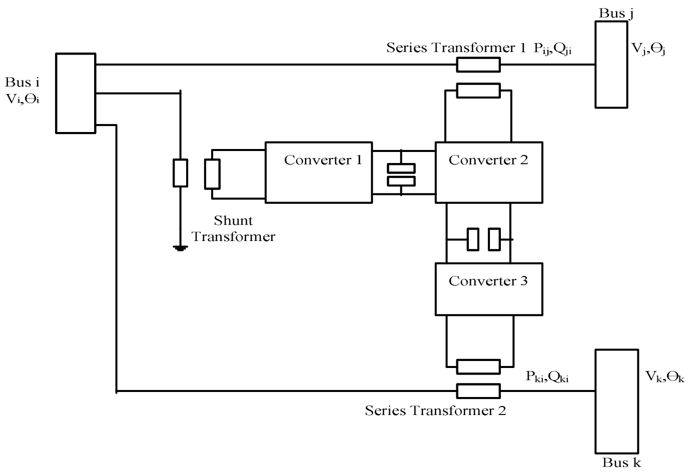

Figure 1. *Typical GUPFC with three voltage source converters.*

The injected and absorbed power by each voltage source converter is expressed in rectangular form, for it incorporation into Newton-Raphson algorithm for power flow analysis. Each network element is expressed in it real and imaginary form.

The injected power by shunt connected converter:

$$S_{sh} = V_{sh} Y_{sh} \tag{1}$$

The injected power by series converters

$$S_{ser} = V_{ser} Y = V_{ser} Y_{ser} \tag{2}$$

Where V_{sh} is the shunt converter voltage

Y_{sh} is the line impedance with shunt converter

V_{ser} is the series converter voltage

Y_{ser} is the line impedance with series converter

S_{sh} is the shunt injected power

S_{ser} is the series injected power

The shunt converter is connected to bus *i,* with bus *i* connected to bus *j* and *k.*

Therefore, the admittances are

$$Y_{ij} = g_{ij} + jb_{ij}, \tag{3}$$

$$Y_{ik} = g_{ik} + jb_{ik} \tag{4}$$

The active power injected by shunt converter is equal to the active power absorb by series converters when losses are neglected [2, 7].

$$P_{sh} = P_{ser1} + P_{ser2} \tag{5}$$

The power injected in each bus without GUPFC is

$$S_i = (P_i + jQ_i)^* \text{ at bus i} \tag{6}$$

$$S_{ij} = (P_{ij} + jQ_{ij})^* \text{ along line i-j} \tag{7}$$

$$S_{ik} = (P_{ik} + jQ_{ik})^* \text{ along line i-k} \tag{8}$$

The power flow along the transmission lines with GUPFC incorporated

At shunt bus

$$S_{sh} = -\left\{V_i (V_i Y_{sh} - V_{sh} Y_{sh})\right\} \tag{9}$$

The active and reactive power is obtained as:-

$$P_{sh} = \left\{(e_i^2 - f_i^2 - e_i e_{sh} + f_i f_{sh}) g_{sh} - (f_i e_i - e_i f_{sh} + f_i e_i - f_i e_{sh}) b_{sh}\right\} \tag{10}$$

$$Q_{sh} = -\left\{(e_i f_i - f_i e_{sh} + f_i e_i - f_{sh} e_i) g_{sh} - (f_i^2 - e_i^2 - f_i f_{sh} + e_i e_{sh}) b_{sh}\right\} \tag{11}$$

The power flow along transmission lines with GUPFC by series connected converters

$$S_{ij} = V_i^2 Y_{s1} - V_i V_j Y_{s1} + V_j V_{s1}^* Y_{s1}^* \tag{12}$$

The resulting active and reactive power flow from bus i to bus j is obtained as:-

$$P_{ij} = (e_i^2 - f_i^2 - 2e_i e_j + 2 f_i f_j + f_j f_{s1} + e_j e_{s1}) g_{s1} + (f_j e_{s1} - f_{s1} e_j - 2 f_i e_j - 2 e_i f_j) b_{s1} \tag{13}$$

$$-Q_{ij} = (e_i^2 - f_i^2 - 2e_i e_j + 2 f_i f_j + e_j e_{s1} + f_j f_{s1}) b_{s1} + (f_i e_j + e_i f_j + f_j e_{s1} - f_{s1} e_j) g_{s1} \tag{14}$$

$$S_{ik} = V_i^2 Y_{s2} - V_i V_k Y_{s2} + V_k V_{s2}^* Y_{s2}^* \tag{15}$$

The resulting active and reactive power flow from bus i to bus k is obtained as:-

$$P_{ik} = (e_i^2 - f_i^2 - 2e_i e_k + 2 f_i f_k + f_k f_{s2} + e_k e_{s2}) g_{s2} + (f_k e_{s2} - f_{s2} e_k - 2 f_i e_k - 2 e_i f_k) b_{s2} \tag{16}$$

$$-Q_{ik} = (e_i^2 - f_i^2 - 2e_i e_k + 2 f_i f_k + e_k e_{s2} + f_k f_{s2}) b_{s2} + (f_i e_k + e_i f_k + f_k e_{s2} - f_{s2} e_k) g_{s2} \tag{17}$$

The resulting Jacobian matrix from partial derivatives of the power system component model equations are:-

$$F(X) = J \Delta X \tag{18}$$

$$F(X) = \begin{bmatrix} \Delta P_j \\ \Delta P_k \\ \Delta Q_j \\ \Delta Q_k \\ \Delta V_i^2 \\ P_{sh} \\ Q_{sh} \end{bmatrix}, \quad \Delta X = \begin{bmatrix} \Delta e_k \\ \Delta e_j \\ \Delta e_{sh} \\ \Delta e_{s1} \\ \Delta e_{s2} \\ \Delta f_k \\ \Delta f_j \\ \Delta f_{sh} \\ \Delta f_{s1} \\ \Delta f_{s2} \end{bmatrix}$$

$$J = \begin{pmatrix}
\frac{\partial P_{jg}}{\partial e_k} & \frac{\partial P_{jg}}{\partial e_j} & \frac{\partial P_{jg}}{\partial e_{sh}} & \frac{\partial P_{jg}}{\partial e_{s1}} & \frac{\partial P_{jg}}{\partial e_{s2}} & \frac{\partial P_{jg}}{\partial f_k} & \frac{\partial P_{jg}}{\partial f_j} & \frac{\partial P_{jg}}{\partial f_{sh}} & \frac{\partial P_{jg}}{\partial f_{s1}} & \frac{\partial P_{jg}}{\partial f_{s2}} \\
\frac{\partial P_{kg}}{\partial e_k} & \frac{\partial P_{kg}}{\partial e_j} & \frac{\partial P_{kg}}{\partial e_{sh}} & \frac{\partial P_{kg}}{\partial e_{s1}} & \frac{\partial P_{kg}}{\partial e_{s2}} & \frac{\partial P_{kg}}{\partial f_k} & \frac{\partial P_{kg}}{\partial f_j} & \frac{\partial P_{kg}}{\partial f_{sh}} & \frac{\partial P_{kg}}{\partial f_{s1}} & \frac{\partial P_{kg}}{\partial f_{s2}} \\
\frac{\partial Q_{jg}}{\partial e_k} & \frac{\partial Q_{jg}}{\partial e_j} & \frac{\partial Q_{jg}}{\partial e_{sh}} & \frac{\partial Q_{jg}}{\partial e_{s1}} & \frac{\partial Q_{jg}}{\partial e_{s2}} & \frac{\partial Q_{jg}}{\partial f_k} & \frac{\partial Q_{jg}}{\partial f_j} & \frac{\partial Q_3}{\partial f_{sh}} & \frac{\partial Q_3}{\partial f_{s1}} & \frac{\partial Q_3}{\partial f_{s2}} \\
\frac{\partial Q_{kg}}{\partial e_k} & \frac{\partial Q_{kg}}{\partial e_j} & \frac{\partial Q_{kg}}{\partial e_{sh}} & \frac{\partial Q_{kg}}{\partial e_{s1}} & \frac{\partial Q_{kg}}{\partial e_{s2}} & \frac{\partial Q_{kg}}{\partial f_k} & \frac{\partial Q_{kg}}{\partial f_j} & \frac{\partial Q_{kg}}{\partial f_{sh}} & \frac{\partial Q_{kg}}{\partial f_{s1}} & \frac{\partial Q_{kg}}{\partial f_{s2}} \\
\frac{\partial V_i}{\partial e_k} & \frac{\partial V_i}{\partial e_j} & \frac{\partial V_i}{\partial e_{sh}} & \frac{\partial V_i}{\partial e_{s1}} & \frac{\partial V_i}{\partial e_{s2}} & \frac{\partial V_i}{\partial f_k} & \frac{\partial V_i}{\partial f_j} & \frac{\partial V_i}{\partial f_{sh}} & \frac{\partial V_i}{\partial f_{s1}} & \frac{\partial V_i}{\partial f_{s2}} \\
\frac{\partial P_{sh}}{\partial e_k} & \frac{\partial P_{sh}}{\partial e_j} & \frac{\partial P_{sh}}{\partial e_{sh}} & \frac{\partial P_{sh}}{\partial e_{s1}} & \frac{\partial P_{sh}}{\partial e_{s2}} & \frac{\partial P_{sh}}{\partial f_k} & \frac{\partial P_{sh}}{\partial f_j} & \frac{\partial P_{sh}}{\partial f_{sh}} & \frac{\partial P_{sh}}{\partial f_{s1}} & \frac{\partial P_{sh}}{\partial f_{s2}} \\
\frac{\partial Q_{sh}}{\partial e_k} & \frac{\partial Q_{sh}}{\partial e_j} & \frac{\partial Q_{sh}}{\partial e_{sh}} & \frac{\partial Q_{sh}}{\partial e_{s1}} & \frac{\partial Q_{sh}}{\partial e_{s2}} & \frac{\partial Q_{sh}}{\partial f_k} & \frac{\partial Q_{sh}}{\partial f_j} & \frac{\partial Q_{sh}}{\partial f_{sh}} & \frac{\partial Q_{sh}}{\partial f_{s1}} & \frac{\partial Q_{sh}}{\partial f_{s2}}
\end{pmatrix}$$

3. Result and Discussion

3.1. Implementation

A MATLAB program for power flow analysis was modified to accommodate steady state model of GUPFC for power flow analysis. This was used for power flow analysis of the system without and with GUPFC incorporated. The flow chart of the modified Newton-Raphson method is shown in figure 2.

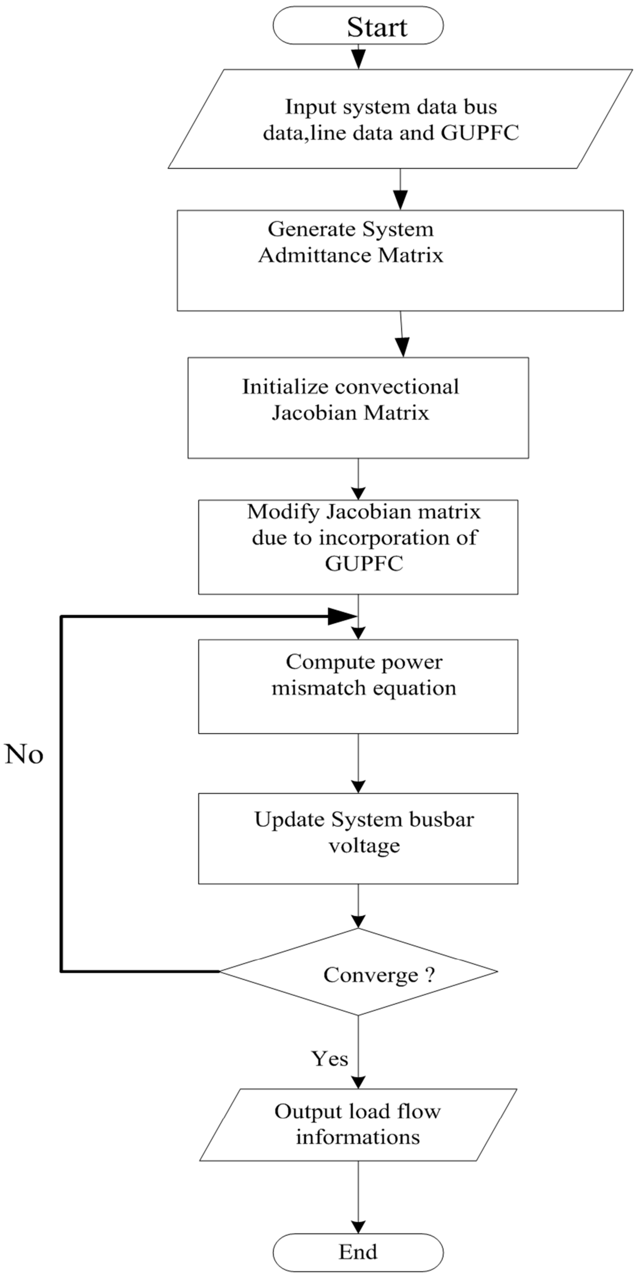

Figure 2. *Newton-Raphson Solution Flow chart with GUPFC incorporated.*

Shown in figure 3 is a Nigerian 330kV 28bus transmission system network, with nine generating stations, 28 load stations and 44 transmission lines. The system may be divided into three major sections, North, South-East and the South-West sections. The North is connected to the south through one triple circuit lines between Jebba and Osogbo while the west is linked to the east through one transmission line from Osogbo to Benin and one double circuit line from Ikeja to Benin [9, 4]. Both the line diagram and data used in this research were obtained from the National Control Centre of the Transmission Company of Nigeria, Osogbo, Nigeria [10].

The power flow analysis of Nigeria 330kV Transmission system was performed using modified Newton-Raphson method. The results of the power flow analysis as shown in Table 1 and 2 were obtained in five (5) iterations and tolerance of 3.26281e-13. The results of Table 1 indicate all the bus voltage magnitude to be within the acceptable voltage limits 10%, with the lowest voltage magnitude of 0.977p.u at bus 13 (Table 1). The results of the transmission line flow in Table 2 show the active and reactive power flow along the lines connecting different buses and the corresponding loss on each line. The lowest active power flow was along line connecting bus 8 to 6 which was 7.002MW, others with low active power flow are lines 8-10, and line 5-9 which have power flow of 29.795MW and 26.862MW respectively. The line with the highest loss was line connecting bus 2 and 8 with active power loss of 4.289MW.

Table 1. *Power flow result for 28bus Nigerian transmission system.*

Bus Number	Bus type	Voltage Mag.	Voltage Ang.
		p.u.	deg.
1	Swing	1.050	0.000
2	PV	1.050	11.840
3	PQ	1.045	-0.284
4	PQ	1.019	0.641
5	PQ	1.026	1.065
6	PQ	1.062	5.964
7	PQ	1.046	10.274
8	PQ	1.041	6.322
9	PQ	0.990	1.971
10	PQ	1.031	7.598
11	PV	1.050	10.228
12	PQ	1.038	9.568
13	PQ	0.977	2.442
14	PQ	0.994	3.766
15	PQ	1.065	13.608
16	PQ	0.994	3.685
17	PQ	1.050	13.292
18	PV	1.050	13.555
19	PQ	1.051	9.797
20	PQ	1.040	5.939
21	PV	1.050	16.460
22	PQ	1.010	1.968
23	PV	1.050	8.110
24	PV	1.050	7.870
25	PQ	1.049	13.631
26	PQ	1.029	6.032
27	PV	1.050	25.280
28	PV	1.050	3.274

Table 2. *Selected line flow for TCN 28bus system.*

Bus number		Line Flow			Line loss	
From bus	**To bus**	**MW**	**Mvar**	**MVA**	**MW**	**Mvar**
1	3	137.358	97.585	168.493	0.158	-5.315
1	3	137.358	97.585	168.493	0.158	-5.315
1	5	-93.269	143.716	171.328	0.694	-20.036
2	8	331.596	-23.729	332.444	4.289	-14.334
5	8	-117.976	-55.946	130.569	1.455	-106.591
5	8	-117.976	-55.946	130.569	1.455	-106.591
5	9	-26.862	67.744	72.875	0.508	-50.423
5	10	158.545	-29.122	161.198	2.414	-86.562
6	8	-7.002	-78.783	79.093	0.102	-83.933
6	8	-7.002	-78.783	79.093	0.102	-83.933
7	24	240.656	-65.062	249.296	1.385	-16.860
8	14	128.344	78.555	150.476	1.398	-45.279
8	10	-29.795	-34.939	45.918	0.111	-105.058
8	24	-203.704	-40.827	207.755	0.782	-15.690
8	24	-203.704	-40.827	207.755	0.782	-15.690
9	10	-303.170	-88.633	315.861	4.426	-12.667
10	17	-233.221	-33.103	235.558	3.120	-42.821
10	17	-233.221	-33.103	235.558	3.120	-42.821
10	17	-233.221	-33.103	235.558	3.120	-42.821
16	19	-130.600	-97.900	163.220	2.207	-107.433
19	20	121.593	-37.595	127.273	1.089	-80.201
19	25	-162.360	-3.260	162.393	1.459	-56.515
19	25	-162.360	-3.260	162.393	1.459	-56.515
20	22	111.430	-14.896	91.308	0.716	-90.715
20	22	111.430	-14.896	91.308	0.716	-90.715
20	23	-147.677	-36.151	152.038	0.776	-35.377
20	23	-147.677	-36.151	152.038	0.776	-35.377
Total					85.177	-2328.358

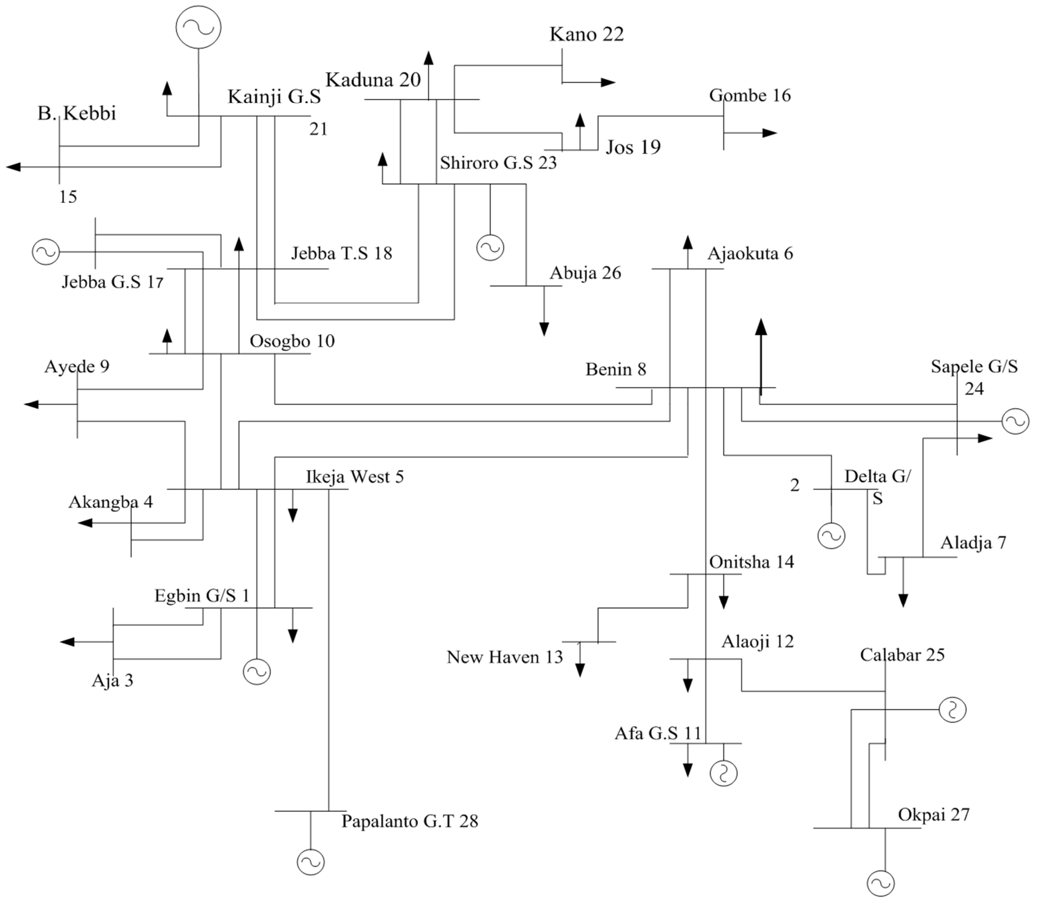

Figure 3. *Nigerian 330kV 28 Bus National Grid.*

3.2. The Incorporation of GUPFC into the 28Bus Nigerian Transmission System

GUPFC was incorporated into the 28bus Nigerian transmission system, test cases were conducted with GUPFC in the system and results are presented.

Test Case 1: The results of the power flow analysis of the system without the Incorporation of GUPFC (base case) have been presented in Tables 1 and 2.

Test case 2: The same as test case 1 except that the shunt of GUPFC was connected to bus 10 to control the magnitude of bus voltage to 1.031p.u and the series converters connected to lines 8-10 and 9-10 respectively. This is to increase active and reactive power flow along line 8-10 by 4% and 46% respectively while reducing the active and reactive power flow along line 9-10 by 3% and 29% respectively (tables 3a). This is to reduce congestion without violation of the bus voltage profile and reduction in line loss Figure 4a and b.

Test case 3: The voltage magnitude of bus 10 was controlled to 1.035p.u and the active power flow along line 8-10 was raised further raised by 65% and reactive power reduced by 4%, and the active power of line 10-9 was raised by 4% and reactive power was reduced by 14% shown in Figure 4a and b.

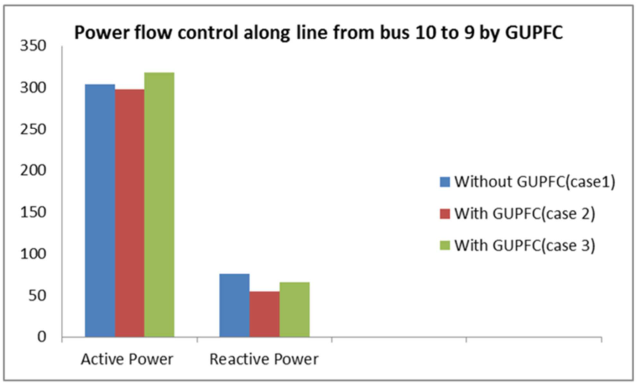

Figure 4a. *Power flow control along line of bus 10 and 9 with GUPFC.*

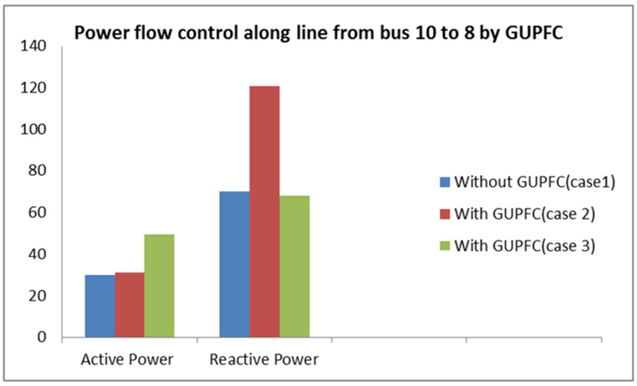

Figure 4b. *Power flow control along line bus 10 and 8 with GUPFC.*

Table 3a. *Controlled Power flow with GUPFC.*

Case No.	$P_{ser10\text{-}9}(MW)$	Loss(MW)	$Q_{ser10\text{-}9}$(Mvar)	$P_{ser10\text{-}8}(MW)$	Loss(MW)	$Q_{ser10\text{-}8}$(Mvar)	$V_{10}(p.u)$
Case 2	-298.104	0.156	54.185	31.223	0.351	102.604	1.031
Case 3	318.125	0.368	-65.545	49.453	2.728	-67.959	1.035

Table 3b. *The GUPFC convergence variables after power flow.*

Case Number	$V_{ser1}(p.u)$	θ_{ser1}(deg)	$V_{ser2}(p.u)$	θ_{ser2}(deg)	$V_{sh}(p.u)$	θ_{sh}(deg)
Case 2	0.0302	-118.9	0.090	105.5	1.00	0.072
Case 3	0.0927	11.2	0.0103	28.80	1.031	0.067

Test case 4: Power flow when the shunt of GUPFC was connected to bus 8 for control of voltage magnitude to 1.040p.u and series converters along line of bus 8-6 to increase the active power flow by 105%, reduce reactive power by 10% and line of bus 8-14 to increase the active power flow along the lines by 1% and reduce reactive power by 5%.

Test case 5: The same as test case 4 except that the active power flow along lines 8-6 was further raised by 133%, reactive power reduced by 5%. The active and reactive power along lines 8-14 was raised by 8% and 3.5% respectively. Test cases 4 and 5 are represented in tables 4a and b, and figures 5a and b.

Table 4a. *Controlled Power flow with GUPFC.*

Case No.	$P_{ser13}(MW)$	Loss(MW)	Q_{ser13}(Mvar)	$P_{ser14}(MW)$	Loss(MW)	Q_{ser14}(Mvar)	$V_8(p.u)$
Case 4	14.435	0.079	-70.731	129.623	1.391	74.755	1.040
Case 5	16.312	0.097	-74.554	138.274	1.563	81.360	1.040

Table 4b. *The GUPFC convergence variables after power flow.*

Case Number	V_{ser1}(p.u)	θ_{ser1}(deg)	V_{ser2}(p.u)	θ_{ser2}(deg)	V_{sh}(p.u)	θ_{sh}(deg)
Case 4	0.0520	246.02	0.0208	160.20	1.040	0.090
Case 5	0.0808	220.05	0.0505	166.54	1.040	0.055

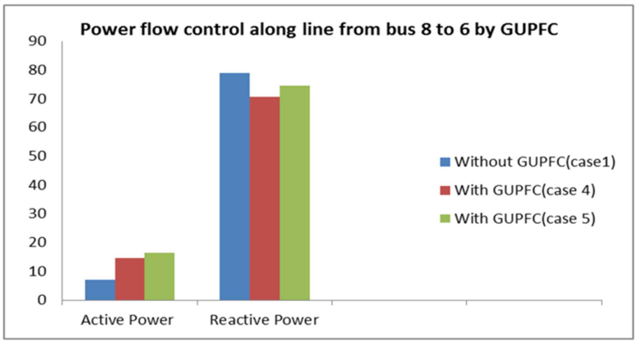

Figure 5a. *Bar chart of power flow along line of bus 8 and 6 with GUPFC.*

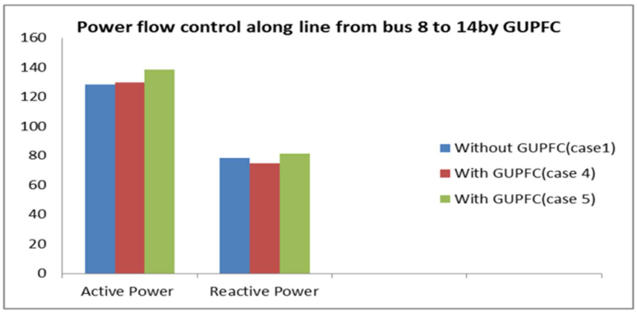

Figure 5b. *Bar chart of power flow along line of bus 8 and 14 with GUPFC.*

The application of GUPFC into Ngerian 28-bus power system has been used to control both its active and ractive power flows, high generation of reactive power was reduced, active power increased and a stable bus voltage magnitude achieved. Results in tables 3a, 3b, 4a, 4b and figures 4a, 4b, 5a, 5b show the impact of incorporation of GUPFC on power system. The device has been used to improve and stabilize the bus voltage profile in sub-stations, control the active as well as the reactive power flow along the transmission lines as illustrated in Figures and tables earlier presented and discused. Tables 5a and b are the result of the power flow anlysis of 28 bus Nigerian system with GUPFC incorporated.

Table 5a is the result of bus voltage magnitude and angle, while table 5b is the selected line flow in the system with their corresponding losses.

Table 5a. *Power flow result with GUPFC for 28bus Nigerian transmission system.*

Bus Number	Bus type	Voltage Mag. p.u.	Voltage. Ang. deg.
1	Swing	1.050	0.000
2	PV	1.050	0.177
3	PQ	1.045	-0.005
4	PQ	1.019	0.001
5	PQ	1.027	0.008
6	PQ	1.062	0.075
7	PQ	1.046	0.150
8	PQ	1.042	0.081
9	PQ	0.992	0.009
10	PQ	1.033	0.094
11	PV	1.050	0.119
12	PQ	1.038	0.108
13	PQ	0.977	-0.001
14	PQ	0.995	0.023
15	PQ	1.063	0.186
16	PQ	0.995	-0.011
17	PQ	1.051	0.180
18	PV	1.050	0.185
19	PQ	1.052	0.095
20	PQ	1.045	0.009
21	PV	1.050	0.235
22	PQ	1.013	-0.070
23	PV	1.050	0.059
24	PV	1.050	0.108
25	PQ	1.050	0.170
26	PQ	1.029	0.023
27	PV	1.050	0.373
28	PV	1.050	0.047

Table 5b. *Selected line flow for TCN 28bus with GUPFC.*

Bus number		Line Flow			Line loss	
From bus	To bus	MW	Mvar	MVA	MW	Mvar
1	3	137.358	97.585	168.493	0.158	-5.315
1	3	137.358	97.585	168.493	0.158	-5.315
1	5	-62.944	142.248	155.552	0.585	-20.853
2	8	330.722	-2.744	330.733	4.292	-13.957
5	8	-96.636	-51.072	109.302	0.982	-109.178
5	8	-96.636	-51.072	109.302	0.982	-109.178
5	9	-17.913	66.718	69.081	0.478	-50.591
5	10	149.352	-30.639	152.462	2.143	-88.446
6	8	-14.356	-70.731	72.189	0.079	-82.449
6	8	-14.356	-70.731	72.189	0.079	-82.449
7	24	241.524	-65.162	250.160	1.395	-16.786
8	14	129.623	74.755	149.634	1.391	-44.520
8	10	-43.405	-41.908	60.335	0.183	-103.586
8	24	-203.997	-96.529	225.682	0.918	-14.519
8	24	-203.997	-96.529	225.682	0.918	-14.519
9	10	-294.191	-89.491	307.501	4.191	-14.373
10	17	-231.555	-35.511	234.262	3.082	-43.041
10	17	-231.555	-35.511	234.262	3.082	-43.041

Bus number		Line Flow			Line loss	
From bus	**To bus**	**MW**	**Mvar**	**MVA**	**MW**	**Mvar**
10	17	-231.555	-35.511	234.262	3.082	-43.041
16	19	-130.600	-97.900	163.220	2.227	-106.477
19	20	116.567	-37.326	122.398	1.001	-80.858
19	25	-159.847	-3.398	159.883	1.415	-56.829
19	25	-159.847	-3.398	159.883	1.415	-56.829
20	22	111.430	-14.896	112.421	1.130	-86.348
20	22	111.430	-14.896	112.421	1.130	-86.348
20	23	-150.147	-35.687	154.329	0.801	-35.188
20	23	-147.147	-35.687	154.329	0.801	-35.188
Total					84.143	-2326.395

4. Conclusion

This research work has presented voltage source converter GUPFC model in rectangular form, and the model was incorporated into the Newton-Raphson algorithm for steady state power flow analys of longitudinal power system, 28-bus 330kV Nigerian Transmission network. Computer programming codes (MATLAB, R2009a) were written for the power flow analysis of power system network without and with GUPFC incorporated. Results without GUPFC indicated disproportionate active power flow, and high power loss along some lines in the power network. The incorporated GUPFC provided the required technical support in controlling appriopriately the disproportionate power flow and power loss reduction without violation of the bus voltage profile. Thus, enhancing the capacity the transmission system without expanding existing power system infrastructure.

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