



## Transmission Capacity Enhancement for Nigerian Power Transmission Grid using TCSC and UPFC

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### A B S T R A C T

#### Keywords:

UPFC,  
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*This study aimed to evaluate the application of Flexible Alternating Current Transmission System (FACTS) for enhancing transmission capacity (TC) of existing lines in Nigeria's 330 kV power transmission grid (PTG). Two FACTS devices, Thyristor Controlled Series Converter (TCSC) and Unified Power Flow Controller (UPFC), were considered and their installation modeled. The PTG was modeled as a complex 28-bus system. Load flow in the PTG was carried out using Newton-Raphson algorithm – coded and implemented in MATLAB. Optimal locations of the respective devices were determined using computation of load flow and known sensitivity functions. The required capacities and pay-back-periods (PBP) on the devices were evaluated using PBP and cumulative gain functions. The results show that the TC of the existing PTG can be enhanced by installing a TCSC in Ikeja-Ayede single circuit line and a UPFC in Jos-Gombe single circuit line. PBP analysis showed that investment in TCSC and UPFC will be recouped in about 3 months and 6 years respectively. This assessment shows that TCSC and UPFC can be deployed for improving the TC of Nigeria's PTG effectively.*

### 1. Introduction

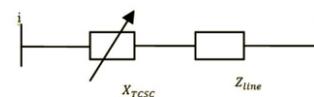
Over the years in Nigeria's power system, the total regional demands for power exceeded both the generation and transmission capacities. The solution to generation adequacy is time intensive. The existing generation increment obtainable from Independent Power Projects (IPP) and repair of existing generating units requires immediate reinforced transmission corridors of network for power supply to consumers. Finding solutions to this prevailing state have been proposed in the system.

Considering the current privatization and deregulation initiative, the power industry in Nigeria is expected to experience a rapid growth in generation of electrical energy to fully meet the National demand. A consequence of this is the need to commensurately reinforce the existing transmission lines (TLs) to carry the increased load. The choice of improving the existing TLs is considered in this study because of the severe limitation in resources and environmental concerns of constructing new TLs (Abido, 2009).

This study is aimed to evaluate the application of selected Flexible Alternating Current Transmission Systems (FACTS) devices to improve the transmission capacity (TC) and profile of existing transmission network. Thyristor Controlled Series Converter (TCSC) and Unified Power Flow Controller (UPFC), FACTS devices, which

are not in use in Nigeria's system, were considered.

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. TCSC functioning can be modeled as shown in Figure 1 (Sayed and Hadi, 2008). TCSC injects voltage in series with the line, and either supplies or consumes variable reactive power during operation (Georgilakis and Vernados, 2011).



**Figure 1: Impedance Diagram of TCSC Connection in TL.**

The UPFC injects current into the TL with the shunt part of its controller, and voltage in series with the line using the series part of its controller. Connection model of UPFC to the TL and the equivalent circuit are as shown in Figure 2 (Sayed and Hadi, 2008). A series inserted voltage (SIV) and its phase angle are introduced into the TL. The SIV is 10% of the nominal voltage of the TL. The UPFC consists of a shunt and a series transformers, and two voltage source converters (VSC) that have a common capacitor between them. The U shunt is the shunt voltage and the U<sub>series</sub> is the series voltage injected by the series transformer.

According to Sayed and Hadi (2008), the application of these FACTS devices can be economically effective if well located. For this to be realized, it is pertinent to connect the devices at the appropriate line (where needed). To achieve this, Sayed and Hadi



Figure 2: (a) Single Line Structure of UPFC; and (b) Impedance Diagram of Connection of UPFC to TL.

(2008) suggested the use of a method based on the sensitivity of the total system reactive power loss with respect to the control variables. This method is adopted for this study. Three specific tasks were carried out and presented in this study:

determining required capacities of FACTS devices; their respective locations for best TC improvement in Nigeria's transmission corridors; and cost effectiveness or PBP on such technical investment. Nigeria's 330 kV 28-bus PTG is as shown in Figure 3

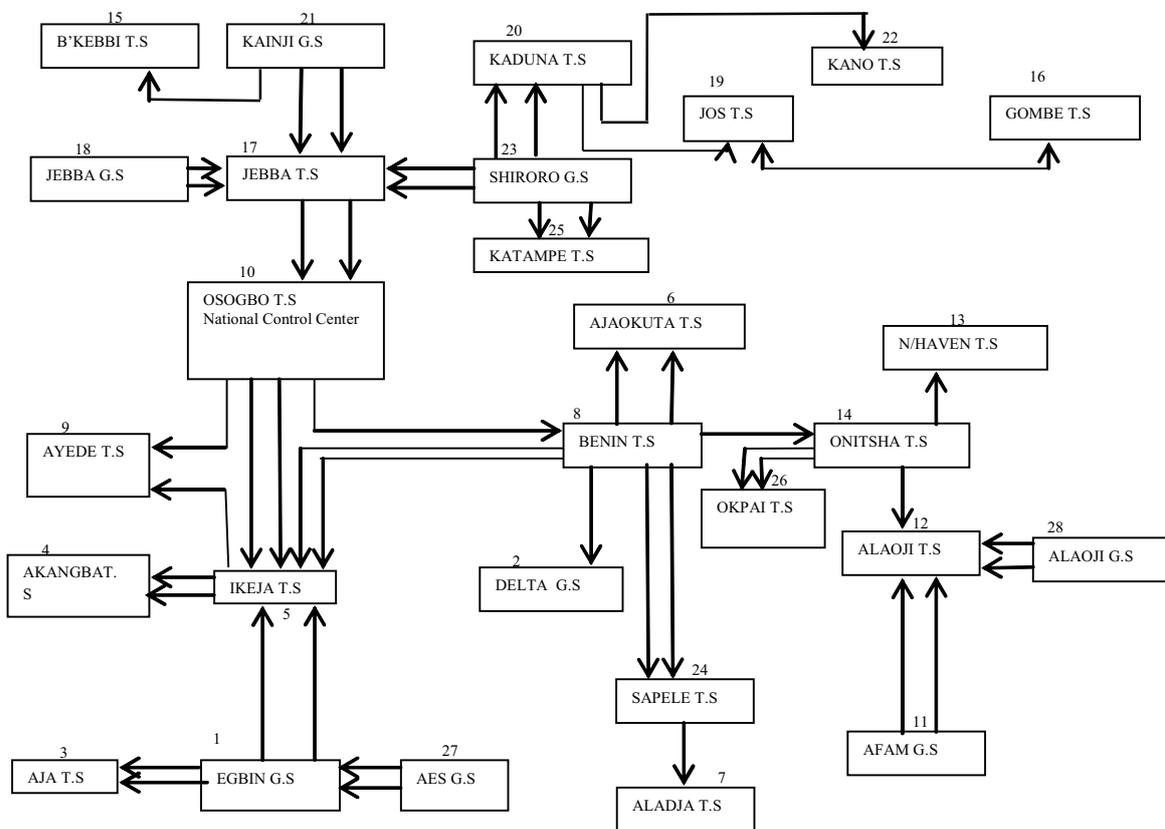


Figure 3: Graphical Display of Process Stages by Simulation (Produced by Metso Minerals)

2. Methodology

In order to achieve the study aim, algorithms of specific tasks were carried out as follows.

a) Power Flow in existing PTG with and without TCSC and UPFC

Normal mode power flow computations incorporating TCSC and UPFC models were carried out using Newton-Raphson method (NRM), which was coded and implemented in Matlab. The applied

equations of state in the power flow algorithm for the PTG are as in Equations 1 to 15 (Acharya and Mithulanantha, 2006).

According to Acharya and Mithulanantha (2006), active and reactive power flows in lines, between the buses *I* and *j*, are evaluated using

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad 1$$

$$Q_{ij} = V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] \quad 2$$

where

$\delta_{ij} = \delta_i - \delta_j$ ,  $V_i$ ,  $\delta_i$ ,  $V_j$ ,  $\delta_j$  are voltages and angles in buses  $i$  and  $j$  respectively

$G_{ij}$  is line conductance for  $B_{ij}$  is line susceptance, and Active and reactive power flows between the buses  $j$  and  $i$  are given by [7];

$$P_{ji} = V_i^2 \Delta G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) - B_{ij} \sin(\delta_{ij})] \quad 3$$

$$Q_{ji} = -V_i^2 (B_{ij} + B_{sh}) + V_i V_j [G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})] \quad 4$$

The voltage magnitude at each node is given as:

$$V_i = V_m (\cos \delta + j \sin \delta) \quad 5$$

where  $V_m$  is the magnitude of voltage in the data collected from the utility.

For TCSC, injected powers are modelled as follows (Chung and Li, 2001; Gerbex, Cherkaoui, and Germond, 2001; Cai, Erlich, and Stamtssis, 2004);  $P$ ,  $P$ ,  $Q$  buses  $I$  and  $j$

$$P_i = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) + \Delta B_{ij} \sin(\delta_{ij})] \quad 6$$

$$P_j = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) - \Delta B_{ij} \sin(\delta_{ij})] \quad 7$$

$$Q_i = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) - \Delta B_{ij} \cos(\delta_{ij})] \quad 8$$

$$Q_j = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) + \Delta B_{ij} \cos(\delta_{ij})] \quad 9$$

where  $\Delta G$  is the conductance and  $\Delta B$  joining buses  $I$  and  $j$

$$\Delta B_{ij} = \frac{X_c R_{ij} (X_{tcsc} - 2X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})^2)}; \quad 10$$

$$\Delta B_{ij} = \frac{-X_{tcsc}(R_{ij}^2 - X_{ij}^2 + X_{tcsc} X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})^2)}$$

For UPFC, the injected powers are modeled as (Chung and Li, 2001; Cai, Erlich, and Stamtssis, 2004):

$$P_i = -V_i^2 G_{ij} - 2V_i V_j G_{ij} \cos(\theta_{upfc} - \delta_{ij}) + [V_i V_j G_{ij} \cos(\theta_{upfc}) + B_{ij} \sin(\theta_{upfc})] \quad 12$$

$$Q_i = V_i V_j [G_{ij} \cos(\theta_{upfc} - \delta_{ij}) + B_{ij} \sin(\theta_{upfc})] \quad 13$$

$$P_j = V_j V_i [G_{ij} \cos(\theta_{upfc}) - B_{ij} \sin(\theta_{upfc})] \quad 14$$

$$Q_j = -V_j V_i [G_{ij} \sin(\theta_{upfc}) + B_{ij} \cos(\theta_{upfc})] \quad 15$$

where  $\theta$  is the phase angle of inserted voltage by Unified Power Flow Controller (UPFC).

#### b) Optimal Location of FACTS Devices.

For the benefit-cost ratio of applying a FACTS device to be maximal, it must be placed at the correct and needed line in the network. Equation

16 was adopted to determine the appropriate line for the TCSC device (Habur and O'Leans, 2004);

$$\alpha_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij}] \cdot \frac{r_{ij}^2 - x_{ij}^2}{(r_{ij}^2 + x_{ij}^2)^2} \quad 16$$

where  $\alpha_{ij}$  is the sensitivity of the line to reactive power loss,  $\partial Q_L$  is the change in the reactive power loss,  $\partial x_{ij}$  is the change in the reactance of the line connecting buses  $i$  and  $j$ . The values of  $\alpha_{ij}$  indicated the expected optimal location of the device; TCSC is placed on the line with the lowest absolute value of  $\alpha_{ij}$ . The results obtained for  $\alpha_{ij}$  is presented in Figure 5. Equation 17, according to Kowsalya et al., was used to determine the appropriate bus for the UPFC device:

$$L = \left| 1 - \frac{Y_{bus} V_{gen}}{V_{regrouped}} \right| \quad 17$$

where  $Y_{bus}$  is the bus admittance,  $V_{gen}$  is generator bus voltage,  $V_{regrouped}$  is the regrouped load bus voltage, and  $L$  is the voltage stability index of the bus. UPFC is placed at the line with the highest value of  $L$ . The flow chart for implementing power flow algorithm is as shown in Figure 4. The input data are the lines and the bus parameters and bus loads ( $R$ ,  $X$ ,  $I_{max}$ ,  $P$ ,  $Q$ , etc).  $\Delta P = P_i - P_j$  are the real power at buses  $I$  and  $j$  respectively. 'r' is the number of iterations.

#### c) Loading Test by Thermal Rating

The loading coefficients of the lines were calculated using Equation 18

$$LC = \frac{P_{ij}}{P_{ij}^{th}} \quad 18$$

where LC is the loading Coefficients of the lines,  $P_{ij}$  is the active power flowing in line connecting buses  $i$  and  $j$  and  $P_{ij}^{th}$  is the thermal limit constraint of the lines. The existing 330 kV transmission system uses double and single circuit twin Bison Aluminium Conductors, Steel Reinforced (ACSR) overhead lines. Bison is a 350 mm<sup>2</sup> conductor, with a continuous current rating of about 680 A per conductor, which equates to a continuous maximum thermal limit for each circuit of 777.3 MVA.

#### d) Pay-Back Period Analysis

The range of cost of major FACTS devices is presented in Siemens AG Database (Habur and O'Leans, 2004). Based on this, a polynomial cost function of FACTS devices is proposed and used in (Cai, Erlich, and Stamtssis, 2004) for FACTS allocation. The cost function of TCSC ( $C_{TCSC}$ ) is given by Equation 19 in US\$/kvar.

$$C_{TCSC} = 0.0015 S_{TCSC}^2 - 0.7130 S_{TCSC} + 153.75 \quad 19$$

Then, the cost function of UPFC ( $C_{UPFC}$ ) is given by Equation 20

$$C_{UPFC} = 0.00035 S_{UPFC}^2 - 0.2691 S_{UPFC} + 188.22 \quad 20$$

where  $C_{TCSC}$  is the cost of TCSC in US\$/kvar and  $S_{TCSC}$  and  $S_{UPFC}$  are

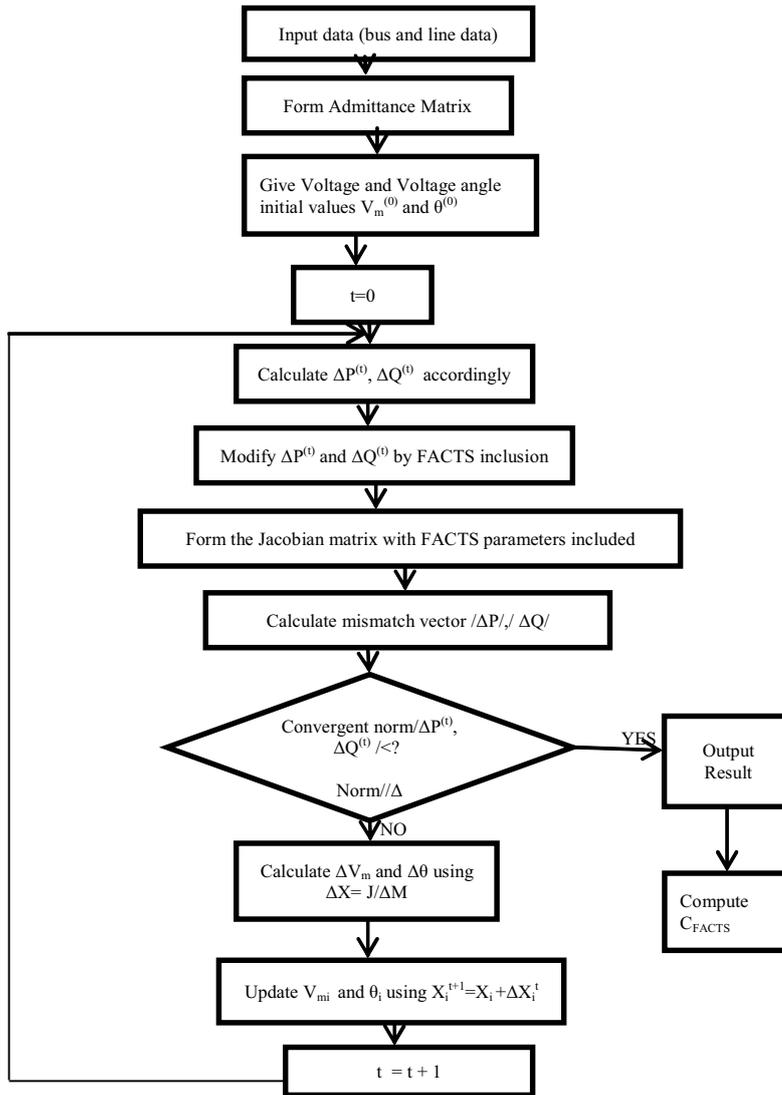


Figure 4: Flow Chart For Newton Raphson Algorithm

are the operating range of TCSC and UPFC respectively in Mvar

The operating range is the difference of the reactive power of the line before and after installation of the device (Hasma, Ismail, and Muhammad, 2010). This is expressed as in Equation 21:

$$S_{rd} = S_{TCSC} = S_{UPFC} = |Q_{ij}^{rd} - Q_{ij}| \tag{21}$$

Where  $Q_{ij}$  is the reactive power flow through the branch before device installation and  $Q_{ij}^{rd}$  is the reactive power flow through the branch after the installation of device 'd' (TCSC or UPFC). The results obtained for S'd' is presented in Table 4.

Pay-Back-Period on investment in FACTS devices was evaluated using

$$PBP_{rd} = \frac{IC_{rd}}{NMR_{rd}} = \frac{C_{rd} S_{rd} C_{rate}}{C_e \Delta P_{rd} T_{op}} \tag{22}$$

where  $IC_{rd}$  is the net investment cost on FACTS device  $C_{rd}$  is per

kvar cost of device (Equations 19 and 20),  $C_{rate}$  is the conversion rate from dollars to naira ( $C_{rate} = 160 \text{ ₦}/\$$ ),  $C_e$  is per unit cost of energy ( $11.35 \text{ ₦}/kWh$ ),  $\Delta P_{rd}$  or  $\Delta P_{ij}^{rd}$  is active power gain from installation of device,  $T_{op}$  is hours in month ( $T_{op} = 720 \text{ hrs}$ ).  $PBP_{rd}$  is in Table 4.

The cumulative gain on the devices  $CG_t^{rd}$  versus time t in months is obtained and plotted using:

$$CG_t^{rd} = \alpha (t \times NMR_{rd}) - IC_{rd} \tag{23}$$

where  $\alpha$  is the discount factor ( $\alpha = \frac{1}{(1+x\%)^t}$ );  $x\%$  is the percentage discount per annum ( $x\%$  taken as 4.25%)

### 3. Results

The values of the variables and indexes considered in this study are presented in this section as Figures 5 to 9 and Tables 1 to 4.

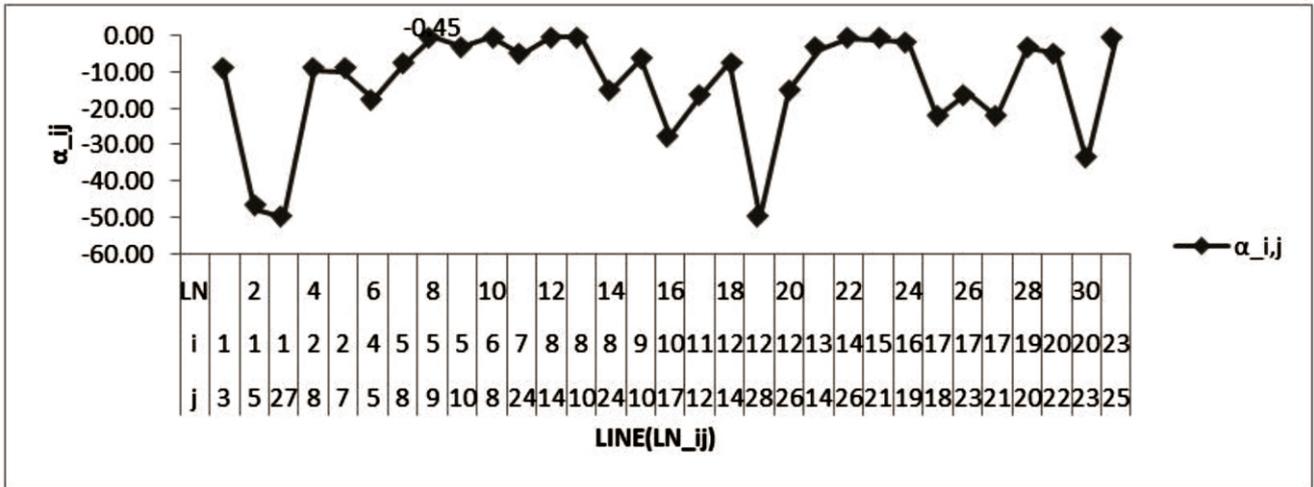


Figure 5: The  $\alpha_{ij}$  Values of System Lines for Location of TCSC.

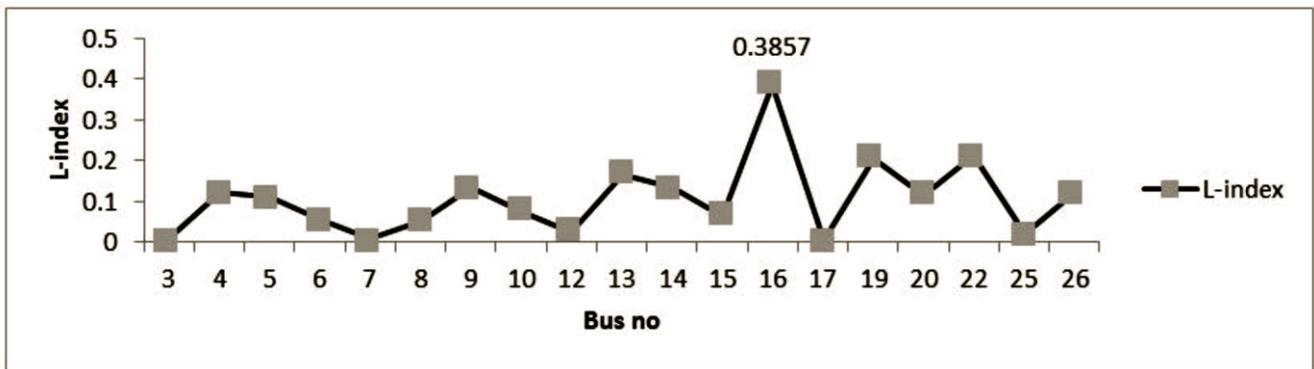


Figure 6: L-index Values for the System Buses for Location of UPFC

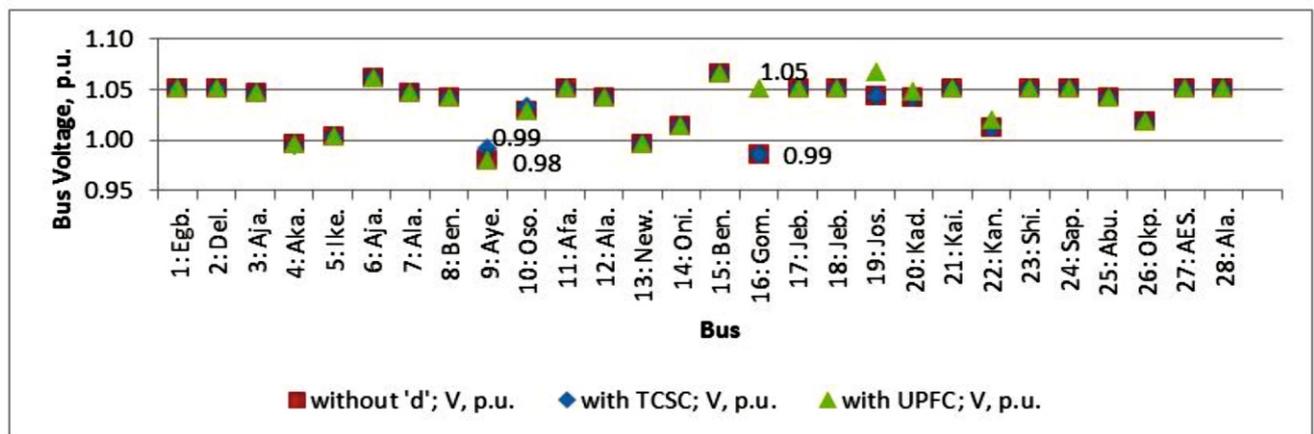


Figure 7: Values of Bus Voltages of the System before and after Installation of FACTS Devices

**Table 1: Load Flow without FACTS**

Bus no	V, p.u.	Angle	Load, MW	Load, Mvar	Gen., MW	Gen., Mvar	Bus Name
1	1.05	0.00	68.90	51.70	147.88	810.96	Egbin
2	1.05	9.70	0.00	0.00	670.00	-18.13	Delta
3	1.05	-0.28	274.40	205.80	0.00	0.00	Aja
4	1.00	-2.76	344.70	258.50	0.00	0.00	Akangba
5	1.00	-2.33	633.20	474.90	0.00	0.00	Ikeja
6	1.06	3.82	13.80	10.30	0.00	0.00	Ajaokuta
7	1.05	8.13	96.50	72.40	0.00	0.00	Aladja
8	1.04	4.18	383.30	287.50	0.00	0.00	Benin
9	0.98	-3.05	275.80	206.80	0.00	0.00	Ayede
10	1.03	1.28	201.20	150.90	0.00	0.00	Osogbo
11	1.05	12.86	52.50	39.40	431.00	250.15	Afam
12	1.04	12.19	427.00	320.20	0.00	0.00	Alaoji
13	1.00	3.85	177.90	133.40	0.00	0.00	New Heaven
14	1.01	5.11	184.60	138.40	0.00	0.00	Onitsha
15	1.06	6.05	114.50	85.90	0.00	0.00	Benin-Kebbi
16	0.99	-16.61	130.60	97.90	0.00	0.00	Gombe
17	1.05	5.72	11.00	8.20	0.00	0.00	Jebba
18	1.05	5.98	0.00	0.00	495.00	-84.74	Jebbaga
19	1.04	-10.41	70.30	52.70	0.00	0.00	Jos
20	1.04	-7.05	193.00	144.70	0.00	0.00	Kaduna
21	1.05	8.90	7.00	5.20	624.70	-265.50	Kainji
22	1.01	-11.01	220.60	142.90	0.00	0.00	Kano
23	1.05	-2.38	70.30	36.10	388.90	-11.04	Shiroro
24	1.05	5.73	20.60	15.40	190.30	122.24	Sapele
25	1.04	-3.15	110.00	89.00	0.00	0.00	Abuja
26	1.02	6.45	290.10	145.00	0.00	0.00	Okpai
27	1.05	0.87	0.00	0.00	750.00	-102.97	AES
28	1.05	14.47	0.00	0.00	750.00	62.24	Alaoji
Total			4371.80	3173.20	4447.80	763.22	

Table 2 : The Line Flow and Losses without FACTS and when TCSC is connected.

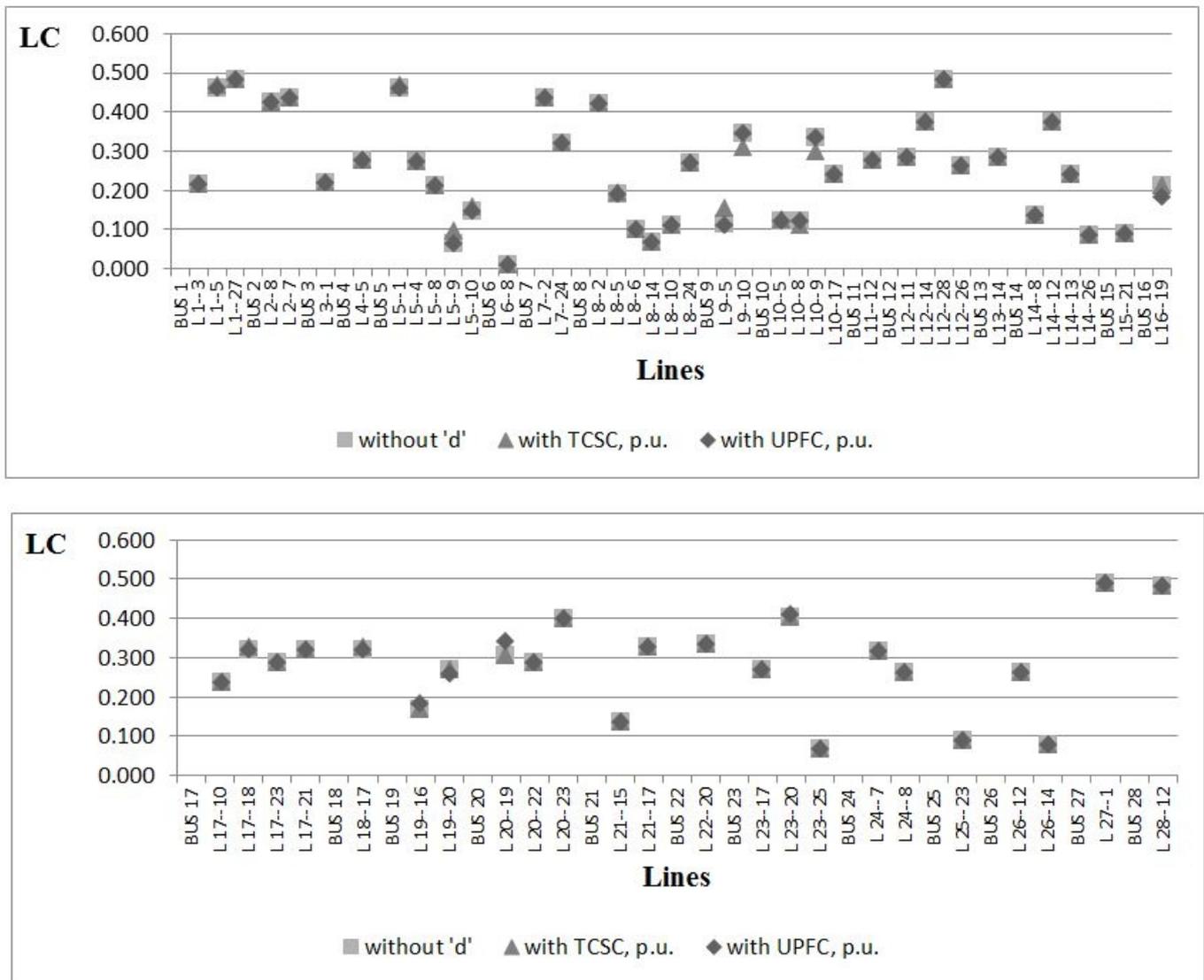
without FACTS						when TCSC is connected					
--Line--		Power at bus and line			--Line loss--		Power at bus and line			--Line loss--	
from	to	MW	Mvar	MVA	MW	Mvar	MW	Mvar	MVA	MW	Mvar
5		-633.20	-474.90	791.50			-633.20	-474.90	791.50		
	1	-546.78	-468.90	720.30	5.92	-6.18	-546.71	-481.45	728.48	6.07	-5.03
	4	345.44	249.78	426.28	0.74	-8.72	345.44	249.83	426.31	0.74	-8.68
	8	-290.66	-146.25	325.39	4.68	-194.70	-295.06	-147.68	329.95	4.84	-193.26
	9	38.28	29.54	48.35	0.25	-50.58	57.08	50.83	76.43	0.50	-52.12
	10	-179.47	-139.07	227.04	1.68	-192.02	-193.95	-146.43	243.01	1.98	-190.07

Table 3: Line Flow and Losses with UPFC.

without FACTS						when UPFC is connected					
--Line--		Power at bus and line			--Line loss--		Power at bus and line			--Line loss--	
from	to	MW	Mvar	MVA	MW	Mvar	MW	Mvar	MVA	MW	Mvar
16	19	-130.60	-97.90	163.22			-130.60	-97.90	163.22		
	19	-130.60	-97.90	163.22	2.27	-104.28	-128.60	-60.87	142.28	1.77	-118.67
19	16	-70.30	-52.70	87.86			-70.30	-52.70	87.86		
	16	132.87	-6.38	133.03	2.27	-104.28	130.37	-57.80	142.61	1.77	-118.67
	20	-203.17	-46.32	208.39	1.62	-163.82	-202.67	3.10	202.70	1.81	-167.66

Table 4: Summary of Incorporation of TCSC and UPFC

'd'	i	j	$P_{ij}, MW$	$P_{ij}^{d'}, MW$	$Q_{ij}, Mvar$	$Q_{ij}^{d'}, Mvar$	$+\Delta P_{ij}^{d'}, MW$	$C_{d'}, \$$ $kvar$	$S_{d'}, Mvar$	$PBP_{d'}, mnth$
TCSC	5	9	38.28	57.08	29.54	50.83	18.8	139.25	21.29	3
UPFC	19	16	132.87	130.37	97.9	60.87	2.5	178.67	37.03	64



(b)

Figure 8: LC Values of lines with and without FACTS Devices: (a) for Buses 1 to 16 Connections; and (b) for Buses 17 to 28 Connections

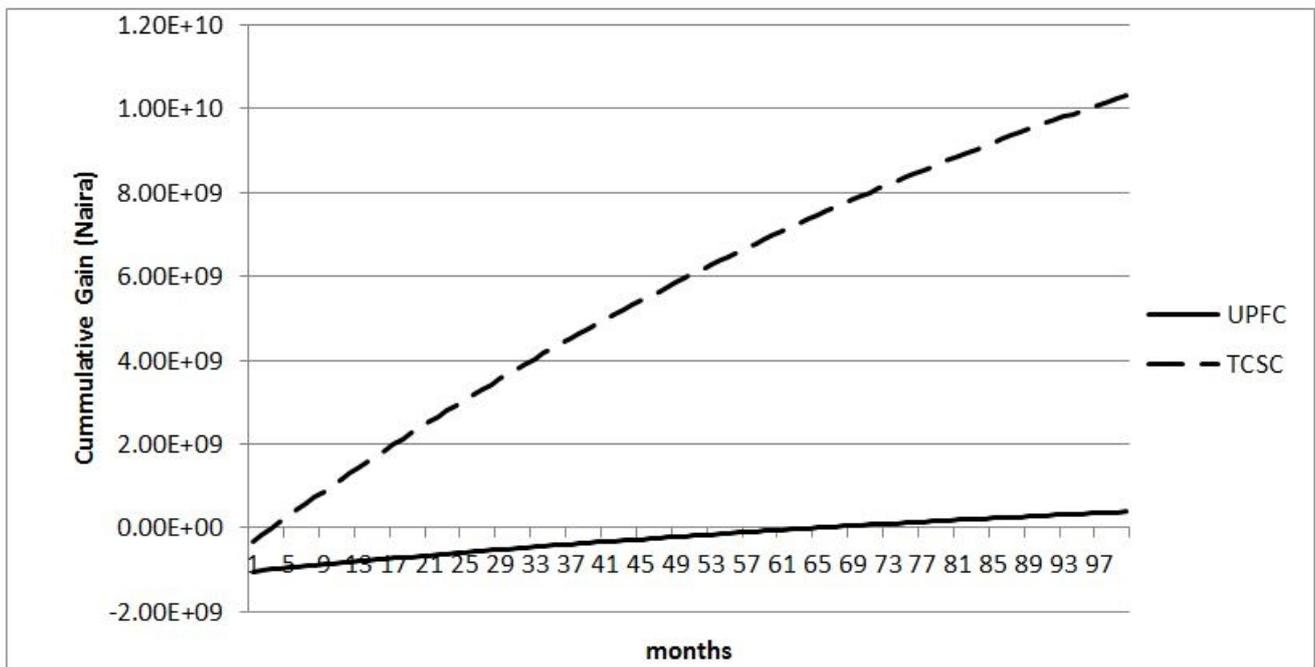


Figure 9: Graph of Cumulative Gain versus Months.

Without the installation of these FACTS devices in the grid, Table 1 shows that the equivalent generated power in the existing system is approximately  $4.45 + j0.76$  GVA, and the equivalent network load is  $4.37 + j3.17$  GVA; and the bus voltages range from 0.98 to 1.06 p.u. of nominal voltage, which is within standard permissible range. From these values, active network losses are approximately 80 MW (2%).

However, the values of  $\alpha_{i,j}$  in Figure 5 show that the weakest link or the expected optimal location of TCSC (*EOL*) is line 5-9 (Ikeja-Ayede line) where  $\alpha_{1,5}$  is the highest (-0.45). Values of the voltage stability index (L-index) in Figure 6 shows that the (*EOL*) for UPFC is bus 16 (Gombe), which is the bus with the highest L-index (approximately 0.4).

Tables 1 to 3 and Figure 7 show that on application of TCSC in line 5-9, it facilitated an improvement in voltage from 0.98 to 0.99 p.u. in receiving transmission station bus 9, which is an increase in voltage stability capability (VSCap) of the line; this facilitates the possibility of increase in power flow from 38.28MW to 57.08MW with higher VSCap. These results show that the TCSC can be deployed to improve the TC of weak regional link-lines of the Nigerian grid significantly in normal operating mode. For UPFC on bus 16 (Gombe), Figure 7 shows an improvement in voltage from 0.99 to 1.05 p.u., further improving the VSCap and a corresponding gain of approximately 2.5 MW (Table 4) in TC of line 19-16 (Jos-Gombe) line in the northeastern region of the national grid.

Also, with the observed gains on installation of these FACTS devices, the thermal capacity reserves of all lines, indicated by LC values in Figure 8, remained substantial (all values of LC were less than 50%). Table 4 and Figure 9 show that installing TCSC and UPFC

for improved TC in the system for normal mode operation have relatively short payback periods of 3 and 64 months respectively, i.e. – less than a year to about 5 years and 4 months respectively. In addition, this shows that with the observed scenarios of weak links in the grid, the application of UPFC is far more expensive compared to TCSC.

#### 4. Conclusion

In this paper, normal steady mode load flow calculation based on Newton-Raphson algorithm was used to evaluate the load flow effect of applying TCSC and UPFC in the 28-bus model of Nigeria's 330kV PTG. The results showed that, using TCSC in the obtained optimal location (line 5-9), the transmission capacity (TC) is increased by 49% from initial 38.28MW. Apart from the certain benefits of improved VSCap (sending and receiving ends voltages) from installing UPFC, a corresponding gain not less than 2.5 MW could be obtained on the Jos-Gombe line alone (that is, besides the sub-transmission grid downstream). Further, PBP analysis, derived as function of reactive power flow reduction and active power gain, established that the investment costs for UPFC and TCSC can be recouped in relatively short periods; PBP for TCSC is about 3 months and for UPFC is between 5 to 6 years. This information can be deployed for use in the Nigerian system planning to improve TC or voltage stability margins of lines.

#### References

- Abido, M. A. (2009, April). Power System Stability Enhancement Using Facts Controllers. *The Arabian Journal for Science and Engineering*, XXXIV, 153.
- Acharya, N., & Mithulanantha, N. (2006). Locating Series FACTS devices for Congestion Management in Deregulated

- Electricity Market.
- Abido, M. A. (2009, April). Power System Stability Enhancement Using FACTS Controllers. *The Arabian Journal for Science and Engineering*, XXXIV, 153.
- Acharya, N., & Mithulanantha, N. (2006). Locating Series FACTS devices for Congestion Management in Deregulated Electricity Market. Naresh Acharya and N. Mithulanantha, "Locating Series FACTS devices *Electric power Research* 77, Thailand,.
- Cai, L. J., Erlich, I., & Stamsis, G. (2004). Optimal Choice and Allocation of FACTS Devices in Deregulated Electricity Market Using Genetic Algorithm. *IEEE PES Power System Conference and Exposition*, (pp. 10-13). New York.
- Chung, T. S., & Li, Y. Z. (2001). A Hybrid GA approach for OPF with Consideration of FACTS Devices. *IEEE Power Engineering Review*, 47-57.
- Georgilakis, S. P., & Vernados, G. P. (2011). Flexible AC Transmission System Controllers: An Evaluation. *Materials Science Forum*, 670, 399-406.
- Gerbex, R., Cherkaoui, R., & Germond, A. J. (2001). Optimal Location of Multi-type FACTS Devices in a Power System by Means of Genetic Algorithms. *IEEE Trans. Power Systems*, XVI, 537-544
- Habur, K., & O'Leans, D. (2004, August). FACTS - Flexible Alternating Current Transmission Systems: for Cost Effective and Reliable Transmission of Electrical Energy. Retrieved from [www.worldbank.org](http://www.worldbank.org)
- Hasma, A. N., Ismail, M., & Muhammad, M. (2010). Transmission Loss Minimization and UPFC Installation Cost Using Evolutionary Computation for Improvement of Voltage Stability. *Proceedings of 14th International Middle East Power Systems Conference*, Cairo University, (pp. 19-21). Egypt.
- Kowsalya, M., Ray, K. K., Shipurkar, U., & Saranathan. (2009). Voltage Stability Enhancement by Optimal Placement of UPFC. *Journal of Electrical Engineering and Technology*, 4(3), 310-314.
- Seyed, A. T., & Hadi, B. (2008). Transmission Congestion Management by Determining Optimal Location of FACTS Devices in Deregulated Power Systems.
- Seyed, A.T . Hadi, B. "Transmission Congestion Management by Determining Optimal Location *American Journal of Applied Sciences*, 5(3), 242-247