Transient Stability Improvement of Power System Using UPFC, a Case Study of 41-Bus Nigerian Grid System Modeled In PSAT

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Abstract— **This paper presents an approach to enhance transient stability of power system using flexible A.C transmission system (FACTS) devices. The study was carried out using 41-Bus Nigerian grid System as the case study. The UPFC was used to assess the improvement in power system stability after fault had occurred on the transmission line. The analysis was done using time domain simulation in PSAT/MATLAB Simulink environment considering a three phase faults applied on bus 10 of the Nigerian grid system. The transient characteristics of the rotor angle, angular frequencies and the output terminal voltage of the existing generators in the network were studied with and without UPFC installed. The results from the analysis shows that UPFC provide better damping during transient disturbance and enhances voltage stability**

Index Terms— **Damping, Transient Stability (improvement), Unified Power Flow Controller, FACTS, disturbance.**

I. INTRODUCTION

The aim of this paper is to present the model and performance of a UPFC connected to a transmission line, when the active and the reactive power reference values are changed. The UPFC is modeled and the time domain simulations are carried out using PSAT software in MATLAB environment on 41-bus Nigerian grid transmission network. A power system is a complex network comprising of numerous generators, transmission lines, variety of loads, switches, active or passive compensators and transformers. Such network when stressed are known to exhibit nonlinear behavior and in practice it is prone to several faults and disturbances[5]. As a consequence of increasing power demand, some transmission lines are more loaded than was planned when they were built. With increased loading of long transmission lines, the problem of transient stability can become a transmission limiting factor [4], [7], [9]. When a system is subjected to large disturbance such as faults and switching of lines, the resulting system response involve large excursion of generator rotor angles and is influenced by the non-linear power angle relationship. The basic requirement is to make the synchronous generators to run in synchronism after disturbance occured in the system. If the oscillation after disturbance is damped the system returns to its stable state. This is the funtion this paper tend to address through the incorporation of a UPFC and other control devices in the modelling of a power system transmission network[8].

Power system can be effectively improved by the use of FACTS devices. Flexible A-C transmission system (FACTS) devices have shown very promising steady – state performances. A unified power flow controller (UPFC) is the most effective device in the FACTS family.

The problem of voltage stability with voltage collapse as its final consequence has been on the increase due to high demand of electrical energy and thus of great concern in power system planning and operation. The electrical power supply and consumptions system always encounter disturbances which introduces oscillation and losses of reactive power components. Power system are planned, designed and built to supply the consumers electrical energy, considering the following:

- What quality of power is transmitted.
- How economical the power system is.
- How reliable and secure is the power supplied.
- What environmental impacts the power makes.

These constitute the basis of the optimization that the power companies must consider regarding their investments and daily operations. It is evident that economic consideration must be regarded when deciding about quality and supply security for the systems [10], [11].

However, the evolution of power electronics technology has given opportunities for developing the FACTS devices for stable operation of power systems. In the last two decades a number of power electronics devices were developed. These devices are effectively used for voltage control, power flow control, harmonics elimination, damping oscillation, improving transient stability and minimization of losses [2]. Many FACTS devices are widely used like SVC (Static Var Compensator,) STATCOM (Static Synchronous Compensators), UPFC (Unified Power Flows Controller), TCSC (Thyristor-Control Compensator). All these FACTS devices have their advantages of controlling active and reactive power for static and dynamic voltage stability.

Studies have revealed in this work that proper placement of FACTS devices (UPFC) solve the aforementioned problems.

II. THE PSAT

PSAT is a MATLAB toolbox for electric power system analysis and control. PSAT includes power flow and small signal stability analysis and time domain simulation. All operation can be assessed by measure of graphical user interface (GUIS) and base library provides a user friendly tool for network design [14].

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III. THE MODELLING OF UPFC

UPFC is the most recent proposed FACTS device which still undergoing development. Unified power flow controllers are capable of directing real and reactive power flows through a designated route and regulating the system voltage through reactive power compensation. UPFC can be viewed as a combining SSSC and STATCOM with a shared d.c bus (i.e common d.c storage capacitor). The UPFC consist of two ac/dc voltage supports for converter operation and functions as energy storage. The a.c side of the booster inserts a synchronous ac voltage of controllable magnitude and phase angle in series with the transmission line through a series booster transformer. The a.c side of the exciter is connected in parallel to the transmission line transformer where current of controllable magnitude and power factor is injected to or absorbed from the power [13]. The block diagram of the UPFC is shown in fig.1.

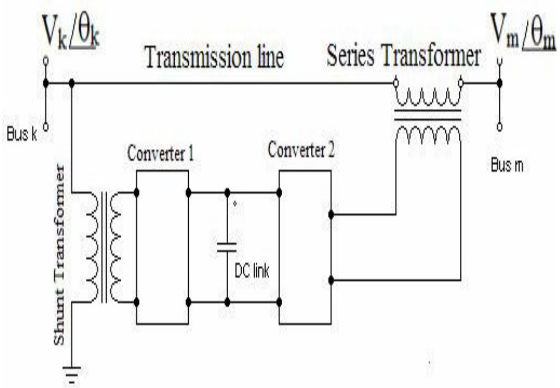


Fig. 1 The block diagram of the UPFC.

The mathematical model equations for active and reactive power can be written as [12]:

At bus K

$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km} Cos(\theta_k - \theta_m) + B_{km} Sin(\theta_k - \theta_m)] + V_k V_{cr} [G_{km} Cos(\theta_k - \delta_{cr}) + B_{km} Sin(\theta_k - \delta_{cr}) + V_k V_{vr} [G_{vr} Cos(\theta_k - \delta_{vr}) + B_{vr} Sin(\theta_k - \delta_{vr})]$$

- - - - ----------- **(1)**

$$Q_k = -V_K^2 B_{kk} - V_k V_m [G_{km} Sin(\theta_k - \theta_m) - B_{km} Cos(\theta_k - \theta_m) + V_k V_{cr} [G_{km} Sin(\theta_k - \delta_{cr}) - B_{km} Cos(\theta_k - \delta_{cr}) + V_k V_{vr} [G_{vr} Sin(\theta_k - \delta_{vr}) + B_{vr} Cos(\theta_k - \delta_{vr})]$$

- - - - ----------------- **(2)**

At bus M

$$P_m = V_m^2 G_{mm} + V_k V_m [G_{mk} Cos(\theta_m - \theta_k) + B_{mk} Sin(\theta_m - \theta_k)] + V_m V_{cr} [G_{mm} Cos(\theta_m - \delta_{vr}) + B_{mm} Sin(\theta_m - \delta_{cr})]$$

- - - ------------ **(3)**

$$Qm = -V^2{}_m B_{mm} + V_k V_m [G_{mk} Sin(\theta_m - \theta_k) - B_{mk} Cos(\theta_m - \theta_k)] + V_m V_{cr} [G_{mm} Sin(\theta_m - \delta_{vr}) - B_{mm} Cos(\theta_m - \delta_{cr})]$$

- - - --------- - - **(4)**

Series converter

$$P_{cr} = V_{cr}^2 G_{mm} + V_{cr} V_k [G_{km} Cos(\delta_{cr} - \theta_k) + B_{mk} Sin(\delta_{cr} - \theta_k)] + V_m V_{cr} [G_{mm} Cos(\partial_{cr} - \theta_m) + B_{mm} Sin(\partial_{cr} - \theta_m)]$$

- - - - - --------- - - - - **(5)**

$$Q_{cr} = -V_{cr}^2 B_{mm} + V_{cr} V_k [G_{km} Sin(\delta_{cr} - \theta_k) - B_{mk} Cos(\delta_{cr} - \theta_k)] + V_m V_{cr} [G_{mm} Sin(\delta_{cr} - \theta_m) - B_{mm} Cos(\delta_{cr} - \theta_m)]$$

- -------- - - - - - **(6)**

Shunt converter+

$$P_{vr} = -V_{vr}^2 G_{vr} + V_{vr} V_k [G_{vr} Cos(\delta_{vr} - \theta_k) + B_{vr} Sin(\delta_{vr} - \theta_k)]$$

- - - ------ **(7)**

$$Q_{vr} = -V_{vr}^2 B_{vr} + V_{vr} V_k [G_{vr} Sin(\delta_{vr} - \theta_k) - B_{vr} Sin(\delta_{vr} - \theta_k)]$$

- - - - ---- - **(8)**

IV. THE CASE STUDY

The Nigeria grid system was used as the case study in this work. The Nigeria grid system modeled in PSAT is a power network of 41 buses; 17 generator buses, 30 load buses and 77alternating current π- transmission lines. It is interesting to note that this system by reason of the location of the generating plants, is zoned into four areas. The four areas are interconnected with lines during normal operating conditions .The instability was simulated by applying a three phase fault at bus 10 and a UPFC was connected between bus 5 and 10 at western and north central zones of the network.

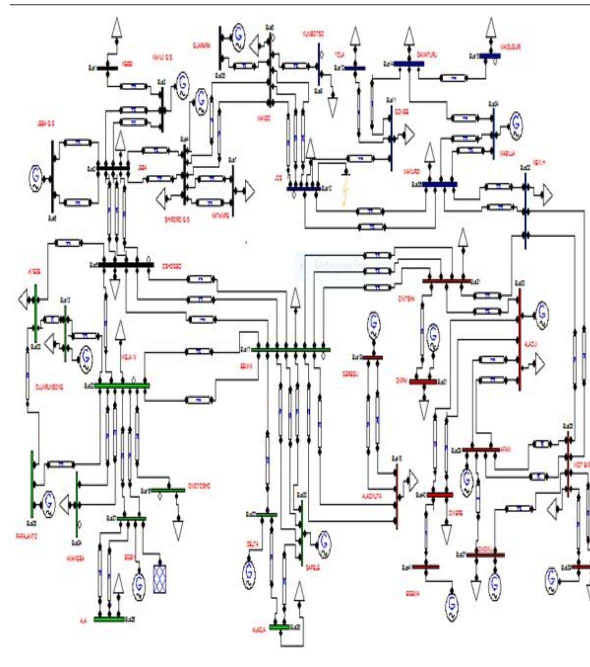


Fig.3a 41-bus Nigerian grid system (without UPFC) under fault condition.

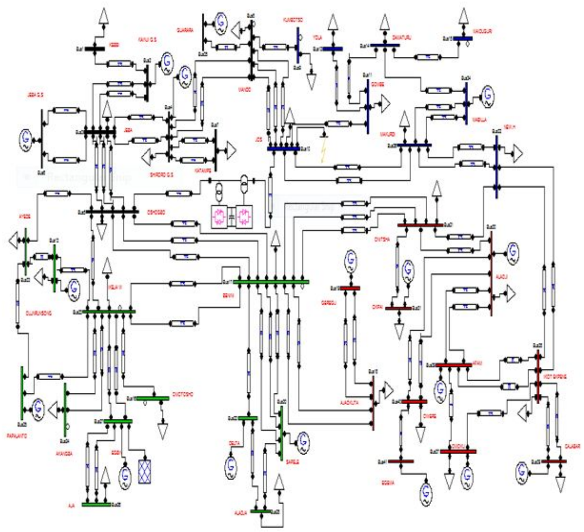


Fig.3b 41-Bus Nigerian grid system in PSAT [With UPFC] under fault condition.

V. CASE STUDY II SIMULATION RESULTS AND DISCUSSION:

The following results were obtained from the time domain simulation carried out on the 41-bus Nigerian grid system depicted in fig.3a and fig.3b.

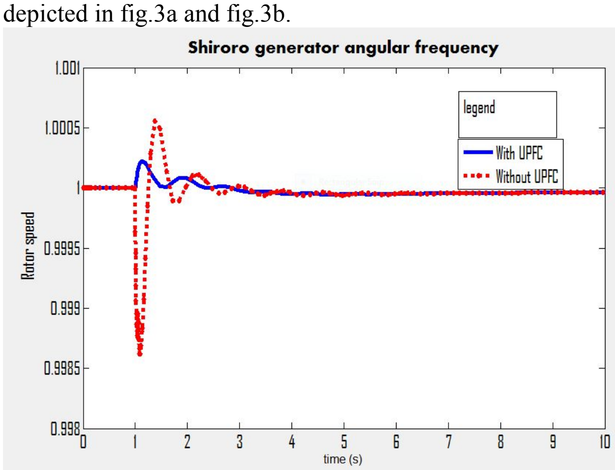


Fig4a Angular frequency of generator at Shiroro hydro station.

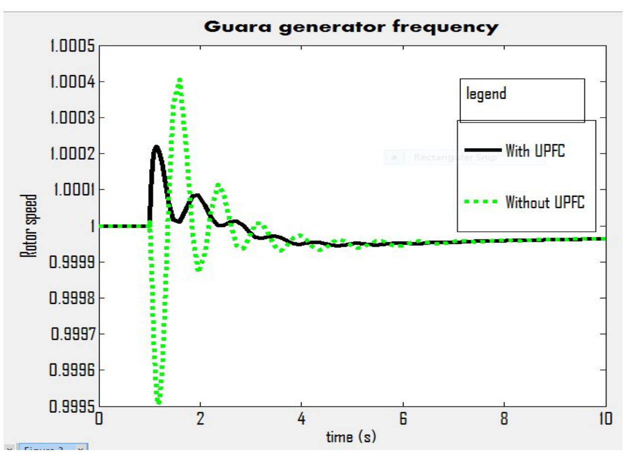


Fig.4 b Angular frequency of generator at Guarara

Figure 4a and 4b shows angular frequency response of generators at Shiroro and Guarara to the three phase to ground fault applied at bus 10 with UPFC installed and without UPFC. The transient characteristic was more severe in term of amplitude swing, frequency of oscillation and settling time without UPFC and this was represented by dotted line .However when UPFC was installed the amplitude of oscillation was damped thus enhanced transient stability and is represented by thin continuous line

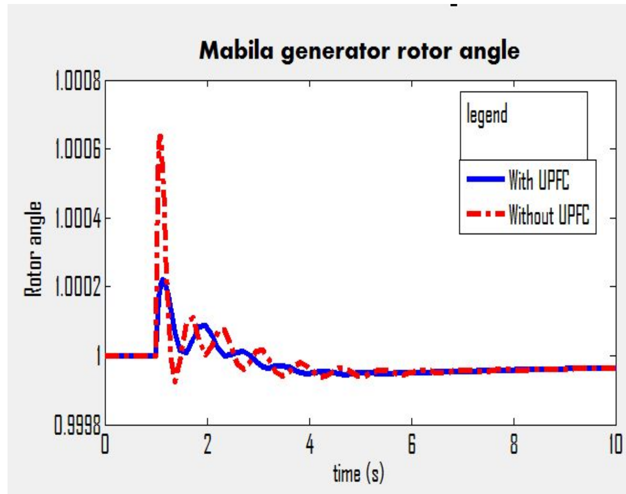


Fig. 4c Rotor angle transient response of Mabila generator

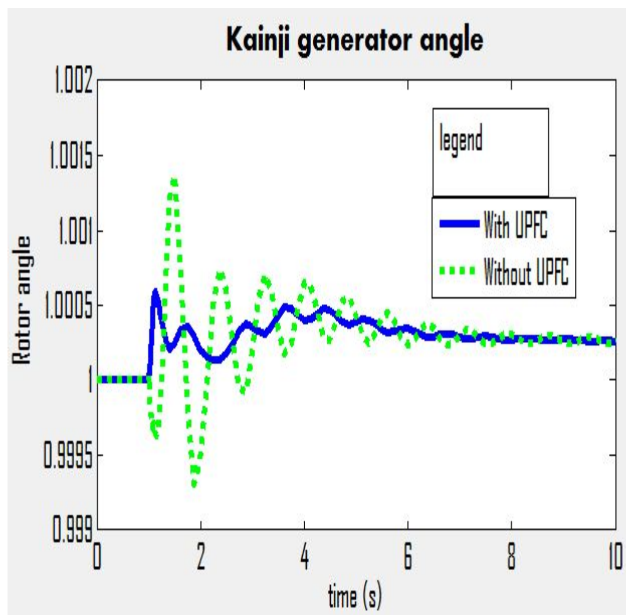
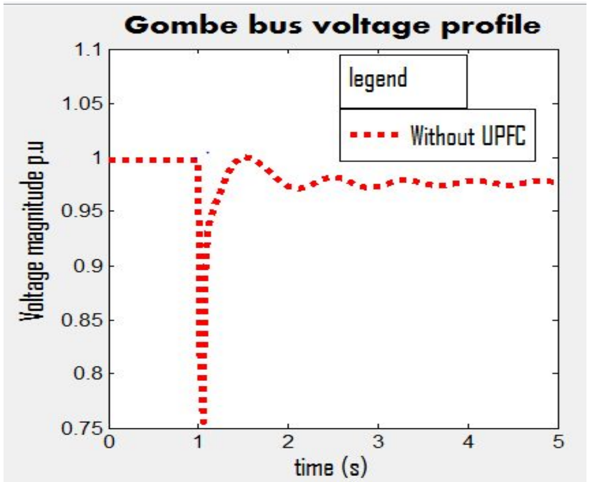


Fig. 4d Rotor angle transient response of generator at Kainji

The application of three phase fault on bus 10 at t=1 sec are performed in the system. The instability increases the amplitude in the oscillation of the rotor angle at Mabilla and Kainji generators due to lack of insufficient synchronizing torque .The installation of UPFC shows improvement in the transient characteristic by damping the oscillation of the rotor angle amplitude. The dotted line shows the oscillation without UPFC while the continuous line shows the damping effect with UPFC



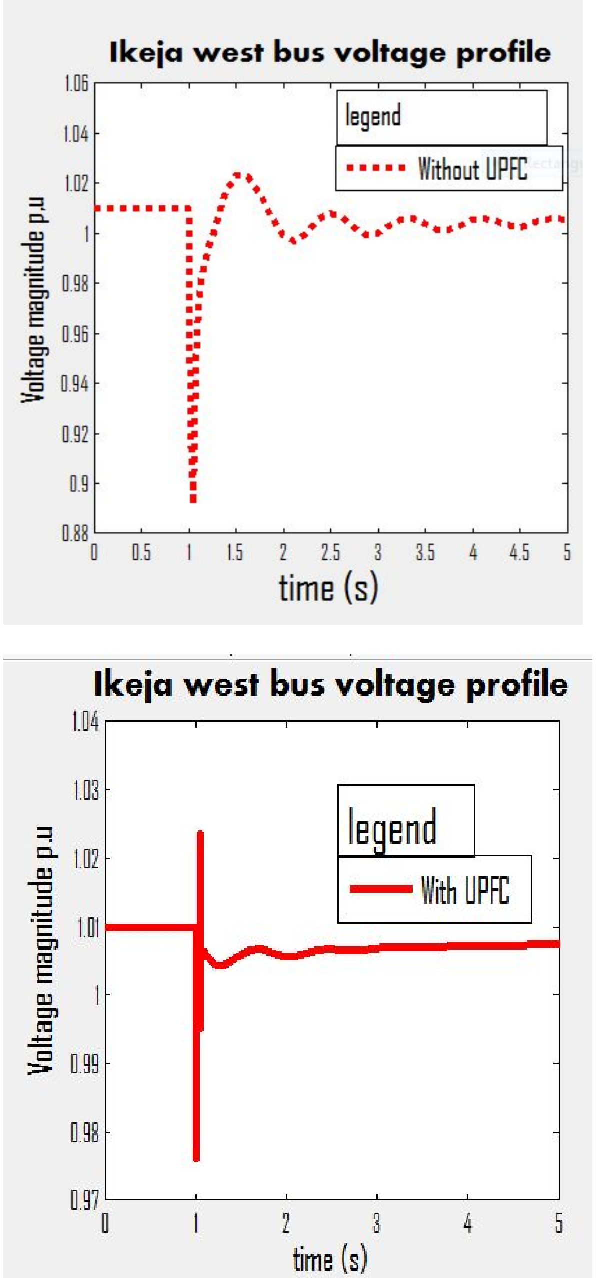


Fig. 4e Bus voltage profile at Ikeja West

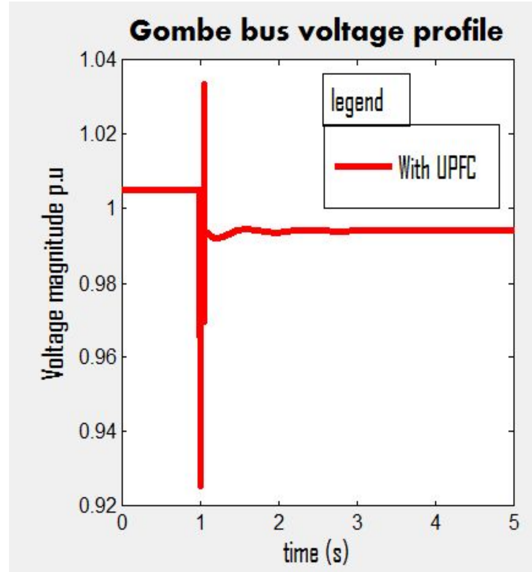


Fig. 4f Bus voltage profile at Gombe

The result of fig. 4e and 4f of Ikeja west and Gombe respectively show appreciable enhancement in the transient characteristics of the voltage profile in the presence of UPFC as indicated by the continuous line.

The appendix shows the result of the line flow and the effect of using UPFC in a transmission line. Without UPFC the P losses (the real power flow in the transmission system) was high at **1.07961p.u** and the Q losses (the reactive power flow) at **12.0940p.u.** However, with UPFC connected the real power losses reduced to **0.87576p.u** thus shows the enhancement in the power flow and the stability of the grid in the presence of UPFC while reactive power loss approximately remain the same at **12.0922p.u.**

CONCLUSION

From the analysis of the result obtained, it shows clearly that power system network without UPFC exhibits minimum damping but with insertion of UPFC devices the transient characteristics improved tremendously as the oscillation at settling time were reduced.

REFERENCES

[1] Mehrdad Amadi, et al 2009" Comparism of SVC and STATCOM in static voltage stability marging enhancement", World academy of science and technology 50, 2005.

[2] Hingoran. N.G. and Gyugyi, L. (1999): Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. IEEE press. N.Y. 24-45.

[3] Uzunovic, E., Reve, J., and Carnizare, A. (1997): Fundamental Frequency Model of Static Synchronous Compensator, Proc. NAPS, Laramie, Wymoming. 47: 49-54.

[4] Canizares, C.A., Berizzi, Berizzi, A. and Uzunovic, E. (1998): using FACTS Controllers to Maximize Available Transfer Capability. Paper presented in Bulk Power System dynamics and controls (IV)-Restructuring Conference, August 24-28, Santorini, Greece

[5] Kothari, M.L. and Tambey, N. (2003): Unified Power Controller (UPFC) Based Damping Controllers for Damping Low Frequency Oscillations in a power system, IE(I) Journal-EL. 84: 34-41.

[6] Limyingcharoen, S., Annakkage, U.D. and Pahalawaththa, N.C. (1998) Effects of Unified Power Flow Controllers on Transient Stability. In: IEEE Proceedings. 182-188.
[7] Nabavi-Niaki A., and M.R. Iravani, (1996): "Steady-state and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies", IEEE Trans. Power Systems. Vol. 11, No. 4, Pp. 1937-1943.
[8] Gyugyi, L. (1994): Dynamic Compensation of AC Transmission Line by Solid state synchronous voltage sources, IEEE Trans. Power delivery. 9: 904-911.
[9] Xiao – Ping Zhang, and Handshin, E., (2001): Modeling of the Generalized Unified Power Flow Controller (GUPFC) in a Non-Linear interior Point OPF, IEEE Trans. On Power Systems. **16**:367-373.
[10] Wang H.F., (1999): "Damping function of Unified Power flow controller", IEEE proc. Generation Transmission and Distribution, Vol. 146, No. 1, Pp. 81-87.
[11] Smith, K.S., Ran, L. and Penman, J. (1997): Dynamic Modeling of a Unified Power Flow Controller. IEEE proc. –Gener. Transm. Distrib., 23-65.
[12] Gholipour, E. and Saadate, S. (2005): Improving of Transient Stability of Power Systems Using UPFC, IEEE Transactions on Power Delivery. 9: 904-911.
[13] Chang, C.T. and Hsu, Y.Y.(2002). Design of UPFC controllers and supplementary Damping Controller for Transmission control and stability Enhancement of a longitudinal power system. In: IEEE proc. Generation, Transmission and Distribution. 463-478.
[14] Federico Milano, Member, IEEE, (2005): An Open Source Power Analysis Toolbox, IEEE transactions on power systems, vol. 20 No.3. August 2005, 1199-1206

APPENDIX

COMPARISON LINE FLOW RESULTS OF 41-BUS NIGERIAN GRID

LINE FLOWS		LINE	WITHOUT UPFC		WITH UPFC	
FROM BUS	TO BUS		P LOSS P.U	Q LOSS P.U	P LOSS P.U	Q LOSS P.U
Bus1	Bus2	1	0.00783	0.22441	0.00701	0.22211
Bus3	Bus2	2	0.00392	0.00138	0.00302	0.00121
BuS4	Bus7	3	0.01087	0.75825	0.01001	0.72623
Bus4	Bus7	4	0.02724	0.11435	0.02423	0.10112
Bus8	Bus4	5	0.03807	0.40293	0.02555	0.40102
Bus8	Bus4	6	0.02389	0.44152	0.02052	0.34113
Bus8	Bus9	7	0.01231	0.69381	0.00241	0.55274
Bus8	Bus10	8	0.00057	0.66596	0.00053	0.65531
Bus8	Bus10	9	0.00057	0.66596	0.00053	0.65531
Bus6	Bus6	10	0.00423	0.2803	0.00324	0.27111
Bus30	Bus33	11	0.00174	0.3118	0.00123	0.30012
Bus14	Bus11	12	0.00190	0.52043	0.00160	0.47091
Bus2	Bus3	13	0.00093	0.07689	0.00088	0.07647
Bus14	Bus15	14	0.01699	0.11866	0.01630	0.11047
Bus5	Bus17	15	0.00227	0.03572	0.00155	0.03435
Bus5	Bus17	16	0.00227	0.03572	0.00155	0.03435
Bus5	Bus17	17	0.00227	0.03572	0.00155	0.03435
Bus17	Bus21	18	0.00229	0.07028	0.00125	0.05041
Bus17	Bus21	19	0.00229	0.07028	0.00125	0.05041
Bus17	Bus21	20	0.00229	0.07028	0.00125	0.05041
Bus17	Bus22	21	0.00483	0.17665	0.00466	0.15647
Bus19	Bus18	22	0.00189	0.17796	0.00183	0.17423
Bus19	Bus18	23	0.00189	0.17796	0.00183	0.17423
Bus3	Bus4	24	0.00056	0.0236	0.00051	0.02311
Bus17	Bus18	25	0.03269	0.03268	0.02162	0.03268
Bus17	Bus18	26	0.03269	0.03268	0.02162	0.03268
Bu17	Bus20	27	0.00303	0.30771	0.00104	0.30706
Bus17	Bus20	28	0.00303	0.11435	0.02123	0.11223
Bus17	Bus20	29	0.00303	0.11435	0.02123	0.11223
Bus17	Bus20	30	0.00303	0.11435	0.00303	0.11223
Bus5	Bus23	31	0.01864	0.77419	0.01553	0.77405
Bus23	Bus17	32	0.00203	0.15401	0.00203	0.15400
Bus23	Bus17	33	0.00203	0.15401	0.00203	0.15400
Bus23	Bus16	34	0.00039	0.04138	0.00027	0.04026
Bus23	Bus24	35	0.00174	0.31180	0.00164	0.31180
Bus3	Bus4	36	0.01539	0.72885	0.01332	0.72881
Bus23	Bus24	37	0.00012	0.51047	0.00012	0.51037
Bus25	Bus23	38	0.00093	0.07689	0.00091	0.07587
Bus27	Bus26	39	0.00203	0.15401	0.00135	0.15401
Bus27	Bus26	40	0.00203	0.15401	0.00135	0.15401

Bus23	Bus27	41	0.00529	0.0632	0.00329	0.06320
Bus23	Bus27	42	0.00529	0.0632	0.00329	0.06320
Bus13	Bus23	43	0.00775	0.2257	0.00754	0.22530
Bus22	Bus28	44	0.00104	0.23343	0.00101	0.23342
Bus20	Bus28	45	0.00323	0.92007	0.00313	0.92007
Bus21	Bus30	46	0.00958	0.26342	0.00933	0.26312
Bus6	Bus3	47	0.0019	0.52043	0.0012	0.52011
Bus29	Bus30	48	0.01801	0.0572	0.01606	0.0572
Bus29	Bus30	49	0.01864	0.77418	0.01755	0.77406
Bus21	Bus31	50	0	0.1968	0	0.1964
Bus21	Bus32	51	0	0.06017	0	0.06012
Bus33	Bus25	52	0	0.19562	0	0.19503
Bus8	Bus35	53	0	0.29728	0	0.29705
Bus10	BuS36	54	0.01773	0.01847	0.01603	0.01845
Bus10	Bus36	55	0.01773	0.01847	0.01603	0.01845
Bus36	Bus34	56	0.04947	0.09741	0.04642	0.09711
Bus36	Bus34	57	0.04947	0.09741	0.04642	0.09711
Bus6	Bus3	58	0.02389	0.00502	0.02313	0.00482
Bus36	Bus32	59	0.01175	0.00466	0.01127	0.00437
Bus36	Bus32	60	0.01175	0.00466	0.01127	0.00437
Bus36	Bus32	61	0.01175	0.00466	0.01127	0.00437
Bus14	Bus34	62	0	0.02122	0	0.02111
Bus29	Bus27	63	0.03047	0.02561	0.02043	0.02550
Bus30	Bus40	64	0.04759	0.05424	0.03842	0.05420
Bus40	Bus41	65	0.00944	0.01075	0.00843	0.01064
Bus33	Bus5	66	0.05913	0.09173	0.05433	0.09167
Bus32	Bus38	67	0.01018	0.01932	0.01016	0.01920
Bus3	Bus5	68	0.03304	0.00612	0.03201	0.00519
Bus38	Bus29	69	0.06003	0.00904	0.04002	0.00901
Bus37	Bus38	70	0.01096	0.02314	0.01032	0.02311
Bus13	Bus33	71	0.08109	0.05203	0.06108	0.05201
Bus12	Bus11	72	0.04279	0.01004	0.03268	0.01001
Bus3	Bus5	73	0.02522	0.73685	0.02113	0.73651
Bus3	Bus5	74	0.02522	0.73685	0.02113	0.73651
Bus38	Bus29	75	0.02357	0.03274	0.02301	0.03271
Bus38	Bus39	76	0.01405	0.19562	0.01202	0.19524
Bus38	Bus39	77	0.01405	0.19562	0.01202	0.19524
TOTAL LOSSES			**1.07961**	**12.0940**	**0.87576**	**12.0922**