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Enhancing Stability & Cost Reduction Of Multigrid System By UPFC

Siddharth Gupta[1], Er. Vinay Kumar Tripathi[2]

Electrical Engineering Department, SHIATS Deemed University Allahabad, India[1]

Assistant Professor, Electrical Engineering Department, SHIATS Deemed University, Allahabad, India[2]

Abstract: In some decades, the demand for electrical power has increased but the generation and transmission remained limited due to limited resources and environmental restrictions. The increased demand for electrical power has also increased the complexity in the transmission system. It resulted in the form of the question of stability of power system. Here the stability of power system with possible minimum cost is the main aspect of the present analysis. This problem is solved by using the Solid State devices, known as Flexible AC transmission systems (FACTS) devices. The UPFC is one of the most promising devices of FACTS devices for power system stability with reduction in cost of power. This paper has a comprehensive review on the research and developments in the matter of enhancing power system stability with cost reduction in multigrid network of power supply with the use of UPFC.

Keywords: power system stability, Solid State devices, FACTS, UPFC

I. INTRODUCTION

Now a days, our politics and policies are in favour of welfare state .There is a continuous increases in the demand for electrical power. There is another fact that we are limited in generation & transmission of power in short term. For welfare of masses with increase in power availability, its cost is also a very important factor. In short period, with limited resources, we find ourselves unable in increasing power production and power transmission network.

To coop with the existing dual natured problem of economic power generation, engineers felt the necessity of a new type of technology which could provide a system suitable for our society in the present prevailing situation.
In power field, there is need for a more efficient and fast responding electrical systems. The solid-state devices are innovative technologies in power system. These are called FACTS devices. This has enhanced the generation and power transmission stabilities and has also solved the problems of overloading of power network along with the question of cost minimization of electrical power.

FACTS have gained a great interest during the last few years, due to recent advancements in power electronics. FACTS devices are being mainly used for solving various problem related to power system steady state control such as voltage regulation, power flow control, and transfer capability enhancement. FACTS devices are the key to produce electrical energy economically and environmental friendly in future. There are many types of FACTS devices such as Static Var Compensators (SVC), static Synchronous Compensators (STATCOM), Thyristor Controlled Series Compensators (TCSC), Static Synchronous Series Compensators (SSSC) and Unified Power Flow Controllers (UPFC). The UPFC is one of the most promising devices of FACTS devices. The UPFC controls all basic power system parameter such as transmission voltage, impedance and phase angle. These devices offer an alternative method to mitigate power system oscillations. UPFC can improve stability of single machine infinite bus (SMIB) system as well as multi-machine system. The interconnected power system shows some special problems related to stability of power system.

This paper investigates the improvement of power system stability and reduction of cost for a multigrid power system using UPFC. A Matlab/Simulink model is developed for a multigrid power system using UPFC. The performance of multigrid electrical network is compared with & without UPFC device.

From the simulation results, we find that UPFC is an effective FACTS device for power system stability and cost reduction of a multigrid power system.

II. UPFC

UPFC is a combination of Static Synchronous Compensator (STATCOM) and SSSC. It is known as third generation FACTS devices. It has unique abilities. It controls real and reactive power flow independently. UPFC was introduced in 1991. The first utility demonstration of a UPFC was constructed at the Inez substation of American Electric Power in 1998.

As shown in figure 2, A UPFC has two convertors. These convertors are self communicating and linked with one another by a common DC capacitor.

Again this entire system is connected to the ac systems though transformers. These transformers are coupled to line as shunts and in series.

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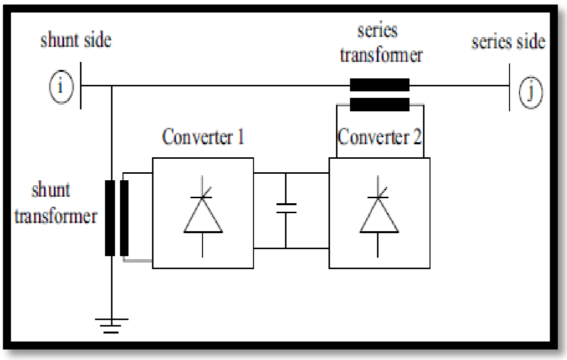

Figure 2: Circuit Diagram of Unified Power Flow Controller (UPFC)

III. MODELLING & OPERATION OF UPFC

This arrangement of UPFC ideally works as a ideal ac to dc power converter in which real power can freely flow in either direction between ac terminals of the two converters angle and magnitude in series with the line. The transmission line current flowing through this voltage source results in real and reactive power exchange between it and the AC transmission system. The inverter converts the real power exchanged at ac terminals into dc power which appears at the dc link as positive or negative real power demand.

Series converter Operation: In the series converter, the voltage injected can be determined in different modes of operation: direct voltage injection mode, phase angle shift emulation mode, Line impedance emulation mode and automatic power flow control mode. Although there are different operating modes to obtain the voltage, usually the series converter operates in automatic power flow control mode where the reference input values of P and Q maintain on the transmission line despite the system changes.

Shunt converter operation: The shunt converter operated in such a way to demand the dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor Vdc constant. Shunt converter operates in two modes: VAR Control mode and Automatic Voltage Control mode. Typically, Shunt converter in UPFC operates in Automatic voltage control mode.

Equivalent Circuit Operation of UPFC :As shown in Fig 3.1, the two-voltage source converters of UPFC can modelled as two ideal voltage sources one connected in series and other in shunt between the two buses. The output of series voltage magnitude V_{se} controlled between the limit Vsemax < V_{se} < V_{semin} and the angle θ_{se} between the limits $0 \le \theta_{se} \le 2\Pi$ respectively. The shunt voltage magnitude V_{sh} controlled between the limits $V_{shmax} < V_{sh} < V_{shmin}$ and the angle between $0 \le \theta_{sh} \le 2\Pi$ respectively. Z_{se} and Z_{sh} are considered as the impedances of the two transformers one connected in series and other in shunt between the transmission line and the UPFC as shown in the Fig 3.1 which is the UPFC equivalent circuit.

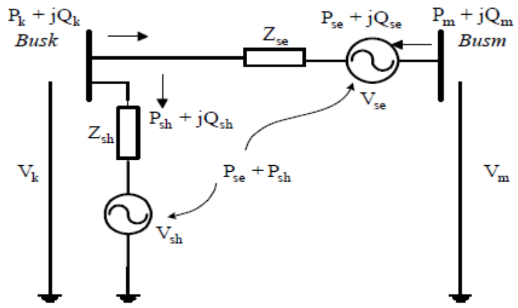

Figure 3.1: Equivalent circuit of UPFC

The ideal series and voltage source from the Fig 3.1 can written as

$$V_{se} = V_{se}(\cos\theta_{se} + j\sin\theta_{se}) \quad (1)$$

$$V_{sh} = V_{sh}(\cos\theta_{sh} + j\sin\theta_{sh}) \quad (2)$$

The magnitude and the angle of the converter output voltage used to control the power flow mode and voltage at the nodes as follows:

1. The bus voltage magnitude can be controlled by the injected a series voltage V_{se} in phase or anti-phase.
2. Power flow as a series reactive compensation controlled by injecting a series voltage V'_{se} in quadrature to the line current.
3. Power flow as phase shifter controlled by injecting a series voltage of magnitude V''_{se} in quadrature to node voltage θ_m

UPFC power Equations Based on the equivalent circuit as shown in Fig 3.1, the active and reactive power equations can be written as follows:

At node k:

$$P_k = V^2{}_k G_{kk} + V_k V_m (G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)) + V_k Vse(G_{km}\cos(\theta_k - \theta_{se)}) + B_{km}\sin(\theta_k - \theta_{se})) + V_k V_{sh}(G_{sh}\cos(\theta_k - \theta_{sh}) + B_{sh}\sin(\theta_k - \theta_{sh}))...(3) \quad (3)$$

$$Q_k = -V^2{}_k B_{kk} + V_k V_m (G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)) + V_k V_{se}(G_{km}\sin(\theta_k - \theta_{se}) - B_{km}\cos(\theta_k - \theta_{se})) + V_k V_{sh}(G_{sh}\sin(\theta_k - \theta_{sh}) - B_{sh}\cos(\theta_k - \theta_{sh}))...(4) \quad (4)$$

At node m:

$$P_m = V^2{}_m G_{mm} + V_m V_k (G_{mk}\cos(\theta_m - \theta_k) + B_{mk}\sin(\theta_m - \theta_k)) + V_m V_{se}(G_{mm}\cos(\theta_m - \theta_{se}) + B_{mm}\sin(\theta_m - \theta_{se})).....5 \quad (5)$$

$$Q_m = -V^2{}_m B_{mm} + V_m V_k (G_{mk}\sin(\theta_m - \theta_k) - B_{mk}\cos(\theta_m - \theta_k)) + V_m V_{sh}(G_{mm}\sin(\theta_m - \theta_{se}) - B_{mm}\cos(\theta_m - \theta_{se}))...6 \quad (6)$$

Series converter:

$$P_{se} = V^2{}_{se} G_{mm} + V_{se} V_k (G_{km}\cos(\theta_{se} - \theta_k) + B_{km}\sin(\theta_{se} - \theta_k)) \quad (7)$$
$$\ldots + V_{se} V_m (G_{mm}\cos(\theta_{se} - \theta_k) + B_{mm}\sin(\theta_{se} - \theta_m))....7$$

$$Q_{se} = -V^2{}_{se} B_{mm} + V_{se} V_k (G_{km}\sin(\theta_{se} - \theta_k) - B_{km}\cos(\theta_{se} - \theta_k)) + V_{se} V_m (G_{mm}\sin(\theta_{se} - \theta_m) - B_{mm}\cos(\theta_{se} - \theta_m))$$

Shunt converter:

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$$P_{sh} = -V^2{}_{sh}G_{sh} + V_{sh}V_k(G_{sh}\cos(\theta_{sh}-\theta_k) + B_{sh}\sin(\theta_{sh}-\theta_k)..8 \quad (8)$$

$$Q_{sh} = V^2{}_{sh}B_{sh} + V_{sh}V_k(G_{sh}\sin(\theta_{sh}-\theta_k) - B_{sh}\cos(\theta_{sh}-\theta_k)) \quad (9)$$

Where

$$Y_{kk} = G_{kk} + jB_{kk} = Z^{-1}{}_{se} + Z^{-1}{}_{sh}....10 \quad (10)$$

$$Y_{mm} = G_{mm} + jB_{mm} = Z^{-1}{}_{se} \quad (11)$$

$$Y_{km} = Y_{mk} = G_{km} + jB_{km} = -Z^{-1}{}_{se} \quad (12)$$

$$Y_{sh} = G_{sh} + jB_{sh} = -Z^{-1}{}_{sh} \quad (13)$$

Assuming a free converter loss operation, the active power supplied to the shunt converter P_{sh} equals to the active power demanded by the series converter P_{se}.

$$P_{se} + P_{sh} = 0 \quad (14)$$

Furthermore if the coupling transformers are assumed to contain no resistance then the active power at bus k matches the active power at bus m; that is,

$$P_{sh} + P_{se} = P_k + P_m = 0 \quad (15)$$

The UPFC power equations linearised and combined with the equations of the AC transmission network. For the cases when the UPFC controls the following parameters:
1) Voltage magnitude at the shunt converter terminal
2) Active power flow from bus m to bus k and
3) Reactive power injected at bus m, and taking bus m to be PQ bus.

IV. TRANSMISSION PRICING

There is great task of the fair allocation of the transmission cost to the transmission users .The tariffs should be such that it reflect the actual usage of the network and it should also work as incentives for the right placement of new generation facilities. The calculation of tariff should be done by taking into consideration load forecast, generation availabilities and possible line outages, and evaluated ex-post when all the necessary data are available. A fixed amount for transmission cost should be allocated to both the producers and consumers considering the idea of present maintenance and future installation as a part of development.

Different types of pricing schemes are in the world, these are also implemented in different markets. The name of the some of the pricing scheme are as fallows-

1. Postage Stamp;
2. MW-Mile (original);
3. Unused absolute MW-Mile;
4. Unused reverse MW-Mile;
5. Unused zero counter-flow MW-Mile;
6. Used absolute MW-Mile;
7. Used reverse MW-Mile and
8. Used zero counter-flow MW-Mile

Out of these methods an improved method is MW-Mile Method. This method is also known as line by line method. In this method power flow and the distance between injection and withdrawal locations are taking into consideration for transmission charges calculation. The aspect of transmission congestion not taken into consideration. This method gives the full recovery of the fixed transmission cost. This cost is calculated on the basis of actual use of the transmission network. For obtaining transacted power transmission capacity is used. Line length, the cost per unit megawatt per unit length for all the lines are considered, next thing the net power flow impact is find out by using and incremental absolute approach.

The power flow impact $\Delta P = |\Delta P_{t,i}|-|\Delta P_{b,i}|$ in line i .
$P_{t,i}$ is the power flow in MW in line i during transaction .$P_{b,i}$ is power flow in MW in line i for base case.
The total contribution of each transaction t to the total transmission capacity cost is given by the formula

$$TC_t = TC \frac{\sum_{k\in K} C_k}{\sum_{t\in T}\sum_{k\in K}} \frac{L_k}{C_k} \frac{MW_{t,k}}{L_k MW_{t,k}}$$

Where,

TC_t = price charged for transaction t in \$/MW
TC = total cost of all lines in \$
L_k= length of line k in mile
C_k= cost per MW per unit length of line k
$MW_{t,k}$ = flow in line k due to transaction t
T= set of transactions
K= set of lines

This analysis of the contribution of each transaction is done before and after the placing FACTS devices. This gives us information about the share of each transaction. We find that this share change after inclusion of FACTS devices.

The pricing methodology is given below:
Step-A: The total cost of the line is equal to the unit cost of the line into line length.

Step-B: Using MATLAB/Simulink model, base case power flow on all lines is find out.

Step-C: find the new power flow solution with the transaction T1, and hence the power flow on each line.
(A negative sign indicates a reversal of flow direction with respect to the base case power flow. Here negative sign is dropped because of absolute approach).

Step-D: Similarly the new power flow solution with the transaction T2 is calculated, and hence the power flows on each line is obtained.

Step-E: By the transaction T1 the incremental power flow on each line is calculated.

Step-F: Similarly using transaction T2 the incremental power flow on each line is calculated.

Step-G: After calculating usage for each line because of transaction T1, usage for total transmission system is find out.

Step-H: Same thing is done for transaction T2.

Step-I: For proportional allocation of the cost total transmission system usage by T1 and T2 are calculated.

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Step-J: Similarly for transactionT1 & transactionT2, proportional allocation of costs is calculated.

For calculating wheeling charges for each participant according to their contribution in MW power flow for each line. Here it is assumed that the generators pay 100% of the transmission cost of services to the transmission utility.

IV. TEST SYSTEM FOR STABILITY & PRICING ANALYSIS

In this system, there are three transmission lines with two generators supplying an industrial load is choosen for analysis purpose. The load is supplied by the two generators with G1 supplying 700 MW, G2 supplying 800 MW. Table 1 shows the line lengths and the cost per MW per unit length of the line. This data is used for calculating the contributions of each generator transaction towards the total transmission capacity cost using the MW-mile methodology. The main aim of the analysis is to look at the impact of the FACTS devices on the system pricing and how the contributions of each transaction change with the inclusion of FACTS devices.

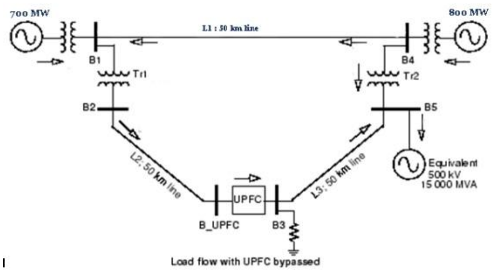

Figure.4- Test System

VI. DESCRIPTION OF TEST SYSTEM

Using the Machine Initialization tool of the Powergui block, the model has been initialized with plants #1 and #2 generating respectively 700 MW and 800 MW and with the UPFC out of service (Bypass breaker closed). The resulting power flow obtained at buses B1 to B5 is indicated on the model.

A UPFC is used to control the power flow in a 500 kV /230 kV transmission systems. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through five transmission lines (L1, L2, L3,L4 & L5) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV, 15000 MVA equivalent and to a 200 MW load connected at bus B3.

Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 800 MW generation capacity of power plant #2 is exported to the 500 kV equivalent through two 400 MVA transformers connected between buses B4 and B5. For this example we are considering a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA).

The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected through a DC bus). The series converter can inject a maximum of 10% of nominal line-to-ground voltage in series with line L2.

TABLE I

CALCULATION OF COST ALLOCATION BASED ON THE MW-MILE METHOD WITHOUT UPFC IN THE SYSTEM

Steps	L1	L2	L3	L4	L5
Cost ($)	176000	313650	138800	129200	56550
Base power flow(MW)	176	697	694	646	1131
Power flow due to T1	101	421	420	100	316
Power flow due to T2	286	284	284	533	609
$MW_{t,k}$ due to T1**	75	276	274	546	815
$MW_{t,k}$ due to T2**	110	413	410	113	522

****Incremental power flow**

CALCULATION OF COST ALLOCATION BASED ON THE MW-MILE METHOD WITH UPFC IN THE SYSTEM

Steps	L1	L2	L3	L4	L5
Cost ($)	168000	301500	137400	130800	56550
Base power flow(MW)	168	670	687	654	1131
Power flow due to T1	24	498	497	24	315
Power flow due to T2	363	361	360	455	608
$MW_{t,k}$ due to T1**	144	172	190	630	816
$MW_{t,k}$ due to T2**	195	309	327	199	523

**Incremental power flow

VII. POWER MEASUREMENT AT VARIOUS LINES

In this system, the series converter is rated 100 MVA with a maximum voltage injection of 0.1 pu. The shunt converter is also rated 100 MVA. Also verify, in the control parameters, that the shunt converter is in Voltage regulation mode and that the series converter is in Power flow control mode.

The UPFC reference active and reactive powers are set in the magenta blocks labelled Pref(pu) and Qref(pu).

At t=5 s, when the Bypass breaker is opened, the natural power is diverted from the Bypass breaker to the UPFC series branch without noticeable transient.

At t=10 s, the power increases at a rate of 1 pu/s. It takes one second for the power to increase. See the variations of active powers at buses B1 to B5 on the VPQ Lines scope.

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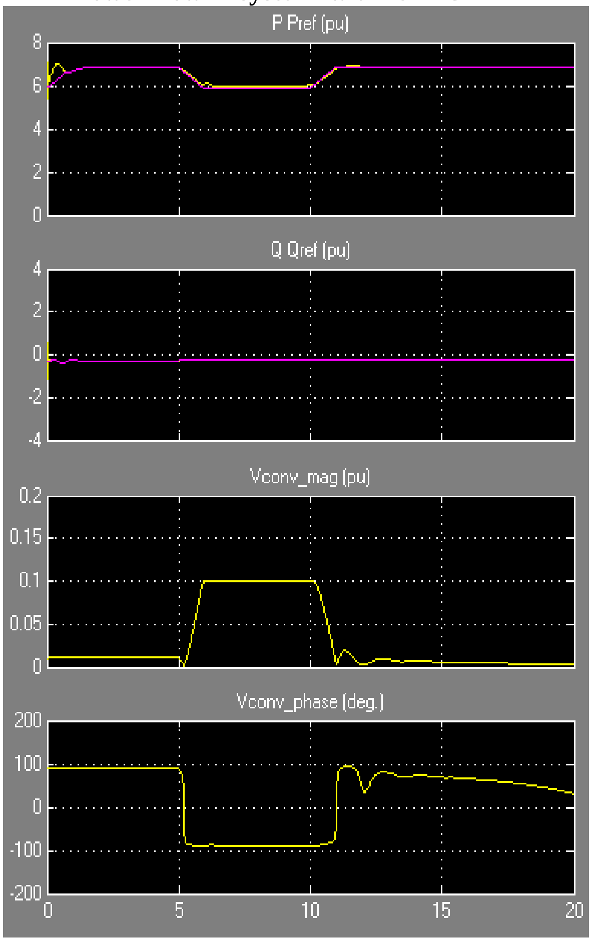
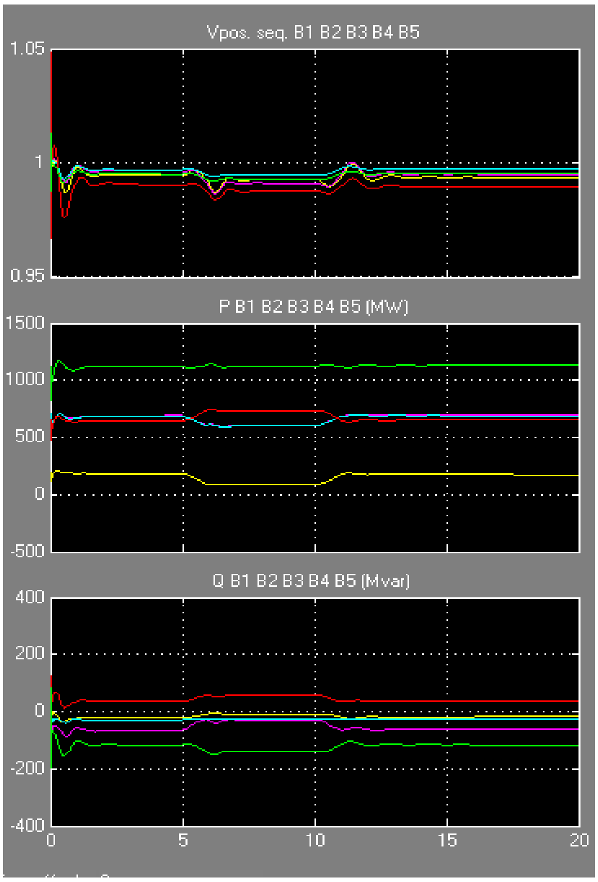
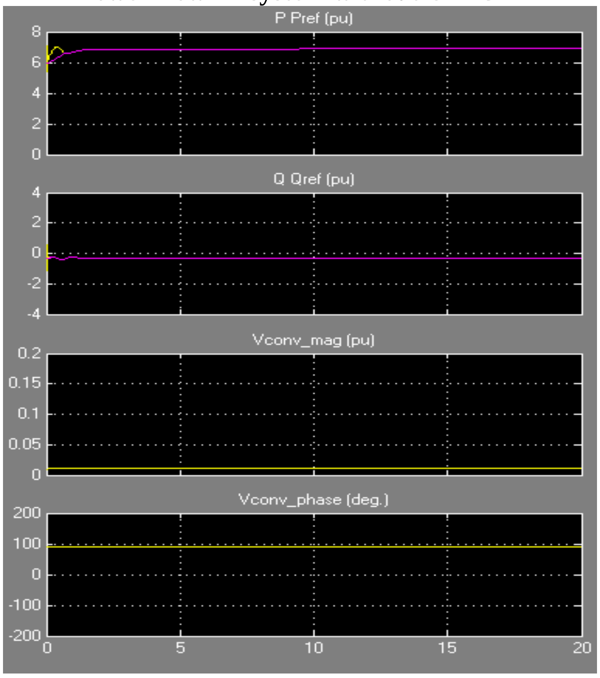
Vol. 2, Issue 5, May 2014

1. Power flow in system with UPFC





2. Power flow in system without UPFC



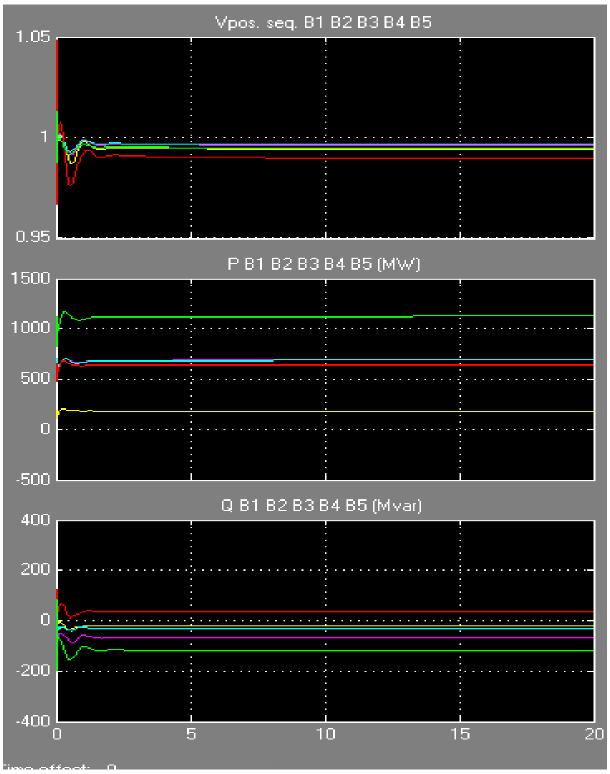


TABLE II
Pricing With And Without FACTS

Pricing / PLANT	WITHOUT FACTS ($)	WITH FACTS ($)
P1	396022	309665
P2	448179	380585

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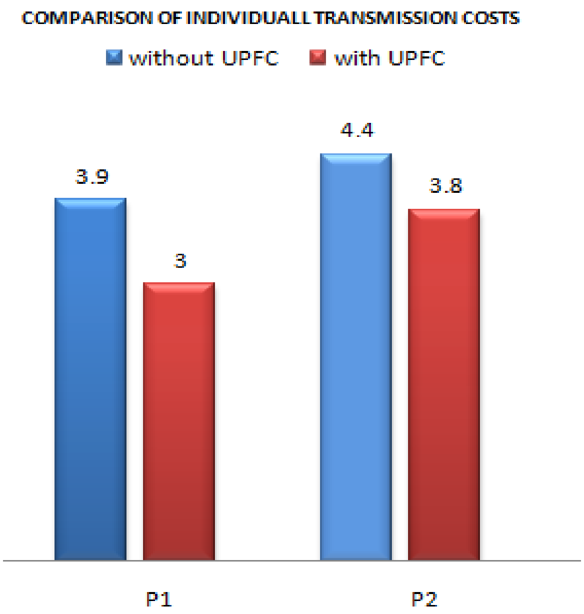

Figure 7. Comparison of transmission costs

VIII. CONCLUSIONS

This paper investigates the capability of UPFC on system stability with cost reduction in multigrid power system. It has 5 bus system B1, B2, B3, B4 & B5 for measure the power flow in complete power system. The analysis of power flow is done with and without UPFC at different mode of operation. It reduces the flow in heavily loaded lines, resulting in an increased loadability of network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network. Without UPFC the power flow losses of all the buses increases so the cost of power flow of complete system becomes increases but using the UPFC the losses become less so the cost become also decreases.

REFERENCES

[1] A.V .Naresh Babu and S.Sivanagaraju: Multi-Line Flexible Alternating Current Transmission System (FACTS) Controller for Transient Stability Analysis of a Multi-Machine Power System Network : International Journal of Electronics and Electrical Engineering 6 2012

[2] D. Murali (Research Scholar in EEE Dept.,Government College of Engineering,) Comparison of FACTS Devices for Power System Stability Enhancement: International Journal of Computer Applications (0975 – 8887) Volume 8– No.4, October 2010

[3] power flow controller(IPFC),” ARPN Journal of Engineering and Applied Sciences, vol.5, no.10,pp.1-4, Oct. 2010.

[4] M. A. Abido (Electric Engineering Department, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia) POWER SYSTEM STABILITY ENHANCEMENT USING FACTS CONTROLLERS: April 2009

[5] Alok Kumar Mohanty, Amar Kumar Barik (Asst. Professor, Department of EN, Raajdhani Engineering College, Bhubaneswar-17) Power System Stability Improvement Using FACTS Devices: International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.1, Issue.2, pp-666-672 ISSN: 2249-6645, 2009,

[6] MATLAB Based Simulation of TCSC FACTS Controller : Proceedings of 2nd National Conference on Challenges & Opportunities in Information Technology (COIT-2008) RIMT-IET, Mandi Gobindgarh. March 29, 2008

[7] Sidhartha Panda and Narayana Prasad Padhy Power System with PSS and FACTS Controller,Modelling, Simulation and Simultaneous Tuning Employing Genetic Algorithm : International Journal of Electrical and Electronics Engineering 1:1 2007 ,

[8] A.V.Naresh Babu, S.Sivanagaraju, Ch.Padmanabharaju and T.Ramana“Power flow analysis of a power system in the presence of interline

[9] H.Saadat,“ Power System Analysis,” Tata McGraw-Hill Edition, 2002.

[10] Pinnarelli, De Martinis, Andreotti, “Modelling of unified Power Flow Controller into Power System using P-Spice.”, in IPST 2001-paper 205, Ago 2001.

[11] D.Thukaram and A.Lomi, “Selection of static VAR compensator location and size for system voltage stability improvement,” Electric

[12] Power Systems Research, vol. 54 , pp. 139-150, 2000.

[13] N.G. Hingorani and L. Gyugyi, “Understanding FACTS: concepts and technology of flexible ac transmission systems”, IEEE Press, NY, 1999.

[14] Y.H. Song and A.T. Johns, “Flexible ac transmission systems (FACTS)”, The Institute of Electrical Engineers, London, 1999.

[15] D. Shirmohammadi et al., “Evaluation of transmission network capacity use for wheeling transactions,” IEEE Trans. on Power Systems, vol. 4, no. 4, Oct. 1989, pp. 1405–1413.

BIOGRAPHIES

Siddharth Gupta Belong to UP Received his Bachelor of Technology degree from Uttar Pradesh Technical University, Allahabad in 2012. He is pursuing his M.Tech in Electrical Engg. (Power System) from SHIATS, Allahabad, UP-India.

Er.Vinay. Kumar Tripathi (Assistant Professor) Belongs to Allahabad, Received his Bachelor of Technology degree from the UCER (India) in 2003, He obtained his M.Tech in control & instrumentation engineering from MNNIT Allahabad, India and pursuing Ph. D. From SHIATS Deemed University, Allahabad in 2013.He is working as Assistant Professor (Electrical Engineering Department) in SSET, SHIATS (Formerly Allahabad Agriculture Institute (deemed University) Allahabad from last 10 years. His field of interest includes control & instr. Multiphase, power quality.