Research Journal of Applied Sciences, Engineering and Technology 3(7): 640-649, 2011
ISSN: 2040-7467

Received: May 13, 2011 Accepted: June 15, 2011 Published: July 25, 2011

Study of UPFC Location for Installing in Power System to Control Power Flow

Amir Kahyaei
Department of Engineering, Shoushtar Branch, Islamic Azad University,
Shoushtar, Iran

Abstract: This research studies the effect of location of Unified Power Flow Controller (UPFC) on power system. In this study the several case studies including various points for installing UPFC on power system are considered and results of profile of voltage at all of buses of system is obtained. The active and reactive of all transmission lines of power system following installing UPFC at various points of system is discussed and results are analyzed. The encouragement to the construction of HV lines, the amount of power transmission/km on HV line and the amount of power transaction as seen from economic side is much responsible for concern towards congestion in power system. The solution is the use of FACTS devices especially the use of UPFC. In this research the study of UPFC with its various candied locations for installing on power system is understood. Second, the operation of control system used in its converters is also studied. Finally by help of modeling of a power system in MATLAB/SIMULINK, and by installing UPFC in transmission link, its use as power flow controller and voltage injection is seen. Conclusion is made on different results to see the benefit of UPFC in power system.

Key words: Facts devices, Unified Power Flow Controller (UPFC), voltage source convertor, power flow controller, power flow

INTRODUCTION

The ongoing deregulation of power systems around the world may not only bring cheaper electricity and better service to the customers but also present new technological challenges to the power industries and researchers. In a deregulated environment, the open access to the transmission networks requires adequate Available Transfer Capability (ATC) to guarantee economic transactions (Carsten, 2002). However, in a privatized electricity market, the major traditional ways to enhance ATC, such as rescheduling active power generations, adjusting terminal voltage of generators, and changing taps of on-load tap changer, etc, may not be centrally controlled by the transmission network owner or system operator. Construction of new transmission lines has always been an option, but it is subject to tougher and tougher environmental restrictions and sometimes social problems too (Enrique *et al*., 2004). Besides, it is quite expensive to construct new transmission lines, which is not profitable for the network owners. Thus, effective utilization of the existing transmission systems with the help of new technologies will be a choice in many power systems in the world (Taranto *et al*., 1992). This affords very good opportunities for the application of the so-called Flexible AC Transmission System (FACTS) devices. Generally speaking, the FACTS devices are to make the power network controllable by means of the substantial incorporation of power electronic devices and their control methods into the high voltage side of the network. With the availability of the fully controlled semiconductor devices such as the Gate Turn-off Thyristor (GTO) and the Insulated Gate Bipolar Transistor (IGBT), and the invention of new topologies, i.e. the combination of multiple compensators, the hitherto most powerful and versatile group of FACTS devices, namely combined compensators, has been developed. Its representatives include the Famous Unified Power Flow Controller (UPFC) and the Interline Power Flow Controller (IPFC) (Handschin and Lehmkoster, 1999). The latter is the latest generation of FACTS devices. It is well known that heavily loaded lines and buses with relatively low voltages are factors that significantly limit ATC (Noroozian *et al*., 1997). Facilitated by its multiple series compensators combined by a common DC voltage link, the IPFC can not only regulate bus voltages but also directly transfer active power among/between the compensated lines (Narain *et al*., 2000; Jun and Akihiko, 2006). This feature offers a very good solution for ATC enhancement. Therefore, this study investigates the impact of the IPFC on ATC enhancement, in which the evaluation of ATC is formulated as an optimal power flow (OPF) control problem. Comparison with the results of UPFC is also presented for better understanding of the characteristics of these combined compensators.

However not of previous work has investigated the effect of locations of UPFC on desired parameters such as voltage magnitude and phase (angle) of voltage at all buses of system. In addition to in previous work the effect of location candied for installing UPFC on real and reactive power flow in transmission lines in power system has not been considered. So in this study the effect of location of installing UPFC on profile of voltage including magnitude and phase (angle) of voltage has been investigated. In addition to the effects of various locations of installing UPFC on power flow in transmission lines of power system such as real and reactive power flow are analyzed and discussed.

UNIFIED POWER FLOW CONTROLLER

Line outage, congestion, cascading line tripping, power system stability loss are the major issues where capability and utilization of FACTS are noticed. Representative of the last generation of FACTS devices is the Unified Power Flow Controller (UPFC). The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). Such "new" FACTS device combines together the features of two "old" FACTS devices (Venkataraman, 2002; Peng *et al*., 2004): The Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). In practice, these two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer, connected to each other by a common dc link including a storage capacitor. The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with the transmission line .Thereby, the UPFC can fulfill functions of reactive shunt compensation, active and reactive series compensation and phase shifting. Besides, the UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system (Xiao-Ping and Handschin, 2001a; Ying *et al*., 2000). As the need for flexible and fast power flow controllers, such as the UPFC, is expected to grow in the future due to the changes in the electricity markets, there is a corresponding need for reliable and realistic models of these controllers to investigate the impact of them on the performance of the power system. In this article emphasis is laid to project the use of UPFC in transmission link to increase the power flow and to improve the voltage profile of the system using MATLAB SIMULINK.

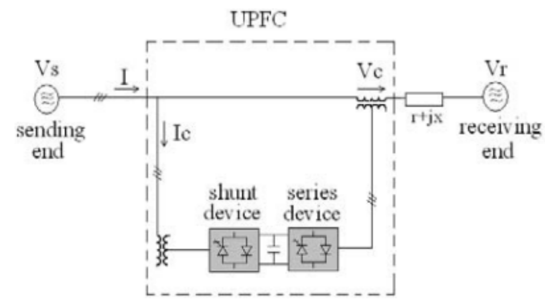

Fig. 1: Basic UPFC functional scheme

The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer; while the other one is connected in series through a series transformer (Xiao-Ping, 2003).A basic UPFC functional scheme is shown in Fig. 1.

The series inverter is controlled to inject a symmetrical three phase voltage system (Vc), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals (Xiao-Ping *et al*., 2001). The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor Vdc constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.

The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a STATCOM (Static Synchronous Compensators) that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC (Static Synchronous series compensators) that generates or absorbs reactive power to regulate the current flow, and hence the power flows on the transmission line.

The UPFC has many possible operating modes. In particular, the shunt inverter is operating in such a way to inject a controllable current, into the transmission line. This current consists of two components with respect to the line voltage: the real or direct component, which is in phase or in opposite phase with the line voltage, and the reactive or quadrature component, which is in quadrature.

The direct component is automatically determined by the requirement to balance the real power of the series inverter. The quadrature component, instead, can be independently set to any desired reference level (inductive or capacitive) within the capability of the inverter, to absorb or generate respectively reactive power from the line. The shunt inverter can be controlled in two different modes:

VAR control mode: The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the Var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, Vdc, is also required.

Automatic voltage control mode: The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer.

The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.

Direct voltage injection mode: The reference inputs are directly the magnitude and phase angle of the series voltage.

Phase angle shifter emulation mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage.

Line impedance emulation mode: The reference input is an impedance value to insert in series with the line impedance

Automatic power flow control mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

UPFC CONTROL SYSTEM

In order to understand the UPFC Control System the phasor diagram in the Fig. 2 and 3.

This FACTS topology provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with

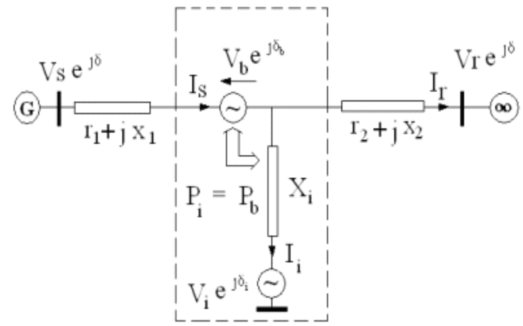

Fig. 2: Single-line diagram of a UPFC

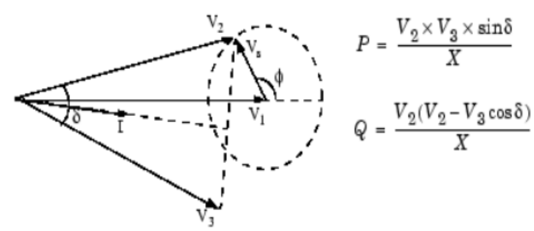

Fig. 3: Phasor diagram of voltages and currents

respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle with respect to V1 is varied from 0 to 360 degrees, the locus described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled. The shunt converter operates as a STATCOM (Teerathana *et al*., 2005).

In summary, the shunt converter controls the AC voltage at its terminals and the voltage of the DC bus. It uses a dual voltage regulation loop: an inner current control loop and an outer loop regulating AC and DC voltages.

Control of the series branch is different from the SSSC. In a SSSC the two degrees of freedom of the series converter are used to control the DC voltage and the reactive power (Xiao-Ping and Handschin, 2001b) .In case of a UPFC the two degrees of freedom are used to control the active power and the reactive power. A simplified block diagram of the series converter is shown in Fig. 4.

The series converter can operate either in power flow control (automatic mode) or in manual voltage injection mode. In power control mode, the measured active power and reactive power are compared with reference values to produce P and Q errors. The P error and the Q error are used by two PI regulators to compute respectively the Vq

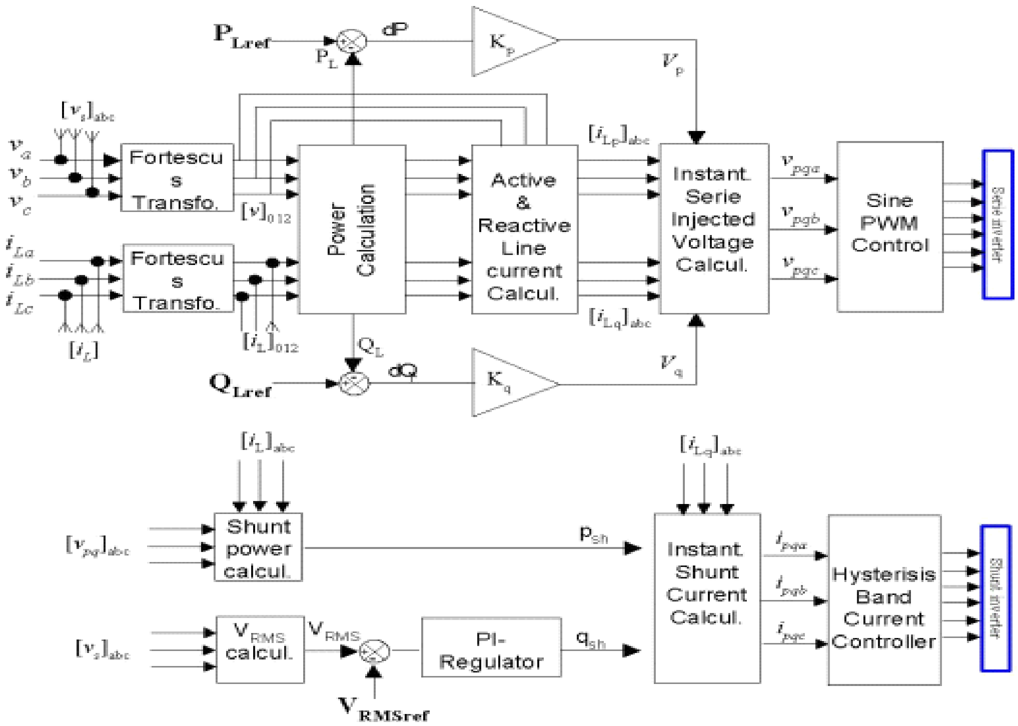

Fig. 4: Simplified block of the series converter control system

and Vd components of voltage to be synthesized by the VSC. (Vq in quadrature with V1controls active power and Vd in phase with V1 controls reactive power).

In manual voltage injection mode, regulators are not used. The reference values of injected voltage Vdref and Vqref are used to synthesize the converter voltage.

SIMULATION AND RESULTS

Using the concept of the control system a power system is taken to implement the use of UPFC. The two modes i.e. the power flow control and the voltage injection mode are simulated in SIMULINK to see the effect of UPFC on a power system. Study is carried out to verify the utility of FACT device. The Fig. 5 illustrates application study the steady-state and dynamic performance of a unified power flow controller (UPFC) used to relieve power congestion in a transmission system. The load flow analysis and the single line diagram simulation are done on power flow simulator. This software helps to calculate the power flow, the voltage at each bus and the cost effectiveness of the system.

Based on test power system shown in Fig. 5 the Optimal Power Flow Analysis (OPF) has been implemented for various case studies. Figure 6 shows the case 1 that in this one the UPFC is not implemented. This case is considered in order to investigate the effect of absence of UPFC in comparison with presence of UPFC in OPF. Other case studies are shown in Fig. 7-9. Figure 7 shows the simulink model of test power system with UPFC in Bus 6. Figure 8 shows the simulink model of test power system with UPFC in Bus 3. Figure 9 shows the simulink model of test power system with UPFC in Bus 4.of course the other candied locations for installing UPFC are not shown in this study..

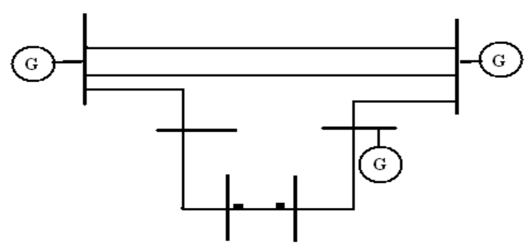

Fig. 5: Test power system

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 three transmission lines (L1, L2, L3) 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 (Fig. 6) which is transmitted to a 500 kV, 15000 MVA equivalent and to a

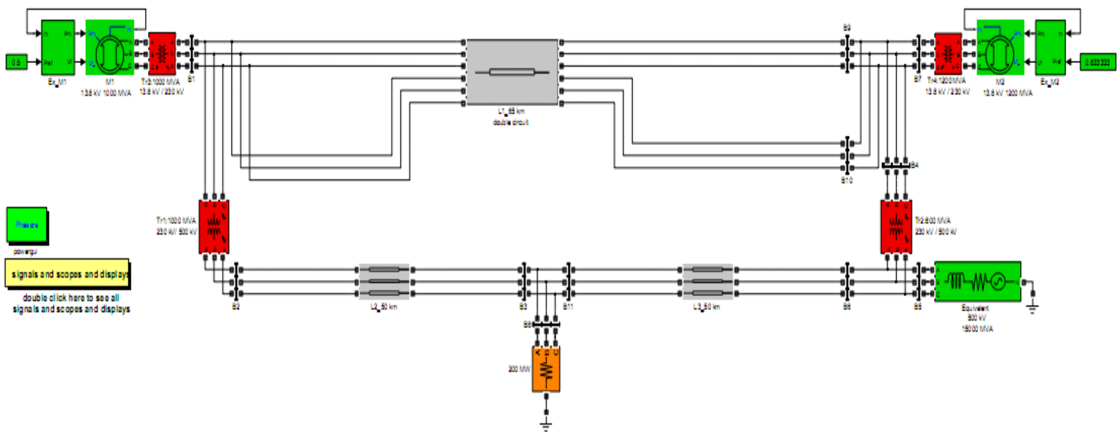

Fig. 6: Simulink model of test power system with UPFC

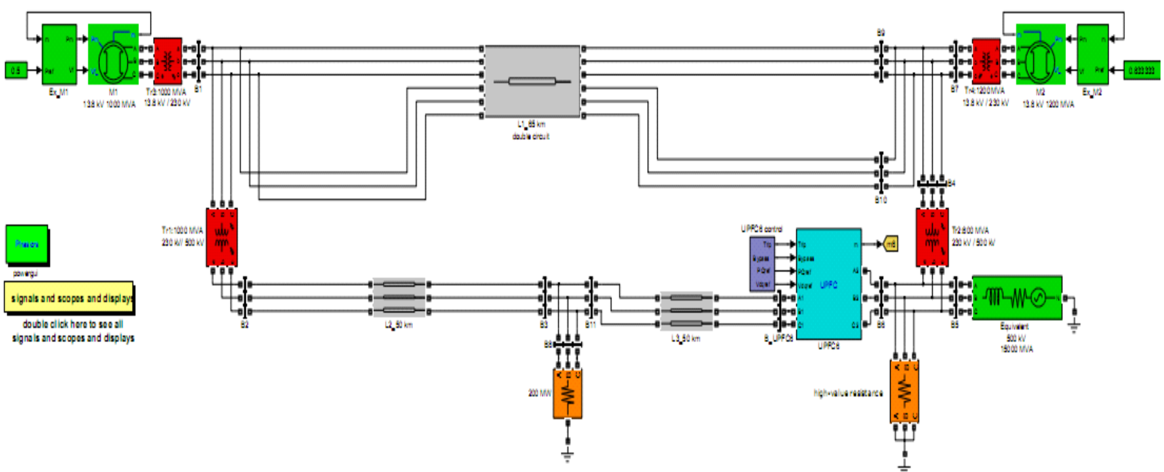

Fig.7: Simulink model of test power system without UPFC in Bus 6

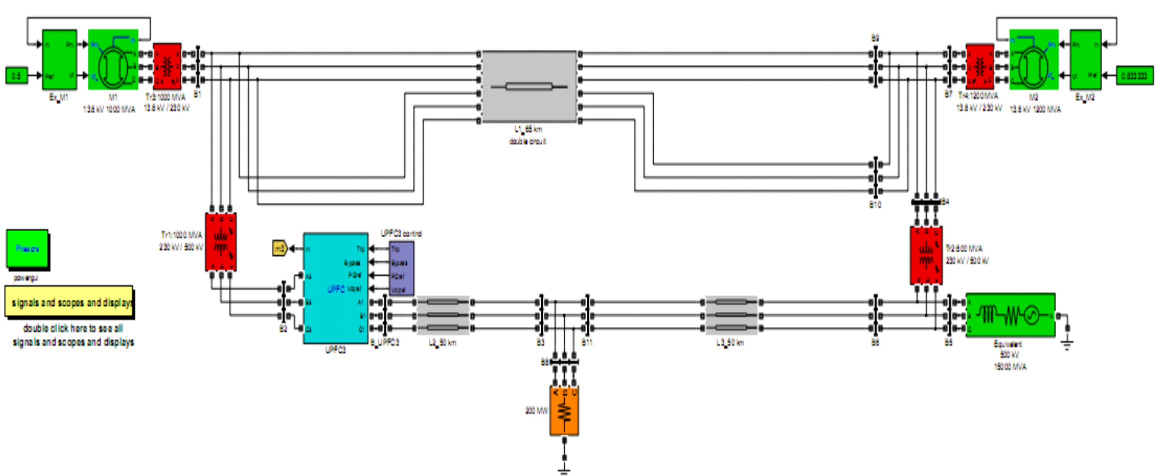

Fig. 8: Simulink model of test power system with UPFC in Bus 3

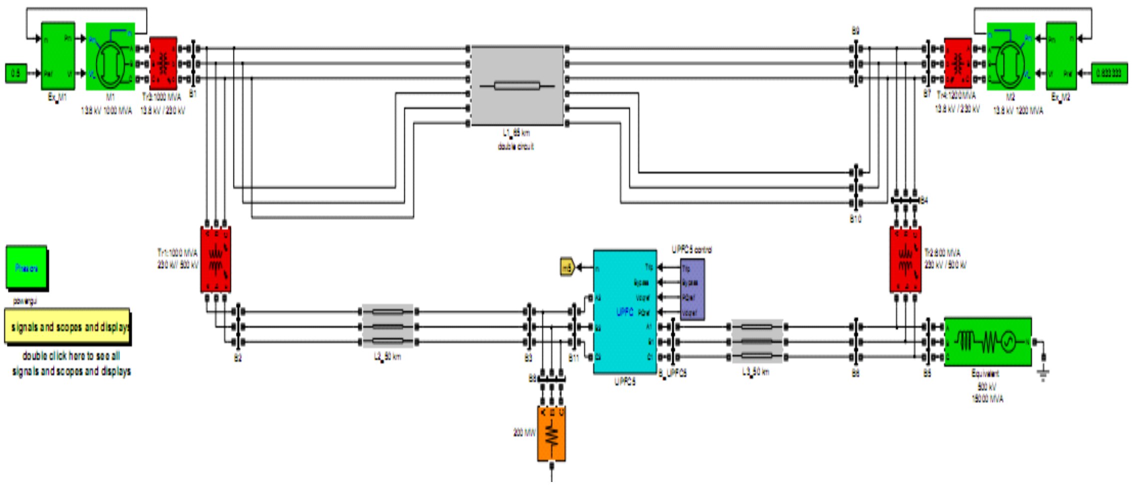

Fig. 9: Simulink model of test power system with UPFC in Bus 4

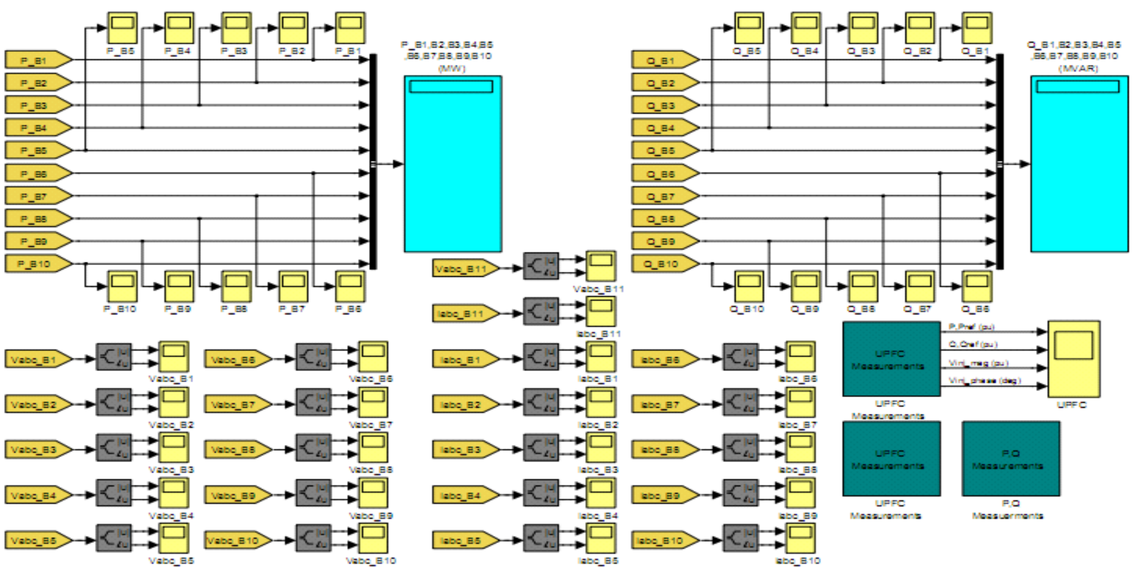

Fig. 10: Arragment output measurements

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 1200 MW generation capacity of power plant #2 is exported to the 500 kV equivalents through two 400 MVA transformers connected between buses B4 and B5. For this illustration we consider a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA). The load flow shows that most of the power generated by plant #2 is transmitted through the 800 MVA transformer bank (899 MW out of 1000 MW) and that 96 MW is circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. This will now illustrate how a UPFC can relieve this power congestion. 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 (28.87 kV) in series with line L2.

The single line diagram illustrated in Fig. 5 is implemented on MATLAB SIMULINK to check the validity of the UPFC controller. The Model of UPFC will generate two kinds of results. The arrangement of

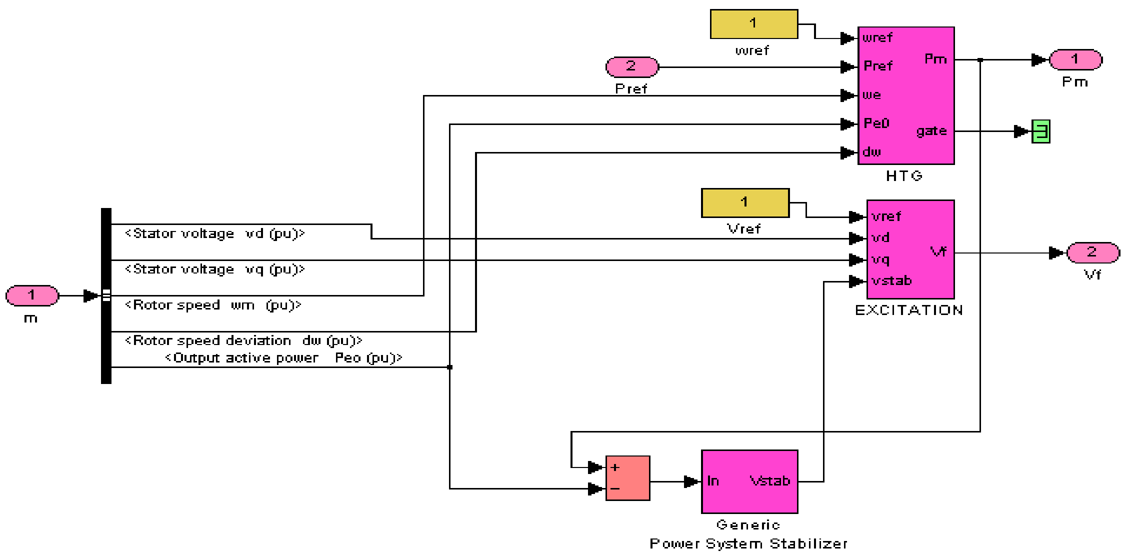

Fig. 11: UPFC controller in SIMULINL

Table 1: Magnitude of voltage at buses of system

	magnitude of Voltages(pu)					
bus	without UPFC	with UPFC1	with UPFC2	with UPFC3	with UPFC4	with UPFC5
B1	0.9965	0.9976	0.9971	0.9967	0.9949	1.0009
B2	0.9993	0.9983	0.9893	1.0018	0.9936	1.0026
B3	0.9995	0.9956	0.9992	1.0009	0.9909	1.0017
B4	0.9925	0.9913	0.9863	0.9942	0.9899	0.9923
B5	0.9977	0.9887	0.9987	0.9988	0.9972	0.9982

measurements and model of UPFC controller are shown in Fig. 10-11 respectively. First is based upon the simulations at power flow control mode and second on voltage injection Mode. The important keys to note in the block diagram are, Parameters of the UPFC are given in the dialog box. In the Power data parameters that 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, 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 labeled Pref(pu) and Qref(pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587 MW and -27 Mvar. The Pref block is programmed with an initial active power of 5.87 pu corresponding to the natural power flow. Then, at t = 10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 p.u.

The results of OPF such as voltage profile, active and reactive power flow in transmission lines are analyzed and discussed. The effect of presence of UPFC and effect of locations of UPFC on buses of power system in magnitude voltage and angle voltage and active and reactive of power flow in transmission lines are investigated and results are analyzed. Table 1 shows the magnitude of voltage at buses of power system. Magnitude of voltage at buses of power system for 6 case studies ate buses 1, 2,3,4,5 of power system have been illustrated. In order to better understand the effect of location of installing UPFC, Fig. 12 shows the variation of magnitude of voltage at different busses of system for various locations.

Table 2 shows the phase voltage or angle of voltage at buses of power system. Angles of voltage at buses of power system for 6 case studies ate buses 1, 2,3,4,5 of power system have been illustrated. In order to better understand the effect of location of installing UPFC, Fig. 13 shows the variation of phase of voltage at different busses of system for various locations.

Table 3 shows the real power flow in transmission lines of power system. Results of simulation for active power flow for 4 case studies at lines L1, L2, L3, and L5 of power system have been illustrated. In order to better understand the effect of location of installing UPFC, Fig. 14 shows the variation of real power flow in transmission lines of system for various UPFC locations.

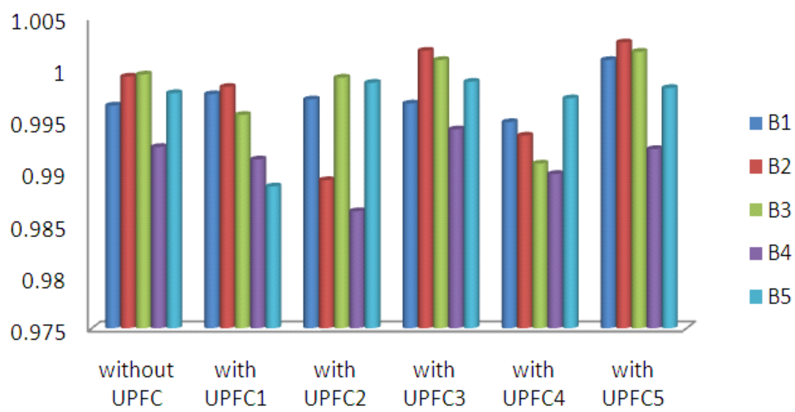

Fig. 12: Magnitude of voltage at buses of system

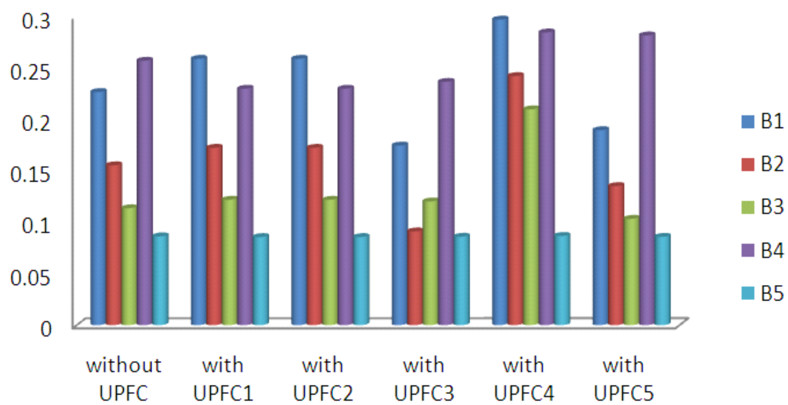

Fig. 13: Angle of voltage at buses of system

Table 2: Angle of voltage at buses of system

	Angle of voltages(rad)					
Bus	without UPFC	with UPFC1	with UPFC2	with UPFC3	with UPFC4	with UPFC5
B1	0.2265	0.2588	0.2588	0.1745	0.2969	0.1895
B2	0.1553	0.1723	0.1723	0.0911	0.242	0.1351
B3	0.1136	0.1218	0.1218	0.1202	0.2097	0.1033
B4	0.2569	0.2297	0.2297	0.2364	0.2844	0.2815
B5	0.086	0.0856	0.0856	0.0859	0.0867	0.0858

Table 3: Real power flow results

	Active powers(MVAR)					
Line	without UPFC	with UPFC1	with UPFC2	with UPFC3	with UPFC4	with UPFC5
L1	- 47.785	- 276.747	46.9413	- 99.147	21.12	182.1
L2	- 47.785	46.9413	- 276.747	- 99.147	21.12	- 146.73
L3	586.997	712.2808	712.2808	687.000	450.8	451.97
L5	386.444	511.0886	511.0886	485.445	254	250.978

Table 4 shows the reactive power flow in transmission lines of power system. Results of simulation for reactive power flow for 4 case studies at lines L1, L2, L3, and L5 of power system have been illustrated. In order to better

Table 4: Reactive power flow results

	Reactive powers (MVAR)					
Line	without UPFC	with UPFC1	with UPFC2	with UPFC3	with UPFC4	with UPFC5
L1	18.0234	67.338	0.701	20.3157	10.8885	18.00
L2	18.0234	0.7005	67.34	20.3157	10.8885	32.89
L3	- 27.7881	- 44.77	- 44.80	- 27.8000	27.8000	3.784
L5	21.5407	- 3.318	- 3.320	15.6074	54.8512	59.32

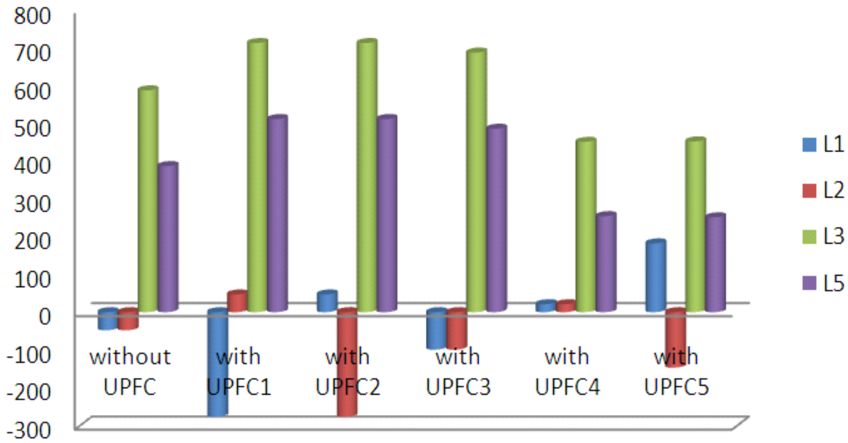

Fig. 14: Real power flow in transmission lines of power system

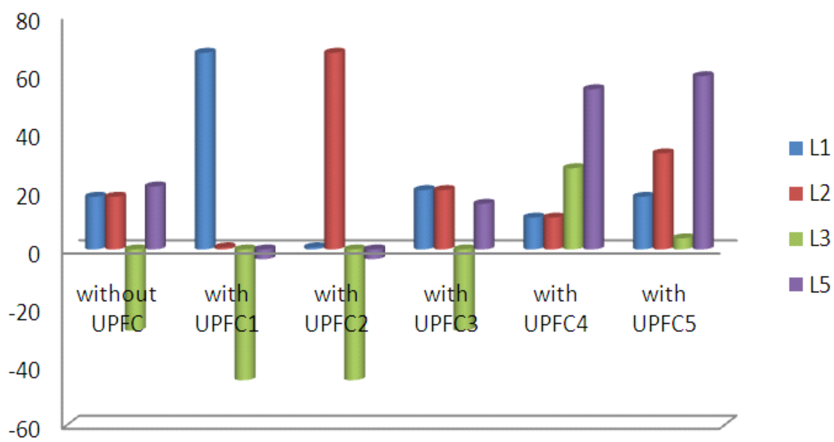

Fig. 15: Reactive power flow in transmission lines of power system

understand the effect of location of installing UPFC, Fig. 14 and 15 shows the variation of reactive power flow in transmission lines of system for various UPFC locations.

CONCLUSION

In power system transmission, it is desirable to maintain the voltage magnitude, phase angle and line impedance. Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is applied. Modeling the system and studying the results have given an indication that UPFC are very useful when it comes to organize and maintain power system. In this study the effects of UPFC locations are investigated on voltage profile and transmission lines power flow as active and reactive power are analyzed.

Following conclusions are made:

- Power flow control is achieved and congestion is less
- Transient stability is improved
- Faster Steady State achievement
- Improved Voltage Profile

REFERENCES

Carsten, L., 2002. Security constrained optimal power flow for uneconomical operation of FACTS-devices in liberalized energy markets. IEEE Trans. Power Delivery, 17: 603-608.

Enrique, A., C.R. Fuerte-Esquivel, H. Ambriz-Perez and C. Angeles-Camacho, 2004. FACTS Modelling and Simulation in Power Networks. West Sussex, England: John Wiley & Sons Ltd., pp: 200-307.

Handschin, E. and C. Lehmkoster, 1999. Optimal power flow for deregulatedsystems with FACTS-devices. Proceeding 13th Power Systems Computation Conference, Trondheim, Norway, pp: 1270-1276.

Taranto, G.N., L.M.V.G. Pinto, and M.V.F. Pereira, 1992. Representation of FACTS devices in power system economic dispatch. IEEE Trans. Power Sys., 7: 572-576.

Jun, Z. and Y. Akihiko, 2006. Optimal power flow for congestion management by Interline Power Flow Controller (IPFC). International Conferance on Power System Technology, Chongqing, China.

Noroozian, M., L. Angquist, M. Ghandhari and G. Andersson, 1997. Use of UPFC for optimal power flow control. IEEE Trans. Power Delivery, 12: 1629-1634.

Narain, G.H. and G. Laszlo, 2000. Understanding FACTS: Concepts and technology of flexible AC transmission systems. NewYork, NY: The Institute of Electrical and Electronics Engineers, pp: 297.

Venkataraman, P., 2002. Applied Optimization with Matlab Programming. John Wiley & Sons, New York, pp: 353.

Peng, Y., Y. Ying and S. Jiahua, 2004. A reliable UPFC control method foroptimal power flow calculation. Proc. 2004 IEEE Power Engineering Society General Meeting, Denver, pp: 1178-1183.

Teerathana, S., A. Yokoyama, Y. Nakachi and M. Yasumatsu, 2005. Anoptimal power flow control method of power system by Interline Powerf Low Controller (IPFC). Proceeding 7th International Power Engineering Conference, Singapore, pp: 1-6.

Xiao-Ping, Z., 2003. Modelling of the interline power flow controller and the generalized unified power flow controller in Newton power flow. IEE Proceedings-Generation, Transmission and Distribution, 150: 268-274.

Xiao-Ping, Z. and E.J. Handschin, 2001a. Advanced implementation of UPFC in a nonlinear interior-point OPF. IEE Proceedings-Generation,Transmission and Distribution, 148: 489-496.

Xiao-Ping, Z., H. Edmund and Maojun, 2001. “Mike” Yao, Modeling of the generalized unified power flow controller (GUPFC) in a nonlinear interior point OPF. IEEE Trans. Power Sys., 16: 367-373.

Xiao-Ping, Z. and E.J. Handschin, 2001b. Optimal power flow control by converter based FACTS controllers. Proceeding 2001 7th International Conference on AC-DC Power Transmission, London, United Kingdom, pp: 250-255.

Ying, X., Y.H. Song and Y.Z. Sun, 2000. Power injection method andlinear programming for FACTS control. Proceeding 2000 IEEE Power Engineering Society Winter Meeting, Singapore, pp: 877-884.