Research Journal of Applied Sciences, Engineering and Technology 3(7): 633-639, 2011
ISSN: 2040-7467

Received: May 13, 2011 Accepted: June 07, 2011 Published: July 25, 2011

Analysis of Interline Power Flow Controller (IPFC) Location in Power Transmission Systems

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

Abstract: The Interline Power Flow Controller (IPFC) is one of the latest generation Flexible AC Transmission Systems (FACTS) controller used to control power flows of multiple transmission lines. The aim of this paper is investigation of the effect of location of IPFC on profile of voltage and real and reactive power flow in transmission lines in power system. This model is incorporated in Newton- Raphson (NR) power flow algorithm to study the power flow control in transmission lines in which IPFC is placed. A program in MATLAB/SIMULINK has been written in order to extend conventional NR algorithm based on this model. Numerical results are carried out on a standard power system. The results without and with IPFC for various locations are compared in terms of voltages, active and reactive power flows to demonstrate the performance of the IPFC model.

Key words: Flexible AC Transmission Systems (FACTS), Interline Power Flow Controller (IPFC), Newton-Raphson (NR) power flow algorithm, power flow control, Power Injection Model (PIM)

INTRODUCTION

Opportunities to the operation and control of modem power systems. For instance, in the steady-state operation, FACTS devices are often presented and implemented for power flow regulation to improve the transfer capability of existing transmission lines. Traditionally, FACTS devices can only regulate either the active power flow or reactive power flow of a single transmission line (Ying *et al*., 2000). A breakthrough is made by the availability of the UPFC, which is one of the most versatile FACTS devices and is capable to control the active and reactive power flows in the transmission line at the same time. Another newly developed FACTS device, namely the IPFC, further extends the capability of independently influencing the active and reactive power flows to simultaneous compensation of multiple transmission lines. These main functions are made possible by the combination of multiple compensators coupled via a common dc link. Thus, both the UPFC and the IPFC are defined as the combined compensators (Teerathana *et al*., 2005).

Recently, Because of the problems such as the congestion management, the reduction of the operational cost and the overall generating cost, the additional control freedoms of FACTS devices have aroused great interest in the application of FACTS devices especially the UPFC the IPFC and the Generalized Unified Power Flow Controller (GUPFC), in the OPF control (Xiao-Ping *et al*., 2001). However, very few publications have been presented on the investigation on the location of IPFC in power system and its effect in the OPF control. So, the study on optimal placement and location investigation is described in this article, in which the OPF control incorporating either a IPFC for several places has the same optimization objective and is subject to the same power flow regulation constraints.

Proper modeling of the FACTS devices is much important to the success of the corresponding OPF calculation (Peng *et al*., 2004).In this paper, the power injection models of the IPFC and is adopted and reviewed, because they do not destroy the symmetric characteristics of the admittance matrix and are very convenient to be incorporated in OPF programs. In next step a common OPF problem incorporating combined compensators is outlined. This Type of problems, which are nonlinear optimization problems essentially, could be solved by Linear Programming (LP), SQP, the Newton's method, and the nonlinear interior point method, etc., (Carsten, 2002).

Because the SQP is a powerful technique which has quadratic convergence properties such as the Newton's method, and allows the inclusion of inequality constraints without barrier functions or interior methods, it is applied to carry out the numerical simulations as presented in section 3 (Jun and Akihiko, 2006). It is natural that correct initialization of the voltage-sourced converters (VSCs) is mandatory for the gradient-based algorithms such as SQP because of serious nonlinearity and non convexity of these combined compensators. Thus, analytical solution to initialize the series VSC is also reviewed in this study.

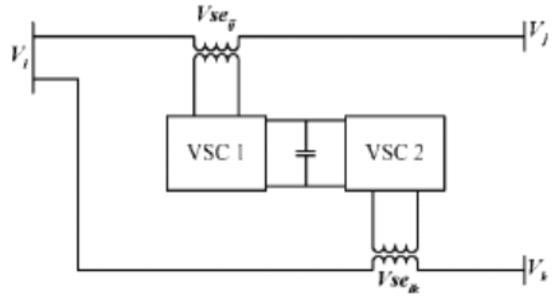

Fig.1: Schematic diagram of two converters IPFC

Inter Line Power Flow Controller (IPFC): In its general form the inter line power flow controller uses a number of dc-to-ac converters each supplying series compensation for a different line. In other words, the IPFC comprises a number of Static Synchronous Series Compensators (SSSC). The simplest IPFC consist of two back-to-back dc-to-ac converters, which are connected in series with two transmission lines through series coupling transformers and the dc terminals of the converters are connected together via a common dc link as shown in Fig. 1.With this IPFC, in addition to providing series reactive compensation, any converter can be controlled to provide real power to the common dc link from its own transmission line (Enrique *et al*., 2004).

A mathematical model for IPFC which will be referred to as power injection model is derived. This model is helpful in understanding the impact of the IPFC on the power system in the steady state. Furthermore, the IPFC model can easily be incorporated in the power flow model. Usually, in the steady state analysis of power systems, the VSC may be represented as a synchronous voltage source injecting an almost sinusoidal voltage with controllable magnitude and angle. Based on this, the equivalent circuit of IPFC is shown in Fig. 2.

In Fig. 2, V_i, V_j and V_k are the complex bus voltages at the buses x = i, j and k respectively, defined as $V_i < \theta_i$ (x = i, j, k). Vse_{in} is the complex controllable series injected voltage source, defined as $Vse_{in} = Vse_{in} < \theta se_{in}$ (n = j. k) and Zse_{in} (n = j,k) is the series coupling transformer impedance. The active and reactive power injections at each bus can be easily calculated by representing IPFC as current source. For the sake of simplicity, the resistance of the transmission lines and the series coupling transformers are neglected. The power injections at buses are summarized (Venkataraman, 2002) as:

$$P_{inj,i} = \sum_{n=j,k} V_i Vse_{in} b_{in} \sin(\theta_i - \theta se_{in}) \qquad (1)$$

$$Q_{inj,i} = -\sum_{n=j,k} V_i Vse_{in} b_{in} \cos(\theta_i - \theta se_{in}) \qquad (2)$$

$$P_{inj,n} = -V_n Vse_{in} b_{in} \sin(\theta_n - \theta se_{in}) \qquad (3)$$

$$Q_{inj,n} = V_n Vse_{in} b_{in} \cos(\theta_n - \theta se_{in}) \qquad (4)$$

The equivalent power injection model of an IPFC is shown in Fig. 2a. neither absorbs nor injects active power with respect to the ac system; the active power exchange between the converters via the dc link is zero,

$$\mathrm{Re}\left(Vse_{ij} I_{ji}^{*} + Vse_{ik} I_{ki}^{*}\right) = 0 \qquad (5)$$

where the superscript * denotes the conjugate of a complex number. If the resistances of series transformers are neglected, (5) can be written as:

$$\sum_{m=i,j,k} P_{inj,m} = 0 \qquad (6)$$

Normally in the steady state operation, the IPFC is used to control the active and reactive power flows in the transmission lines in which it is placed.

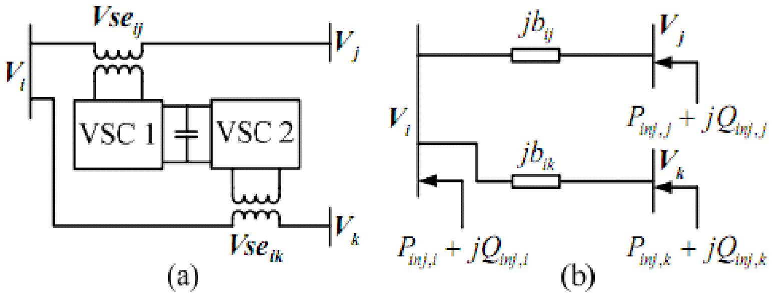

Fig. 2: Schematic representation of IPFC (a) Equivalent circuit of two converter IPFC; (b) Power injection model of two converter IPFC

The active and reactive power flow control constraints are:

$$P_{ni} - P_{ni}^{spec} = 0 \qquad (7)$$

$$Q_{ni} - Q_{ni}^{spec} = 0 \qquad (8)$$

where n = j, k; P_{ni}^{Spec}, Q_{ni}^{Spec}, are the specified active and reactive power flow control references respectively, and

$$P_{ni} = \mathrm{Re}\left(V_n I_{ni}^*\right) \qquad (9)$$

$$Q_{ni} = \mathrm{Im}\left(V_n I_{ni}^*\right) \qquad (10)$$

Thus, the power balance equations are as follows (Zhang, 2003):

$$P_{gm} + P_{inj,m} - P_{lm} - P_{line,m} = 0 \qquad (11)$$

$$Q_{gm} + Q_{inj,m} - Q_{lm} - Q_{line,m} = 0 \qquad (12)$$

where P_{gm} and Q_{gm} are generations active and reactive powers, P_{lm} and Q_{lm} are load active and reactive powers. $P_{lin,m}$ and $Q_{line,m}$, are conventional transmitted active and reactive powers at the bus m = i, j and k.

SIMULATION AND RESULTS

To investigate the effect of location of IPFC in power system and study it's effect of power flow the simplest power system as shown in Fig. 3 are implemented as test

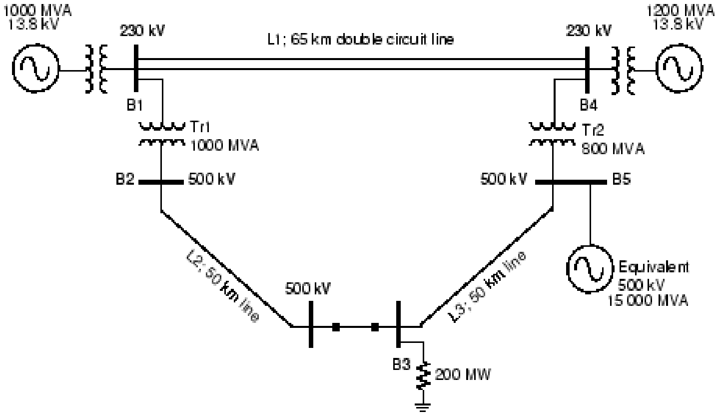

Fig. 3: Test power system for analyzing the effect of location of IPFC

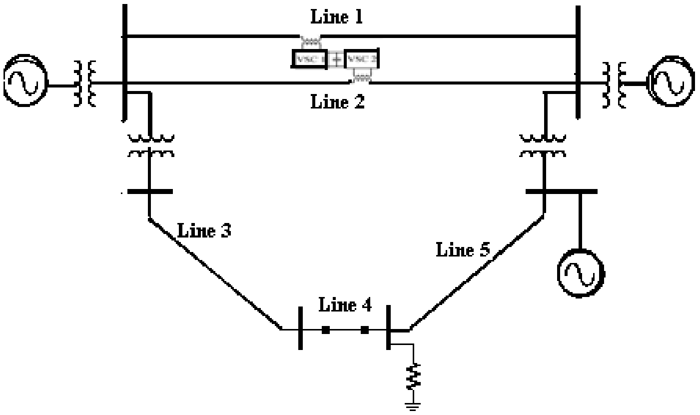

Fig. 4: Test power system with IPFC

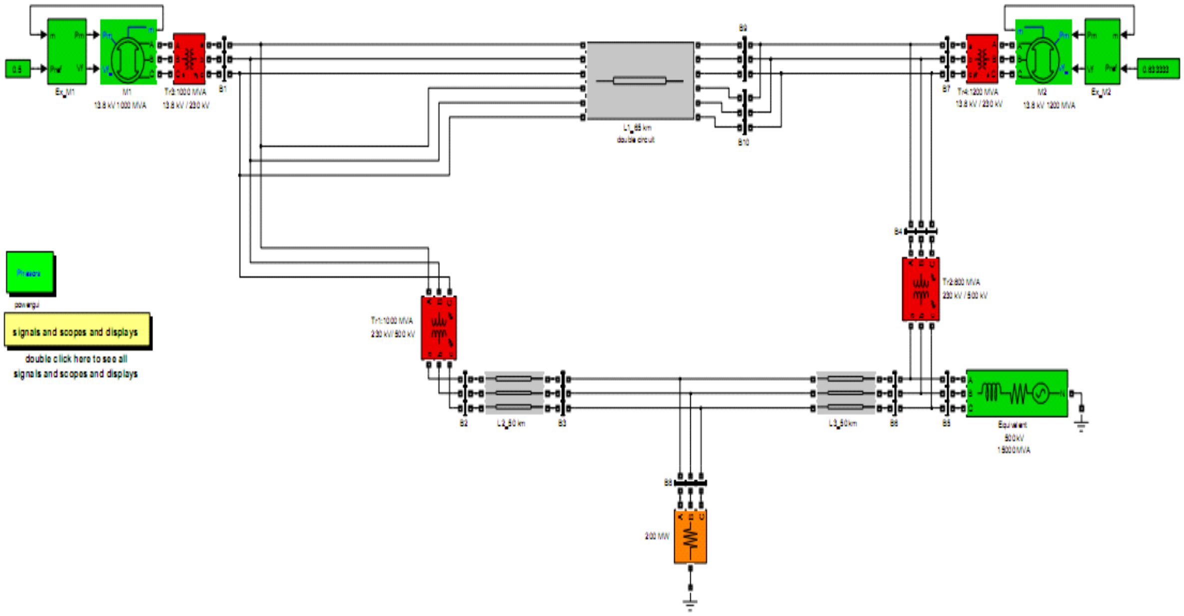

Fig. 5: Test power system model in SIMULINK without IPFC

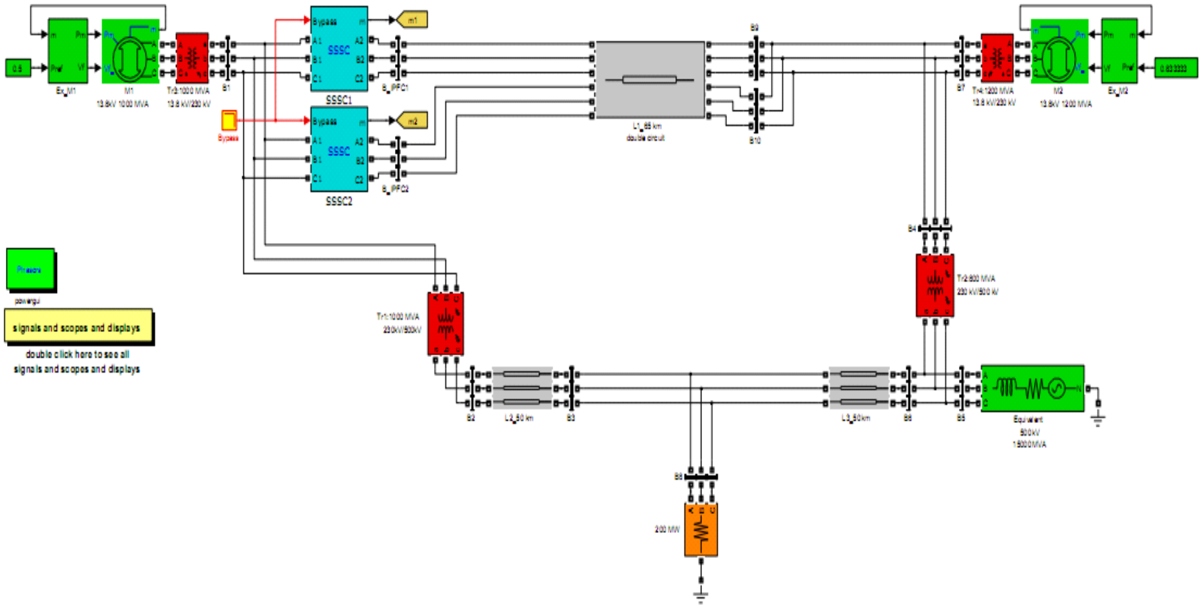

Fig. 6: Installing IPFC between Line 1 and Line 2 as case 1

power system. This test power system with installing IPFC is shown in Fig. 4.

MATLAB/SIMULINK model of IPFC is shown in Fig. 5. In this model the IPFC is not considered yet. For better understanding the effect of IPFC on power system the results of power flow including voltage magnitude and voltage profile and real and reactive power flow in all transmission lines without IPFC are presented in Table 1-4. After obtaining initial results without IPFC the three case studies are presented and analyzed to

Table 1: Magnitude of bus voltages without and with various locations of IPFC in power system

	Magnitude of voltages (pu)			
Bus no.	Without IPFC	Case 1	Case 2	Case 3
B1	0.9965	0.9979	0.9979	0.9985
B2	0.9993	0.9928	0.9928	1.0066
B3	0.9995	0.9955	0.9955	1.0107
B4	0.9925	0.9991	0.9991	0.9948
B5	0.9977	0.9976	0.9976	0.9987
B6	0.9977	0.9976	0.9976	0.9987
B7	0.9925	0.9991	0.9991	0.9948
B8	0.9995	0.9955	0.9955	1.0051
B9	0.9925	0.9991	0.9991	0.9948
B10	0.9925	0.9991	0.9991	0.9948

Table 2: Angles (Phase) of bus voltages without and with various locations of IPFC in power system

	Angles of Voltage (rad)			
Bus no.	Without IPFC	Case 1	Case 2	Case 3
B1	0.2265	0.1720	0.1720	0.1596
B2	0.1553	0.1842	0.1842	0.0732
B3	0.1136	0.1278	0.1278	0.0231
B4	0.2569	0.2163	0.2163	0.2306
B5	0.0863	0.0859	0.0859	0.0858
B6	0.0863	0.0859	0.0859	0.0858
B7	0.2569	0.2163	0.2163	0.2306
B8	0.1136	0.1278	0.1278	0.0724
B9	0.2569	0.2163	0.2163	0.2306
B10	0.2569	0.2163	0.2163	0.2306

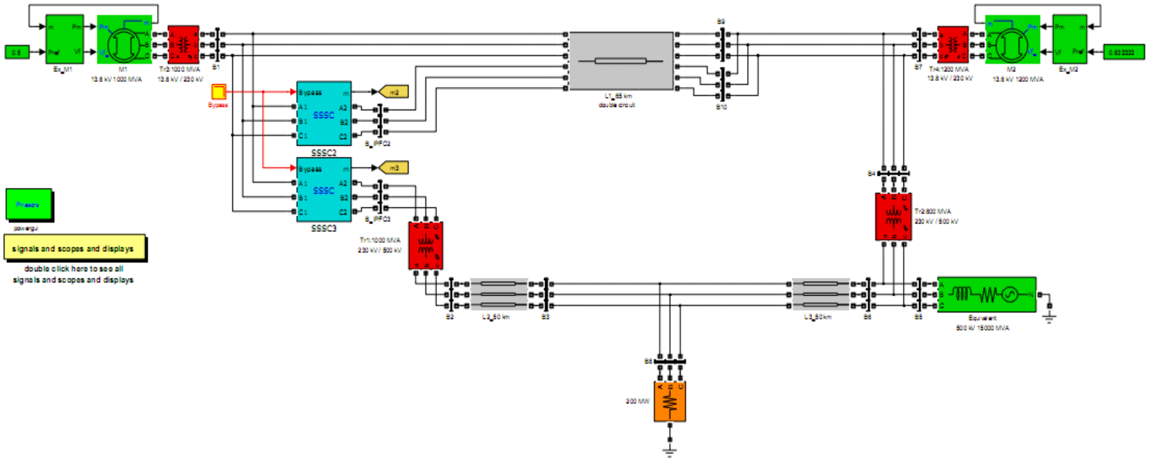

Fig.7: Installing IPFC between Line 2 and Line 3 as case 2

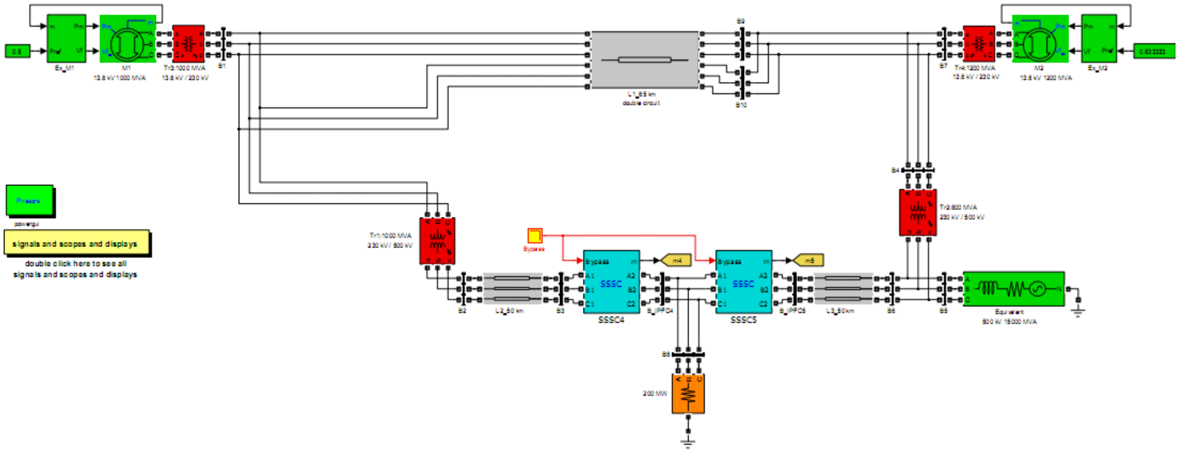

Fig. 8: Installing IPFC between Line 4 and Line 5 as case 3

investigate the effect of IPFC location. In this paper the three locations for analyzing IPFC location are studies that including as cases:

Case 1: Installing IPFC between Line 1 and Line 2
Case 2: Installing IPFC between Line 2 and Line 3
Case 3: Installing IPFC between Line 4 and Line 5

The simulation models of these investigations are shown in Fig. 6-8.

The results of simulation for each case are presented bellow as Table 1-4.The variation of discussed parameters

Table 3: Real power Line flow without and with various locations of IPFC in power system

	(MWAT)			
Line	Without IPFC	Case 1	Case 2	Case 3
L1	- 47.7851	228.4954	-72.099	113.8459
L2	- 47.7851	- 72.0984	228.4954	- 113.846
L3	586.9965	783.9556	783.9578	715.7543
L5	386.4439	583.9559	583.9559	512.2781

Table 4: Reactive power Line flow without and with various locations of IPFC in power system

	(MVAR)			
Line	Without IPFC	Case 1	Case 2	Case 3
L1	18.0234	95.997	12.0118	23.2723
L2	18.0234	12.0117	95.9966	23.2724
L3	- 27.7881	- 88.3761	- 88.376	- 98.531
L5	21.5407	- 53.3292	- 53.3283	4.3903

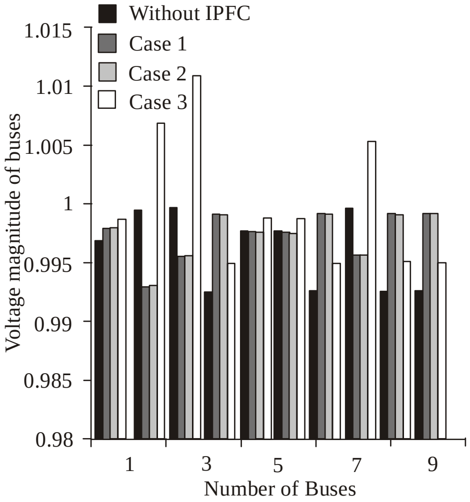

Fig. 9: Voltage magnitude of various buses without and with several locations of IPFC

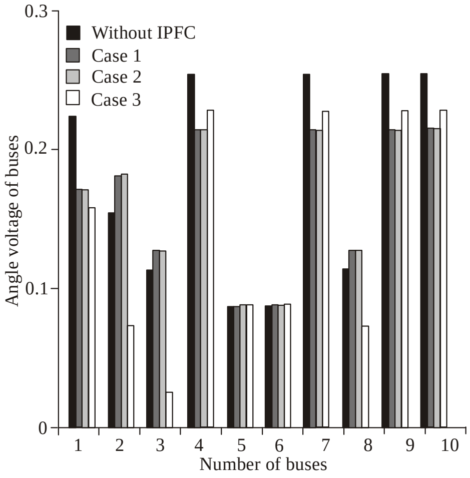

Fig. 10: Voltage angle of various buses without and with several locations of IPFC

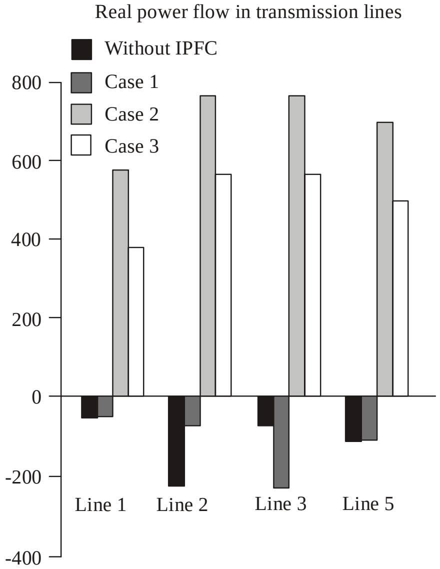

Fig. 11: Active power Line flow without and with various locations of IPFC in power system

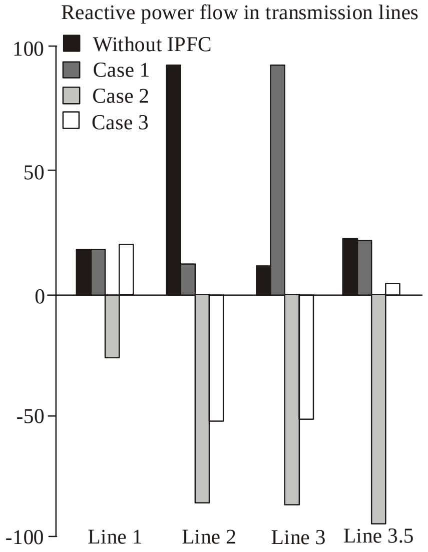

Fig. 12: Reactive power Line flow without and with various locations of IPFC in power system

such as voltage magnitude, voltage angle of system busses and real and reactive power flow in transmission lines are presented as diagram-schematic as Fig. 9-12

CONCLUSION

In this study the effect of location of IPFC in power system is analyzed and various parameters such as voltage profile and real and reactive power flow in transmission lines of system are investigated.

A power injection model of the Inter line Power Flow Controller (IPFC) and its implementation in Newton-Raphson power flow method have been presented. In this model, the complex impedance of the series coupling transformer and the line charging susceptance are included. Numerical results on the test system have shown the convergence and the effectiveness of the IPFC model .It shows that the incoming of IPFC can increase the bus voltage to which IPFC converters are connected and there is a significant change in the system voltage profile at the neighboring buses, increase in active power flow and decrease in reactive power flow through the lines.

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: 200-201, 227-228, 267-307.

Jun, Z. and Y. Akihiko, 2006. Optimal power flow for congestion management by interline power flow controller (IPFC). International Conference on Power System Technology, Chongqing, China.

Peng, Y., Y. Ying and S. Jiahua, 2004. A reliable UPFC control method foroptimal power flow calculation. Proceeding 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 powerflow controller (IPFC). Proceeding 7th International Power Engineering Conference, Singapore, pp: 1-6.

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

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.

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.

Zhang, X.P., 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.