# Interline Power Flow Controller For Damping Low Frequency Oscillations By Comparing PID Controller Andcontroller Using Genetic Algorithm

**Anubha Prajapati**
M Tech (LNCT Bhopal-MP)

**Kanchan Chaturvedi**
Assistant Professor (LNCT Bhopal-MP)

## Abstract

*The effect of Interline Power Flow Controller (IPFC) on damping low frequency oscillations has implied in some papers, but has not investigated in details. This paper investigates the damping control function of an Interline Power Flow Controller installed in a power system. For this purpose,Single Machine-Infinite Bus model integrated with IPFC is used, and the linearized model is established. Using this model, Phillips-Heffron model of system for steady state digital simulations is derived. The common DC link in the IPFC configuration enables each inverter to transfer real power to another, so regulation of DC link voltage is an important issue in overall performance of the system. In this paper, a new method based on Genetic Algorithm (GA) is presented to regulate DC link voltage. In this method, GA and system objective function are adopted to choose best PI parameters for the linear controller of DC link of IPFC In this paper, numerical results withMatlab Simulink toolbox, which show the significant effect of IPFC on damping inter-area oscillations, are represented.*



## 1. Introduction

Recently with interconnection between power system and expansion in transmission and generation for satisfy the increasing power demand, dynamic stability of power systems are an important object in stability of the great power systems. Power System Stabilizer (PSS) have been used as a simple, effective, and economical method to increase power system oscillation stability. While PSS may not be able to suppress oscillations resulting from severe disturbances, such as three phase faults at generator terminals [I]. Flexible AC Transmission System (FACTS) controllers, such as Static Var Compensators (SVC), Static Synchronous Compensators (STATCOM), and Unified Power Flow Controller (UPFC), can be applied for damping oscillationsand improve the small signal stability of power systems by adding a supplementary signal for main control loops.

Interline Power Flow Controller (IPFC) is a newconcept of the FACTS controller for series compensation withthe unique capability of controlling power flow among multilines.The IPFC employs two or more voltage sourceconverters (VSCs) with a common dc-link, Each VSC canprovide series compensation for the selected line of thetransmission system (master or slave line) and is capable of exchanging reactive power with its own transmission system. The damping controller of low frequency oscillations in the power system must be designed at a nonlinear dynamic model of power system, but because of difficulty of thisProcess, generally the linear dynamic model of system at an operating point is put and analysis to design the controller and an obtained controller is investigated in the nonlinear dynamic model for its accuracy and desirable operation at damping of oscillation.In a linearized model of a system with two linesinstalled IPFC has worked, but a SSSC or STATCOM can beemployed in the system with a single machine and two lines, because of economic reasons and an active or reactive power ofthe lines is not controlled independently. In this paper, a connected single machine to infinite buswith three lines installed with the IPFC is used and a novellinearized Phillips-Heffron model for a mentioned power system is derived for design of the IPFC damping controller. In order to enhance dynamical stability of power system, a supplementary signal which is the same as that applied for other FACTS devices is superimposed on the main inputcontrol signals in this paper. In following effect of existenceIPFC damping controller on low frequency oscillations of power system is investigated with considering four alternative IPFC based damping controllers. In this paper Genetic Algorithm as apowerful optimization method is used to find optimized values for PI parameters for regulating DC link voltage of IPFC linear controller. An objective function based on minimization of DC link voltage error is selected. Based on this optimization, best parameters are chosen and the simulations are done to verify the effectiveness of this proposed method in improving of convergence speed, reduction of error, the overshoot in capacitor voltage and other circuit parameters. The results are compared with PI damping controller.

## 2. System investigated

A single-machine infinite-bus (SMIB) system withIPFC, installed on two lines is considered. This configuration which consists of two parallel transmission lines, connects the generator G to an infinite bus, is illustrated in figure 1. PSS is not taking into account in the power system. Operating conditions and parameters are represented in the appendix.

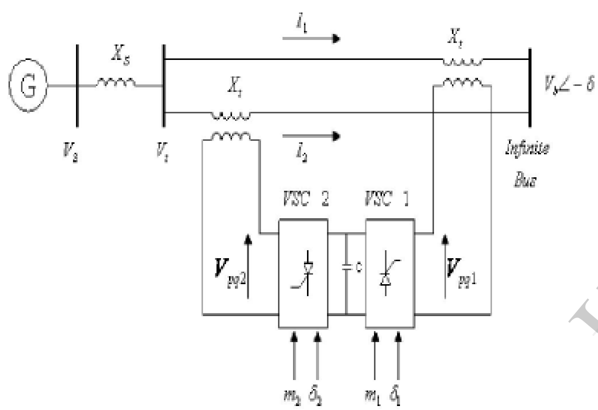



Fig.1 Schematic of the investigated system

## 3. Interline power flow controller

In its general form the Interline Power Flow Controller employs a number of dc to ac inverters each providing series Compensation for a different line. In other words,the IPFC comprises a number of Static Synchronous Series Compensators. However, within the general concept of the IPFC, the compensating inverters are linked together at their dc terminals, as illustrated in Fig. 2. With this scheme, in addition to providing series reactive compensation, any inverter can be controlled to supply real power to the common dc link from its own transmission line. Thus, an overall surpluspower can be made available from the underutilized lines which thencan be used by other lines for real power compensation. In this way, some of the inverters,compensating overloaded lines or lines with a heavy burden of reactive power flow, can be equipped with full two-dimensional, reactive andreal power control capability, similar to that offered by the UPFC. Evidently, this arrangement mandates the rigorous maintenance of the overall power balance at the common dc terminal by appropriate control action, using the general principle that the under loaded lines are to provide help, in the form of appropriate real power transfer, for the overloaded lines.

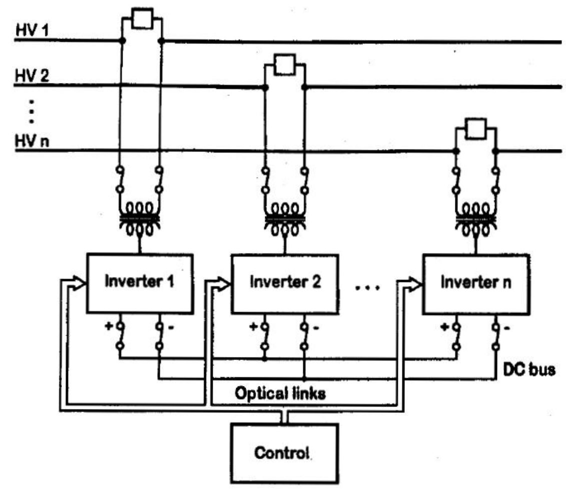



Fig. 2.1 'n' Inverters Configured for an



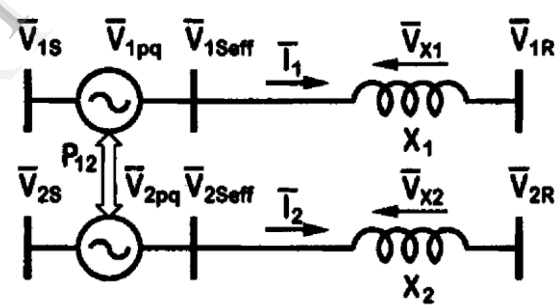


Fig. 2.2 Interline Power Flow Controller

Basic Two-inverter Interline Power Flow ControllerConsider an elementary IPFC scheme consisting of two back-to-back dc to ac inverters, each compensating a transmission line by series voltage injection. This arrangement is shown functionally in Fig. 2.2 where two synchronous voltagesources, with phasors V1pq, and V2pq in series with transmission Lines 1 and 2, representthe two back-to-back dc to ac inverters. (The common dc link is represented by a bidirectional link (P12 = P1pq, = -P2pq,) for real power exchange between the two voltage sources.) Transmission Line 1, represented by reactance X1, has a sending-end bus with voltage phasorV1s and a receiving-end bus with voltage phasor V1R. Thesending-endvoltage phasor of Line 2,represented by reactance X2, is V2s and the receiving-end voltage phasor is V2R. For clarity, all the sending-end and receiving-end voltages are assumed to be constant with fixed amplitudes, $V_{1s} = V_{1R} = V_{2s} = V_{2R} = 1$ p.u. and with fixed angles resulting in identical transmission angles, $\delta_1 = \delta_2\ (=30^0)$, for the two systems. The two line impedances, and the rating of the two compensating voltage sources, are also assumed to be identical, i.e., $V_{1pqmax} = V_{2pqmax}$ and $X_1 = X_2 = 0.5$ P.u., respectively. Although Systems 1 and 2 could be (and in practice are likely to be) different (i.e., different transmission line voltage, impedance and angle), to make the relationships governing the operation of the IPFC perspicuous, the above stipulated identity of the two system is maintained throughout this section.

## 4. Dynamic model of the system with ipfc

Phillips-Heffron linear model of a single-machine infinite bussystem with IPFC is derived from the nonlineardifferential equations. Neglecting the resistances of all thecomponents of the system like generators, transformers, transmission lines, and series converter transformers, anonlinear dynamic model of the system is derived as follows:

$$\dot{\delta} = \omega_b(\omega - 1)$$

$$\dot{\omega} = [P_m - P_e - P_D]/M$$

$$\dot{E}_q' = \left[E_{fd} - (x_d - x_d')i_d - E_q'\right]/T_{do}'$$

$$\dot{E}_{fd} = \left[-E_{fd} + K_A(V_{ref} - V_t)\right]/T_A$$

$$P_e = V_{sd}(I_{1d} + I_{2d}) + V_{sq}(I_{1q} + I_{2q})$$

$$P_e = P_1 + P_2$$

$$v_d = x_q i_q$$

$$v = v_d + v_q,$$

$$i_q = i_{1q} + i_{2q}$$

$$i_d = I_{1d} + i_{2d},$$

$$P_e = v_d i_d + v_q i_q$$

$$E_q = E_q' + (X_d - X_d')(I_{1d} + I_{2d})$$

$$V_s = V_{sd} + jV_{sq} = X_d I_q + j\left[E_q' - X_d'(I_{1d} + I_{2d})\right]$$

From figure 2.1, we have $V_s = jX_s I_s + V_{p2} + jX_L I_2 + V_b$

This equation in d-q coordinates is as follows

$$V_{sd} + jV_{sq} = jX_s[(I_{1d} + I_{2d}) + j(I_{1q} + I_{2q})] + jX_L(I_{2d} + jI_{2q}) + V_{p2} + jV_{q2} + V_b\sin\delta + jV_b\cos\delta$$

From above expressions for $I_{1d}$, $I_{1q}$, $I_{2d}$, $I_{2q}$ are obtained as follows:

$$I_{1d} = X_{11d}E_q' + \frac{1}{2}(X_{12d} - X_{11d})V_{dc}m_2 Sin\delta_2 - \frac{1}{2}X_{12d}V_{dc}m_1 Sin\delta_1 - X_{11d}V_b\cos\delta$$

$$I_{2d} = X_{21d}E_q' + \frac{1}{2}(X_{22d} - X_{21d})V_{dc}m_2 Sin\delta_2 - \frac{1}{2}X_{22d}V_{dc}m_1 Sin\delta_1 - X_{21d}V_b\cos\delta$$

$$I_{1q} = \frac{1}{2}(X_{11q} + X_{12q})V_{dc}m_2\cos\delta_2 + X_{11q}V_b Sin\delta - \frac{1}{2}X_{12q}V_{dc}m_1\cos\delta_1$$

$$I_{2q} = \frac{1}{2}(X_{21q} + X_{22q})V_{dc}m_2\cos\delta_2 + X_{21q}V_b Sin\delta - \frac{1}{2}X_{22q}V_{dc}m_1\cos\delta_1$$

$$\begin{bmatrix} X_{11d} & X_{12d} \\ X_{21d} & X_{22d} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{X_{ds} + X_{d\Sigma}} & \dfrac{X_{d\Sigma}}{X_{TL}(X_{ds} + X_{d\Sigma})} \\ \dfrac{1}{X_{ds} + X_{d\Sigma}} & \dfrac{-X_{ds}}{X_{TL}(X_{ds} + X_{d\Sigma})} \end{bmatrix}$$

$$\begin{bmatrix} X_{11q} & X_{12q} \\ X_{21q} & X_{22q} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{X_{qs} + X_{q\Sigma}} & \dfrac{-X_{q\Sigma}}{X_{TL}(X_{qs} + X_{q\Sigma})} \\ \dfrac{1}{X_{qs} + X_{q\Sigma}} & \dfrac{X_{qs}}{X_{TL}(X_{qs} + X_{q\Sigma})} \end{bmatrix}$$

Where,

$X_{ds} = X_d' + X_s$ 3.26a $\quad X_{d\Sigma} = X_{ds} + X_{TL}$

$X_{qs} = X_q + X_s$ 3.27a $\quad X_{q\Sigma} = X_{qs} + X_{TL}$

$X_{TL} = X_T + X_L$ 3.28

## 5. Power system linearized dynamic model

The non-linear dynamic equations are linearized around a given operating point to have the linear model as given below The non-linear dynamic equations are linearized around a given operating pointto have the linear model as given below-

$$\Delta\dot{\delta} = \omega_o \Delta\omega$$

$$\Delta\dot{\omega} = [P_m - P_e - P_D]/M$$

$$\Delta\dot{E}_q' = [\Delta E_{fd} - (X_d - X_d')\Delta I_d - \Delta E_q']/T_{do}'$$

$$\Delta\dot{E}_{fd} = [Ka(V_{ref} - Vs) - \Delta E_{fd}]/Ta$$

$$\Delta\dot{V}_{dc} = K_7\Delta\delta + K_8\Delta E_q^1 + K_{cm2}\Delta m_2 - K_9\Delta V_{dc}$$

$$\Delta P_e = K_1\Delta\delta + K_2\Delta E_q^1 + K_{pm2}\Delta m_2 + K_{pv}\Delta V_{dc}$$

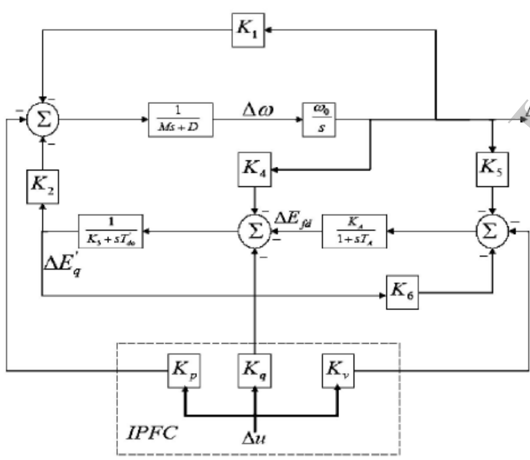
$$\Delta E_q = K_4\Delta\delta + K_3\Delta E_q^1 + K_{qm2}\Delta m_2 + K_{qv}V_{dc}$$

$$\Delta V_s = K_5\Delta\delta + K_6\Delta E_q^1 + K_{vm2}\Delta m_2 + K_{vv}V_{dc}$$

'

'Where

$K_1$ $K_9, K_{pm}, K_{qm}, K_{vm}$ *and* $K_{cm}$ are linearization constants. The 16constants of the model depend on the system parameters and the operating condition.




## 6. Digital simulations

In order to understand the effect of IPFC on damping lowfrequency oscillations, digital simulations using MatlabSimulink toolbox is done in two cases: with and without IPFC.When there is not IPFC in the system, the Phillips-Heffronmodel constants are as presented in table IIFig. 5 to 12 show the numerical results. Fig. 5 to 8illustrates power system oscillations when there is not IPFC inthe system. These figures are related to the two values fordamping coefficient. Fig. 5 and 6 show the rotor deviations and rotor speed deviations, respectively for dampingcoefficientequals to zero, and figures 7 and 8, those fordamping coefficient equals to 2. In the same way, figures 9 to 12 illustrates power system oscillations when IPFC is taking into account. Table for constants of SMIB-

| | |
|---|---|
| **Pe(p.u.)** | **0.8** |
| **K1** | **0.8674** |
| **K2** | **1.0192** |
| **K3** | **0.7143** |
| **K4** | **-0.2854** |
| **K5** | **-0.0994** |
| **K6** | **0.5179** |
| | |

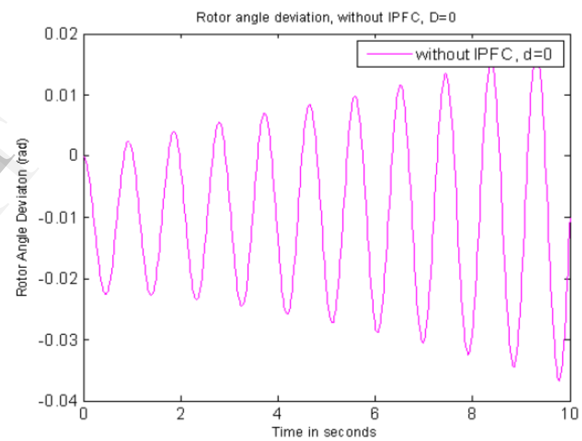



Fig.4.4 Rotor Angle deviation without IPFC,D=0

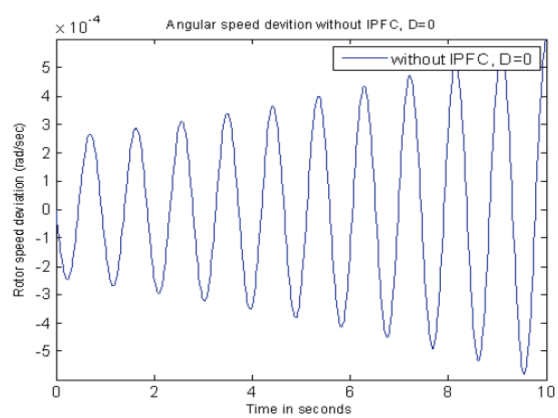



Fig.4.3 Rotor speed deviation without IPFC, D=0

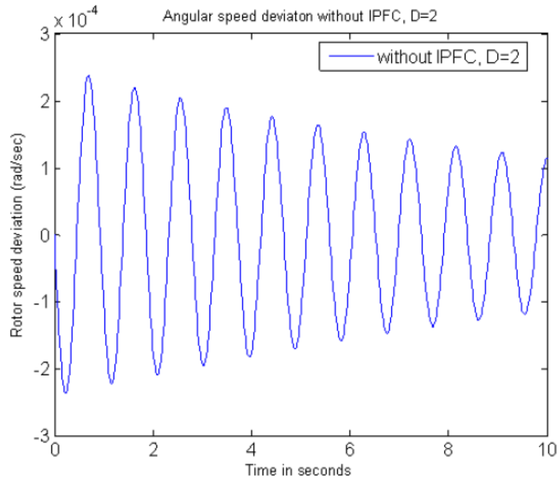



Fig.4.5 Rotor speed deviation without IPFC, D=2

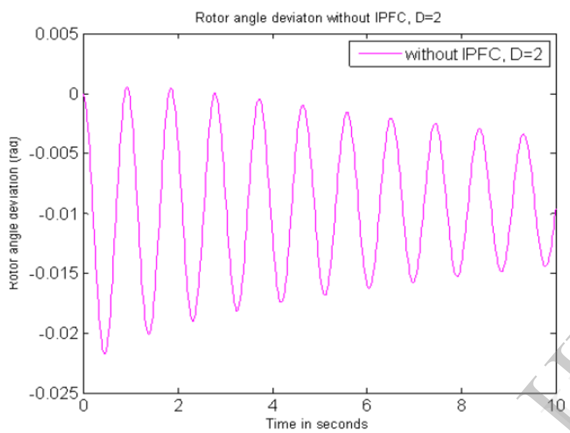



Fig.4.6 Rotor angle deviation without IPFC, D=2

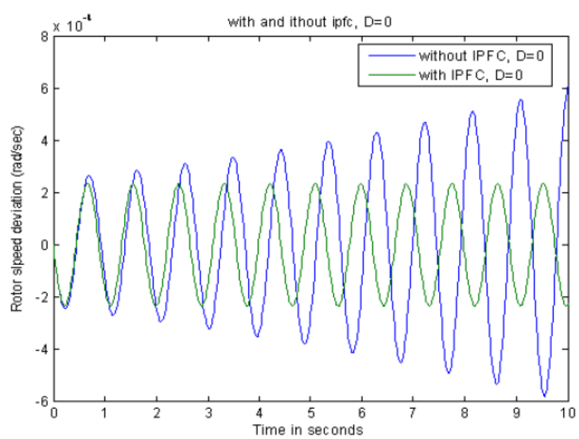



Fig.4.7 Rotor speed deviation with and without IPFC, D=0

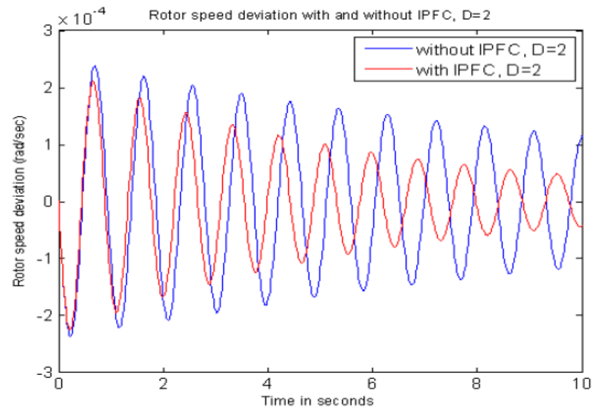



Fig.4.9 Rotor speed deviation with and without IPFC, D=2

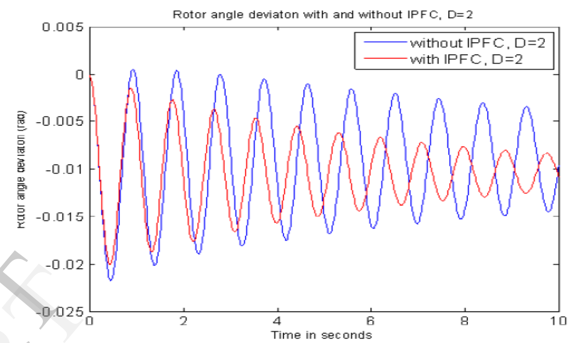



Fig.4.10 Rotor angle deviation with and without IPFC, D=2



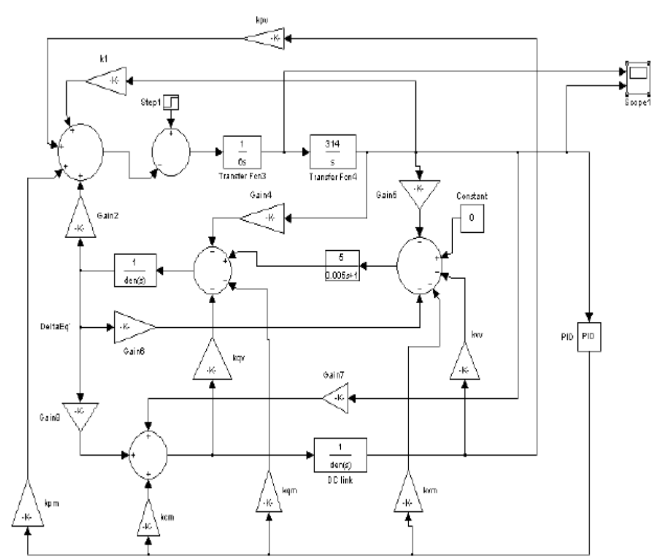



Fig 4.11 Heffron-Philips model of SMIB system with PID as damping controller

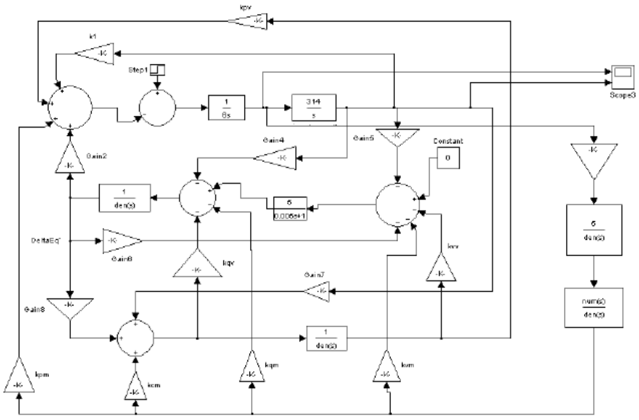


Fig.4.14 SMIB system with IPFC and Supplementary controller lead-lag

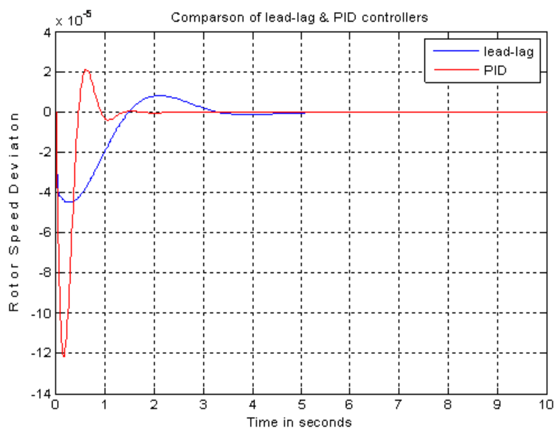



Fig.4.17 Rotor speed deviation for SMIB system with IPFC and supplementary controllers

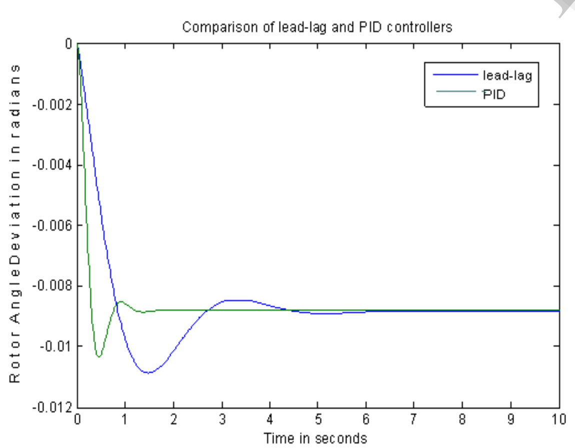



Fig.4.18 Rotor angle deviation for SMIB system with IPFC and supplementary controllers

## 7. Simulation results

The SIMULINK model is simulated for 0.01 pu step load disturbance. Here controller's response is shown in Fig 4.17 and Fig 4.18. We observe the angular frequency deviation the system is becoming stable within 2 seconds and peak over shoot is 3 x 10-5rad/sec for PID controller and for lead-lag stable time is 4 seconds and peak over shoot is 2.4 x 10-5 rad/sec. In case of rotor angle deviation the system is becoming stable within 2 seconds and peak over shoot is -0.025radians for PID controller and for lead-lag stable time is 4 seconds and peak over shoot is -0.025 radians.

## 8. Conclusions

The basic control function within IPFC, voltage control of the DC link capacitor interacts negatively with the system and thus damages the system oscillation stability. This is eliminated by optimal design of IPFC damping controller and feeding an additional supplementary feedback control signal from the damping controller. To achieve this goal, SMIB equipped with IPFC is modeled as non-linear dynamic model. The model is then to be linearized at operating condition and the modified Phillips- Heffrons linearized model for operating condition. The expressions for the initial d-q axes voltage, current components and torque angle was derived from the basic concepts. The K-constants of the model are derived and computed their values using the initial d-q axes components for SMIB system with and without IPFC. The same was validated by simulating the system using MATLAB/SIMULINK model.Supplementary damping controller, lead-lag, is designed using GeneticAlgorithm. Also another supplementary damping controller, PID, is designed using Ziegler Nichol's method. The power system was simulated with IPFC and supplementary controllers. It is found that the lead-lag controller is better than the PID to control angular speed deviation in the system. The effectiveness of the IPFC based damping controller has been investigated in damping low frequency oscillations. The dynamic results have emphasized its significant effect. In fact, even there is not any damping coefficient in power systems; IPFC can damp low frequency oscillations in addition to its other capacities. Dynamic simulations results have emphasized that the damping controller provides satisfactory dynamic performance. Though, the damping duty of FACTS controllers often is not its primary function, their potential of damping low frequency oscillation has attracted interests. IPFC as a multitask controller, has an effective role in damping inter-area oscillations. In fact, even there is not any damping oscillation in addition to its other capabilities.

## 9. Appendix

Operating conditions and parameters are as follows:
Generator:
M = 2H = 6s
D = 2; Td'o = 5.044s
Xd = 1pu; Xd' = 0.025pu;
Xq = 0.6pu
Excitation system:
KA= 5; TA= 0.005s
Converter transformers:
Xt = O.lpu

converter parameters:

m = 0.15; $\delta 1 = 15^{\circ}$

m2=0.10; $\delta 2 = 22^{\circ}$
Transmission line transformers:
XL = 0.01pu; Xs =1.0pu
DC link parameters:
VdC = 0.5pu; Cdc=1.0pu

## 10. References

**[1]**P. Kundur, Power System Stability and Control. Mc Graw-Hill, New York, 1994, chapter 12.

**[2]** IEEE/CIGRE Joint Task Force on Stability Terms and Definition, “Definition and classification of power system stability,” IEEE Trans. Power Systems, vol. 19, pp. 1387-1401, May 2004.

**[3]** P. Kundur, L. Wang, “Small signal stability analysis: experience, achievements, and challenges,” International Conference on Power System Technology Proceedings, vol. 1, 2002, pp. 6-12.

**[4]**N.G. Hingorami, L.Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission system, IEEE Press, 1999.

**[5]** Abido, M.A. “Analysis and assessment of Statcom-based damping stabilizers for power system stability enhancement,” International Journal of Electric Power System Research, Vol. 73, pp.177-185, 2005.

**[6]**Nadarajah MIthulananthan, Claudio A. Canizares, John Reeve, and Graham J Rogers, “Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations, “IEEE Transaction, Power Systems, Vol. 18, No. 2, pp786-792, May, 2003.

**[7]** R. Leon Vasquez-Arnez and Luiz Cera Zanetta, “A novel approach for modeling the steady-state VSC-based multiline FACTS controllers and their operational constraints,” IEEE Trans. power delivery, vol. 23, no. 1, January 2008.

**[8]** Sen, K. K., SSSC - Static Synchronous Series Compensator: Theory, Modeling, and Applications, IEEE Transactions on Power Delivery, Vol. 13, No. I, January 1998. PE-862-PWRD-0-04-1997, IEEE PES Summer Meeting, Berlin, Germany.

**[9]**H.F. Hang, “Design of SSSC Damping Controller to Improve Power System Oscillation Stability,” IEEE 1999.

**[10]**Gyugyi, L., et al., Static Synchronous Series Compensator: A Solid Synchronous Solid – State Approach to the Series Compensation of Transmission Lines, IEEE Transations on Power Delivery, Vol 12, No. 1,January 1997.

**[11]** Gyugyi, L., Dynamic Compensation of AC Transmission Lines by Solid-StateSynchronous Voltage Sources, IEEE Transactions on Power Delivery, Vol.9,No.2, April 1994.

**[12]** Sen, K. K. and Stacey, E. J., UPFC - Unified Power Flow Controller: Theory, Modeling, and Applications, PE-282-PWRD-0- 12- 1997, IEEE PES WinterMeeting, Tampa, USA.

**[13]**Gyugyi, L., et al., The Unified Power Flow Controller: A New Approach to Power Transmission Control, IEEE Transactions on Power Delivery, Vol. 10,No. 2, April 1995.

**[14]** Gyugyi, L., A Unified Power Flow Control Concept for Flexible AC Transmission Systems, IEE PROCEEDINGS-C, Vol. 139, No. 4, July 1992.

**[15]**N.Tambey and M.L.Kothari, “Damping of Power System Oscillation with Unified Power Flow Controller,” IEE Proc. Gener. Trans. Distib. Vol. 150, No.2, March 2003, pp. 129 –140

**[16]** H.F. Wang. “Applications of Modelling UPFC into Multimachine PowerSystems,” IEE Proceedings-C, vol 146, no 3, May 1999, pp. 306.

**[17]**Kazemi, A.; Karimi, E, ”The Effect of Interline Power Flow Controller (IPFC)on Damping Inter-area Oscillations in the Interconnected Power Systems,”Industrial Electronics, 2006.

**[18]** L.Gyugyi, K.K.Sen, C.D.Schauder, “The Interline Power FlowControllerConcept: A New Approach to Power Flow Management in TransmissionSystems,” IEEE Transactions on Power Delivery, Vol. 14, No. 3, July 1999, pp.1115 – 1123.

**[19]**J. Chen, T.T. Lie, D.M. Vilathgamuwa, “Design of Interline Power FlowController,” 14th PSCC, Sevilla, June 2002.

**[20]** Yao-Nan Yu, Electric Power System Dynamics, Academic Press, Inc, London,1983.