Interline Power Flow Controller Based Damping Controllers for Damping Low Frequency Oscillations

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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 with Matlab Simulink toolbox, which show the significant effect of IPFC on damping inter-area oscillations, are represented.

I. 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 oscillations and improve the small signal stability of power systems by adding a supplementary signal for main control loops. Interline Power Flow Controller (IPFC) is a new concept of the FACTS controller for series compensation with the unique capability of controlling power flow among multilines. The IPFC employs two or more voltage source converters (VSCs) with a common dc-link, Each VSC can provide series compensation for the selected line of the transmission 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 this Process, 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 lines installed IPFC has worked, but a SSSC or STATCOM can be employed in the system with a single machine and two lines, because of economic reasons and an active or reactive power of the lines is not controlled independently. In this paper, a connected single machine to infinite bus with three lines installed with the IPFC is used and a novel linearized 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 input control signals in this paper. In following effect of existence IPFC 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 a powerful 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.

II. SYSTEM INVESTIGATED

A single-machine infinite-bus (SMIB) system with IPFC, 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.
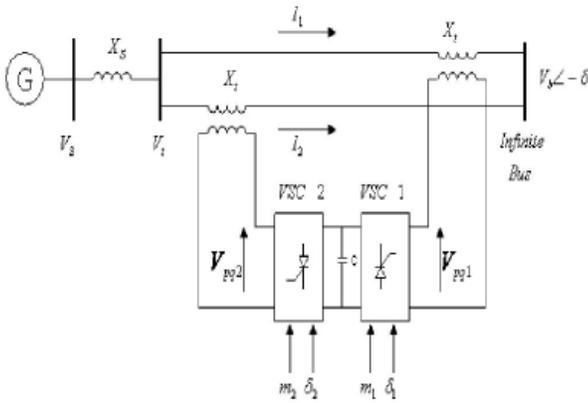

Fig. 1. Schematic of the investigated system.

III. 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 surplus power can be made available from the underutilized lines which then can 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 and real 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.

$$E_q = E'_q + (X_d - X'_d)(I_{1d} + I_{2d})$$

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

IV. DYNAMIC MODEL OF THE SYSTEM WITH IPFC

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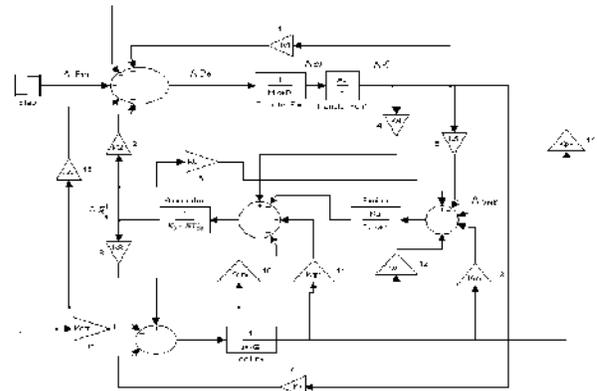

Fig. 2.

$$\dot{\delta} = \omega_b(\omega - 1)$$
$$\dot{\omega} = [P_m - P_E - P_D]/M$$
$$\dot{E'_q} = \left[E_{fd} - (x_d - x'_d) - E'_q\right]/T'_{d0}$$
$$\dot{E}_{fd} = \left[-E_{fd} + K_A(V_{ref} - V_s)\right]/T_A$$
Where
$$P_e = V_{sd}(I_{1d} + I_{2d}) + V_{sq}(I_{1q} + I_{2q})$$
$$P_e = P_1 + P_2$$
$$P_e = v_d i_d + v i_q$$
$$E_q = E'_q + (x_d - x'_d)(I_{1d} + I_{2d})$$

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

From fig 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. DYNAMIC MODEL WITH CONTROLLERS

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 point to have the linear model as given below-'Where

$$\Delta\dot{\delta} = \omega_o \cdot \Delta\omega$$
$$\Delta\dot{\omega} = [P_m - P_E - P_D]/M$$
$$\Delta\dot{E}_q = \left[\Delta E_{fd} - (X_d - X'_d)I_d - \Delta E'_q\right]/T'_{do}$$
$$\Delta\dot{E}_{fd} = \left[-\Delta E_{fd} + K_A(V_{ref} - V_s)\right]/T_A$$
$$\Delta\dot{V}_{dc} = K_7\Delta\delta + K_8\Delta E'_q + K_{cm2}\Delta m_2 - K_9\Delta V_{dc}$$
$$\Delta P_e = K_1\Delta\delta + K_2\Delta E'_q + K_{pm2}\Delta m_2 + K_{pv}\Delta V_{dc}$$
$$\Delta E_q = K_4\Delta\delta + K_3\Delta E'_q + K_{qm2}\Delta m_2 + K_{qv}\Delta V_{dc}$$
$$\Delta V_s = K_7\Delta\delta + K_8\Delta E'_q + K_{cm2}\Delta m_2 - K_9\Delta V_{dc}$$

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

VI. DIGITAL SIMULATIONS

In order to understand the effect of IPFC on damping low frequency oscillations, digital simulations using Matlab Simulink toolbox is done with IPFC and with damping controllers PID and lead lag supplementary controller. Heffron-Philips model of SMIB system with PID as damping controller The SIMULINK model is simulated for 0.01 p.u. step load disturbance.
Modified Phillip-Heffrons model with IPFC as damping controller PID.

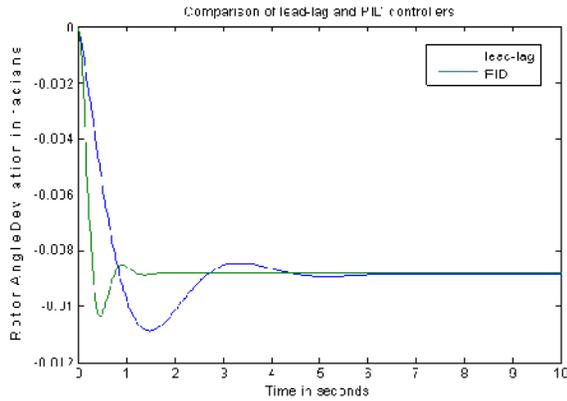| Pe(p.u.)	0.8
K1	0.8674
K2	1.0192
K3	0.7143
K4	-0.2854
K5	-0.0994
K6	0.5179
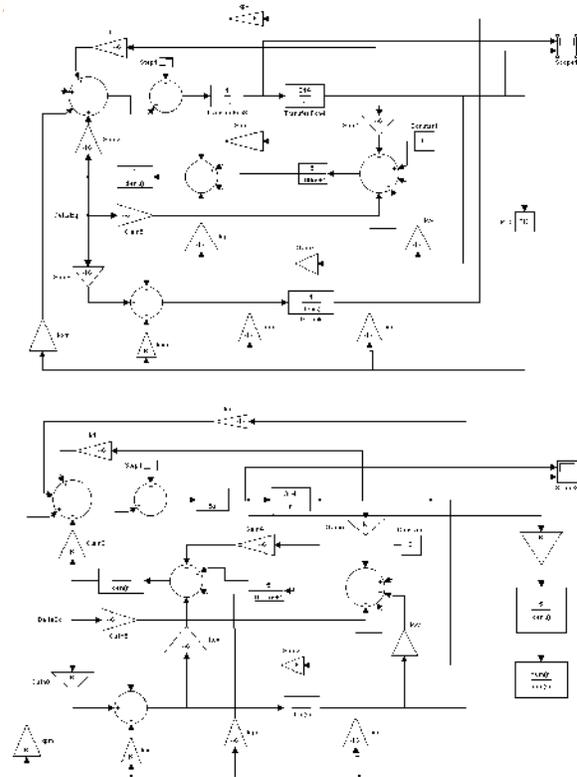
Fig. 3. Modified Phillip- Heffrons model with IPFC as damping controller lead –lag.

VII. SIMULATION RESULTS
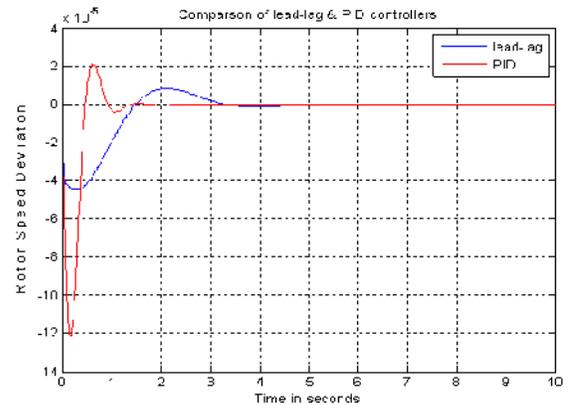
Fig.4. Rotor speed deviation for SMIB system with IPFC and supplementary controllers.

Fig. 5. Rotor angle deviation for SMIB system with IPFC and supplementary controllers.

The SIMULINK model is simulated for 0.01 pu step load disturbance. Here controller's response is shown in Figures. 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.

VIII. 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 Genetic Algorithm. 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.

APPENDIX

Operating conditions and parameters are as follows:
Generator:
M = 2H = 6s
D = 2; T'_{d0} = 5.044s
X_d = 1pu; X'_d = 0.025pu;
X_q = 0.6pu
Excitation system:
K_a = 5; T_a = 0.005s
Converter transformers:
X_t = 0.1pu
Converter parameters:
m_1 = 0.15; δ_1 = 15
m_2 = 0.10; δ_2 = 22
Transmission line transformers:
X_L = 0.01pu; Xs =1.0pu
DC link parameters:
V_{dc} = 0.5pu; C_{dc} =1.0pu

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