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Study of UPFC Control for Power Swings Damping Improvement Using Fuzzy-PI Based PSO

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ABSTRACT

This paper analyzed the effect of Unified Power Flow Controller (UPFC) on the power system oscillation due to fault conditions, disturbance, major block outs. Unified Power Flow Controller (UPFC) is a power electronic based device that is able to control the power flow through the line by controlling appropriate its series and shunt parameter. It has been seen that UPFC can improve transient stability of a simple system. This paper investigates the improvement of transient stability of inter-area power system. The mathematical model of UPFC is present in this paper. The UPFC is modeled as the variable reactance and is incorporated into the model of power system. In this study a UPFC-based Fuzzy-PI controller is proposed and designed to damp generator oscillations. Particle Swarm Optimization technique is used for the best choicest of input parameters of controller.
KEY WORDS: Flexible AC Transmission System, UPFC, Inter-Area Oscillation, Power System Control, Optimization Approach, Particle Swarm Optimization, Fuzzy Logic Program, Low Frequency Oscillation.

INTRODUCTION

Modern power systems are becoming increasingly stressed due to growing power demand. Because of variety of factors, such as environmental legislation, rights of way issues, capital investment, deregulation policies, etc. constrain the construction of new transmission lines, electric utilities are now forced to operate their system in such a way that makes better utilization of existing transmission facilities. It is well known that the power flow through transmission line is a function of line impedance, magnitude and phase angle of bus voltage. If these parameters can be controlled, the power flow through the transmission line can be controlled in a predetermined manner. Flexible AC Transmission System (FACTS) uses advanced power electronics to control the parameters in the power system in order to fully utilize the existing transmission facilities [Hassan Barati, etal. 2009].

A Unified Power Flow Controller (UPFC) is a member of FACTS devices. It consists of two solid state synchronous voltage source converters coupled through a common DC link as shown in Figure 1[M. Nomozian, et.al, 1997]. The DC link supply a path to exchange active power between the converters. The series converter injects a voltage in series with the system voltage through a series transformer. The power flow through the line can be regulated by controlling voltage magnitude and angle of series injected voltage. The injected voltage and line current determine the active and reactive power injected by the series converter. The converter has a capability of electrically generating or absorbing the reactive power. However, the injected active power must be supplied by the DC link, in turn taken from the AC system through the shunt converter. The shunt converter also has a capability of independently supplying or absorbing reactive power to regulate the voltage of the AC system. When the losses of the converters and the associated transformers are neglected, the overall active power exchange between the UPFC and the AC system become zero. However, both the series and shunt converters can independently exchange reactive power [Pavella, M. and P.G. Murthy, 1994]. UPFC can improve both steady sate stability, dynamic stability and transient stability [N. G. Hingorani and L. Gyugyi, 2000]. For the convenience practical of application, the series voltage angle of UPFC is kept in perpendicular with a line current [Dizdarevic, 2001].

It has been reported in many papers that UPFC can improve stability of simple system or single machine infinite bus (SMIB) system and multimachine system [Prechanon Kumkratug, 2009]. The inter-area power system has special characteristic of stability behavior [H.F.Wang' 1999]. Reference [Hassan Barati, etal. 2009] presented the application of SVC, and TCSC to damping power stability in the inter-area power system. This paper investigates the improvement of inter-area system with a UPFC. This paper suggests the method to incorporate UPFC model into the power system model for studying transient stability. The proposed method is then tested on Kundur's inter area-system.

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MODELLING OF UNIFIED POWER FLOW CONTROLLER (UPFC)

The feasibility of different hardware implementations and the basic operating principle of a UPFC have been thoroughly investigated by many researches. Basically the P-Q control function in the UPFC system is accomplished by two dc/ac converter branches, i.e. the series and shunt branches as shown in Figure 1. These two branches are operated via a common dc link with a dc storage capacitor to allow the active power freely flowing in either direction between the ac terminals of the two branches. Besides, each branch is able to independently generate or absorb the reactive power at its own ac output terminal connected to the controlled transmission line.

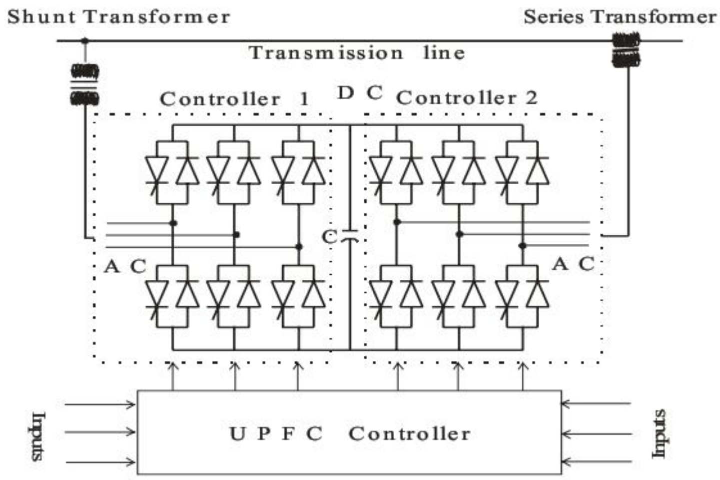

FIGURE 1 Basic Circuit Arrangement of UPFC

Basically, a practical UPFC equivalent circuit can be modeled in many ways. However, to better the presentation of the UPFC in both steady-state and transient state simulations, a straightforward UPFC current injection model can be directly obtained from modeling the two voltage-source inverter units into two equivalent current injections, $I_{i,upfc}$ and $I_{j,upfc}$, as shown in Figure 2.

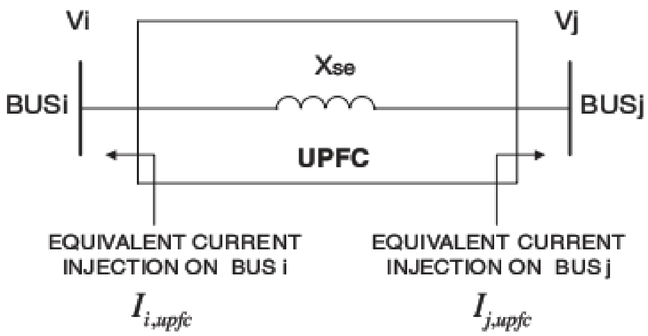

FIGURE 2 UPFC Equivalent Circuits with Controlled Current Sources

$I_{i,upfc}$ and $I_{j,upfc}$ can be expressed as :

$$I_{j,upfc} = \left(\frac{-P_{series}\cdot 1.02}{V_i^*} - \frac{F_{se}}{X_{se}}\right) + j\left(\frac{-Q_{shunt}}{V_i^*} + \frac{E_{se}}{X_{se}}\right)$$

$$= \left(\frac{-1.02 P_{series} E_i}{E_i^2 + F_i^2} + \frac{Q_{shunt} F_i}{E_i^2 + F_i^2} - \frac{F_{se}}{X_{se}}\right) + j\left(\frac{-1.02 P_{series} F_i}{E_i^2 + F_i^2} - \frac{Q_{shunt} E_i}{E_i^2 + F_i^2} + \frac{E_{se}}{X_{se}}\right) \quad 1$$

$$I_{j,upfc} = \frac{F_{se}}{X_{se}} + j\frac{-E_{se}}{X_{se}} \quad 2$$

The detailed mathematical formulations of the above Eq. (1) and (2) can be found in author's previous work [L.Gyugyi, et al., 2001, (Xi Yixin, et al., 2000].

UPFC DAMPING CONTROL STRATEGY

In the authors' previous work [L.Gyugyi, et al.,2001,(Xi Yixin, et al.,2000], the control strategy based on TEF approach for damping of power swings by using the UPFC has been developed. In the proposed control algorithm, the three independent UPFC control variables, K_s, γ_s and K_p ,(γ_p is a dependent control variable, a function of the inserted series voltage, ye, and the system parameters) are mathematically formulated into a general global TEF of power systems to studies the possible damping effectiveness of combining different power flow control modes inherently provided by a UPFC system. Based on the discussion concluded in [Moris,S and et al.,. 2003], to achieve the desired damping effects, during the transient the control criteria stated in the following equations, Eq (3) to (8), must be simultaneously satisfied.

$$P_{j,upfc}\frac{d}{dt}(\theta_{ij}) \leq 0 \tag{3}$$

$$Q_{j,upfc}\left(\frac{1}{V_i}\frac{dV_i}{dt} - \frac{1}{V_j}\frac{dV_j}{dt}\right) \leq 0 \tag{4}$$

$$[2k_s{}^2 b_{se} + 2b_{sh}(k_p - 1)]V_i \frac{dV_i}{dt} \leq 0 \tag{5}$$

$$\begin{aligned}&[b_{se}V_i^2\cos(\gamma_s) + 2k_s b_{se}V_i^2 \\ &- b_{se}V_iV_j\cos(\theta_{ij} + \gamma_s)]\frac{dk_s}{dt} \leq 0\end{aligned} \tag{6}$$

$$\begin{aligned}&[k_s b_{se}V_iV_j\sin(\theta_{ij} + \gamma_s) \\ &- k_s b_{se}V^2{}_i\sin(\gamma_s)]\frac{d\gamma_s}{dt} \leq 0\end{aligned} \tag{7}$$

$$b_{sh}V_i^2\frac{dk_p}{dt} \leq 0 \tag{8}$$

After a close examination of equations, E.q. (3) to (8), an interesting fact is found, that is Eq. (3) to (5) provide the information concerning the possible system parameters to be chosen as the input and output signals for the controllers. In addition, Eq. (6) to (8) give the control rules and constraints concerning how the three UPFC control parameters, K_s, γ_s and K_p , could be manipulated by the controllers with respect to the possible changes of system parameter, V_i, V_i, θ_{ij} , such that the control criteria can be satisfied. Based on the above observation, an innovative control pattern is proposed in which three conventional PI and three fuzzy controllers are utilized and designed to have different input signals, which are locally available system parameters, V_i, V_i, θ_{ij} , and different output signals, which are the imaging component, F_{se} , and the real component E_{se} , of the inserted series voltage, V_{se} , and the shunt reactive power injection, Q_{shunt} , of the UPFC. By activating these controllers at the same time the UPFC can be controlled in a way that the damping criteria stated in Eq. (3) to (8) can be satisfied simultaneously and the best damping effects can be achieved.
The parameters of UPFC are listed in Table 1.

TABLE 1: The Parameters of UPFC

UPFC parameters	Value
Rating of the series branch	100MVA
Rating of the shunt branch	100MVA
The leakage reactance of the series and shunt coupling transformers (Xse and Xsh)	0.025 p.u
Limits of the UPFC internal control parameters of Series branch	$K_{s-\min}$: 0.0; $K_{s-\max}$: 0.15 $\gamma_{s-\min}$: 0.0; $\gamma_{s-\max}$: 2.00
Limits of the UPFC internal control parameters of Shunt branch	$K_{p-\min}$: 0.95; $K_{p-\max}$: 1.05

PARTICLE SWARM OPTIMIZATION APPROCH

Particle Swarm Optimization, as an optimization tool, consists of a characteristic called particle [Erick, T.E., 2000]. Each particle in order to move to optimum position, changes its position with time. Particles move around in a multi dimensional search space, during flight. Each particle according to its own experience, and the experience of neighboring particles, adapt its position. Other characteristic in the PSO approach is called swarm. A swarm consists of a set of particles, neighboring the particle and its history experience. This searching technique used in power system problem with many researches ,for instance this approach used in optimization DG in distribution system by [Yoshida H, et.al, 2000] .in continue the procedure of PSO is described.
X represents a vector that shows various positions of particle. So, the d_{th} particle in a k-dimensional space is represented as:

$$\mathrm{x_d = (x_{dk}, x_{dk}, \dots; x_{dk})} \qquad 9$$

In order to achieve to optimum position, the best previous position is recorded as

$$\mathrm{qbest_d = (qbest_{d1}, qbest_{d2}, \dots; qbest_{dk})} \qquad 10$$

In Eq. (10), the "***sbestd***" is represented as index of the best particle among all the particles in the swarm. Another characteristic defended in the PSO approach is called velocity. The velocity of the ***dth*** particle is expressed as:

$$\mathrm{v_d = (v_{d1}, v_{d2}, v_{d3}, \dots, v_{dk})} \qquad 11$$

In order to search the better velocity and position, in next iteration, velocity and position of each particle may be obtained by using current velocity and position as expressed by:

$$\begin{aligned} v_{dk}^{r+1} &= w.v_{dk}^{r+1} \\ &+ c_1 * rand() * (qbest_{dk} - x_{dk}^r) + c_2 * Rand() * (sbest_{dk} - x_{dk}^r) \end{aligned} \qquad 12$$

$$x_{dk}^{r+1} = x_{dk}^r + v_{dk}^{r+1} \quad d = 1,2,\dots,D \quad k = 1,2,\dots,m \qquad 13$$

That D indicates the number of particles in a group; m is the population size in a particle, r is the number of iterations (generations), w indicates the weight factor, ***c1, c2*** are the acceleration constants. Moreover in above equations the Rand (), rand () are the uniform random values in the range [0, 1], x_{dk}^r is the position of the ***kth*** member in the ***dth*** particle at iteration r and finally v_{dk}^r represents the velocity of the ***kth*** member in the ***dth*** particle at iteratio ***r***.

It is notable that $V_d^{\min} \le v_{dk}^r \le V_d^{\max}$ .The parameter $V^{\max}$ determines the resolution, or fitness, showing which regions are to be searched between the present position and the target position. If $V^{\max}$ is very high, particles might fly past good solutions. Similarly if $V^{\max}$ is too small, particles may not explore sufficiently beyond local solutions. In many experiences with PSO, $V^{\max}$ was often set at 12–25% of the dynamic range of the variable on each dimension. The parameters c1 and c2 represent the weighting of the stochastic acceleration terms. High values result in abrupt movement toward, or past, target regions. On the other hand, low values allow particles to roam far from the target regions before being tugged back.
Suitable choice of the inertia weight w can supply a balance between global and local explorations. In general the inertia weight w is adjusted according to the following equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \qquad 14$$

In this equation $iter_{max}$ represents the maximum number of iterations, and ***iter*** indicates the current number of iterations.
In order to better clarify, the solution of optimization problem in regional level with PSO can be presented by an algorithm in five steps as follows:

Step1: Initialization

In this step ***d, n, T, itermax, w,*** c_1, c_2 and velocities are assigned.
In this step, the lower and higher bound of regional constraints is specified too. Based above d initial particles are generated in random in the range of regional constraint. Set iteration=1.

Step2: Objective function calculation

In this step the objective function and fitness value of each particle ***qi,d*** is calculated. Compare fitness value of each particle with its qbest.The best fitness value among qbest is denoted as ***sbest***.

Step3: Velocity modification

In this step the velocity of each particle is modified based on bellow equation, and then generate the new particles based follow equation:

$$v_{dn}^{t\ r+1} = w.v_{dk}^{r} + c_1 * rand() * (qbest_{dk} - q_{dn}^{t\ (r)}) + c_2 * Rand() * (sbest_d - x_{dk}^{r}) \quad 15$$

$$q_{dn}^{t\ (r+1)} = q_{dn}^{t\ (r)} + v_{dn}^{t\ (r+1)} \quad 16$$

In these equations $q_{dn}^{t\ (r)}$ is a part of above equation in the rth iteration. It should be noted that $q_{dn}^{t\ (r)}$ is defined earlier, if v_{dn}^{t} reaches to its boundary values, it will be adjust to the extreme values. In other words, If $v_{dn}^{t} > V^{\max}$ then $v_{dn}^{t} = V^{\max}$ .Similarly, If $v_{dn}^{t} < V^{\min}$ then $v_{dn}^{t} = V^{\min}$ .Finally the all of regional constraints are checked and the offender particles are penalized with the penalty factor expressed by above equation:

Step4: Upgrading of qbest, sbest

If the fitness value of each particle is better than the previous qbest, then qbest is updated with the current value.If the best qbest is better than sbest, then sbest will be substituted with the best qbest. This is the end of iteration. Set iteration=iteration+1.
If iteration>itermax then the algorithm is stopped unless it is continued by going to step2. Otherwise step 5.

Step5: Results of PSO

The particle that generates the latest sbest is the optimal solution of PSO. Table 2 gives the PSO parameters in this simulation.

TABLE 2 PSO Parameters in Simulation

Indices	Parameter value
Num. of particles(d)	500
C1,C2	5
Wmax,Wmin	9,5
No. of iteration	500
$V_{qd}^{\max}, V_{qd}^{\min}$	$6q_d^{\max} \quad -0.5q_d$

SIMULATION and RESULTS

The two-area system presented in [H.F.Wang' 1999] shown in Figure 3 is considered in this study. The system has a UPFC installed between bus-7 and bus-8. It is considered that a 3-phase symmetrical short-circuit fault of 100 mill-seconds duration occurs at bus-3. The system is simulated in Matlab/Simulink environment and the corresponding graphs are shown in Figure 4 and Figure 5.

It is inferred that without a UPFC, the oscillations in generator rotor angle of Area-1 (Generator 1 and Generator 2) and Area-2 (Generator 3 and Generator 4) increase and the settling time for the oscillations is found to be high. However, it can be seen that with a UPFC, the oscillations in generator rotor angle of Area-1and Area-2 decrease and the settling time for the oscillations is found to be slightly low. Hence, the transient stability of the two-area power system is improved with UPFC.

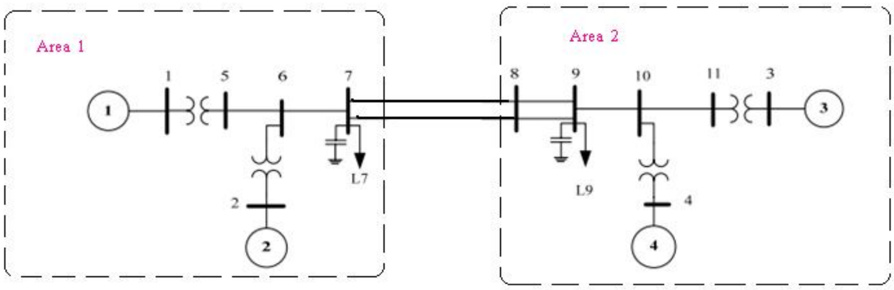

FIGURE 3 Multi-Machine Power System

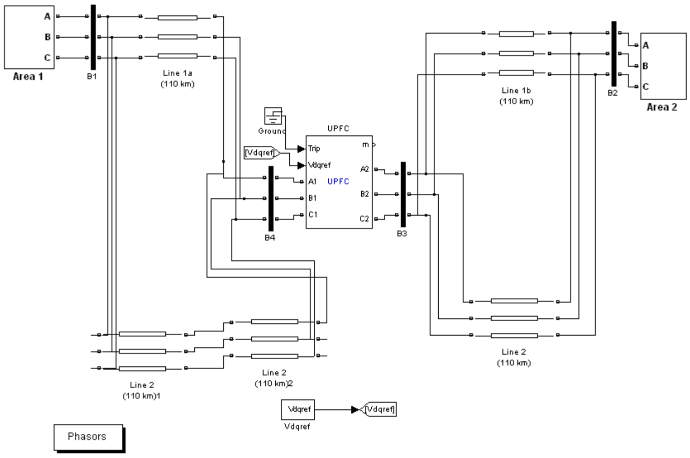

FIGURE 4 Multimachine System with UPFC

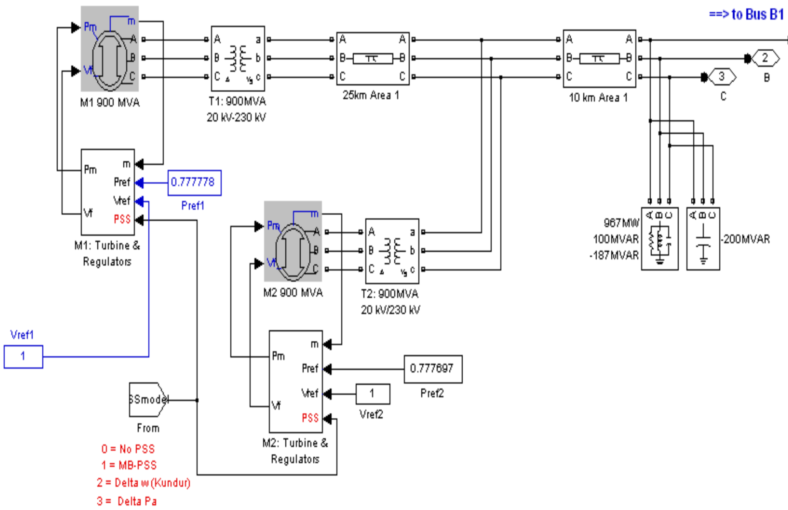

FIGURE 5 Parameters Setting in MATLB

The conventional PI block considered in this paper is depicted in Figure 6.

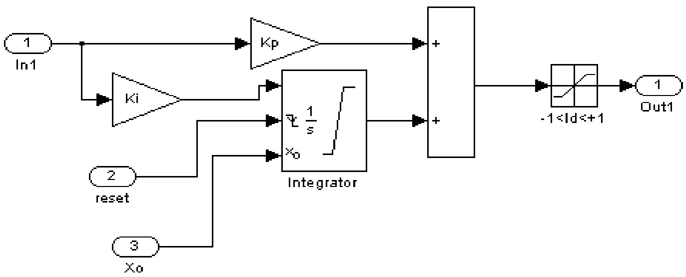

FIGURE 6 Conventional PI Controllers in UPFC

Fyzzy logic was presented and implemetd in several sysideis by [(K. Phorang, et al., 2002),(Tamer Abdelazim, O. P. Malik, 2005)] .

In order to using fuzzy logic program in the inputs are described by the following linguistic variables: P (positive), NZ (near Zero), and N (negative). The output is described by five linguistic variables P (positive), PS (Positive small), NZ (near zero), NS (negative small), and N (negative). Gaussian functions are used as membership functions for both inputs, and triangular membership functions are used for output.

A fuzzy controller structure presented by (Lo, K.L.and Laiq Khan, 2000) is shown in Figure 7. The controller is placed between Pre-processing and post-processing blocks. PI-Fuzzy controller in UPFC is shown in Figure 8.

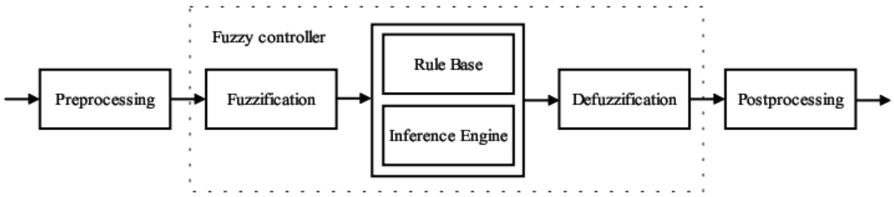

FIGURE 7 Fuzzy Controller Structure

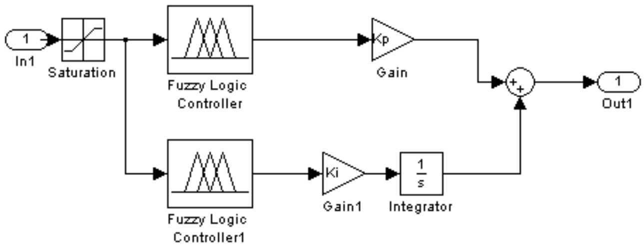

FIGURE 8 Fuzzy Logic PI Controller in UPFC

A three-phase fault of' 100 ms duration is simulated at the middle of one of the line connecting Bus-7 and Bus-8. Figures 9-12 present the local and inter-area mode of oscillations. These figures show the comparison of the conventional PI controller and the proposed controller. The performance of proposed method with improved PSO is quite prominent in comparison to the PI controller. The variation of voltage across the D.C. capacitor shows that the overshoots and the settling time are well controlled by the proposed controller.

The system parameters in this study in p.u of the power network are set to P1=0.5556, Q1=0.2056, P2=0.5556, Q2=0.2611, P3=1.3739, Q3=0.1502, P4=1.5556, Q4= 0.2244. The three-phase fault of case-2 is initiated for 100 ms duration. it is observed that the proposed controller performs significantly in damping inter-area oscillations. It is obvious that using fuzzy-PI controller of UPFC based on PSO, the most damping of oscillations are obtained respect to PI conventional or PI-Fuzzy.

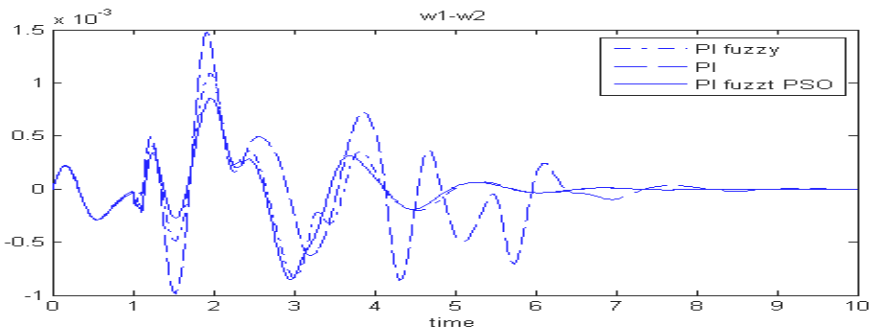

FIGURE 9 Inter-Area Mode of Oscillation for $\omega_1 - \omega_2$ with Three-Phase Fault 100 ms

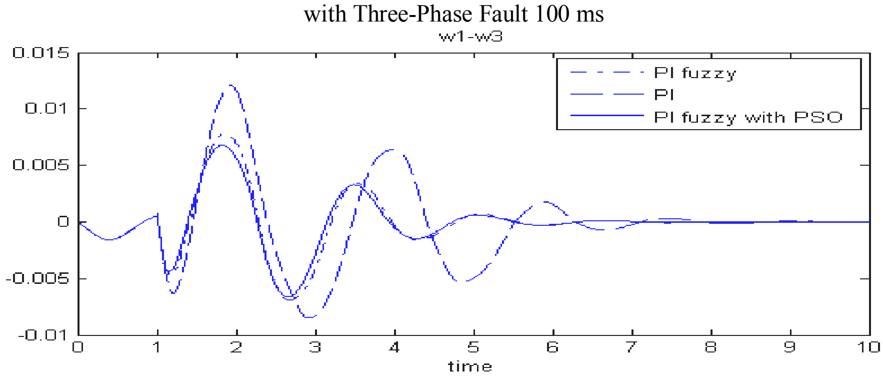

FIGURE 10 Local-Area Mode of Oscillation for $\omega_1 - \omega_3$ with Three-Phase Fault 100 ms

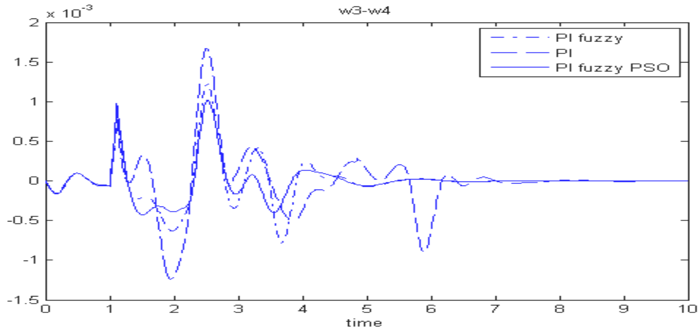

FIGURE 11 Inter-Area Mode of Oscillation for $\omega_3 - \omega_4$ with Three-Phase Fault 100 ms

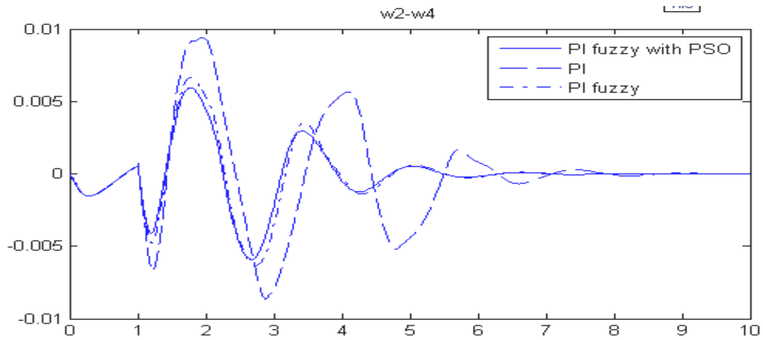

FIGURE 12 Inter-Area Mode of Oscillation for $\omega_4 - \omega_2$ with Three-Phase Fault 100 ms

In order to investigation the capability of proposed controller on damping oscillations on power system in short circuit with linger duration time, a three-phase fault of' 200 ms duration is simulated at the middle of one of the line connecting Bus-7 and Bus-8.Figues 13 and 14 present the local and inter-area mode of oscillations. Results show that in this case with longer duration time of short circuit, that conventional PI and Fuzzy PI controller, can damp oscillation in slowly, PSO-based controller can damp oscillation very fast. In this case the difference between PSO-based controller and conventional PI and Fuzzy-PI is more than the faults with shorter time duration fault.

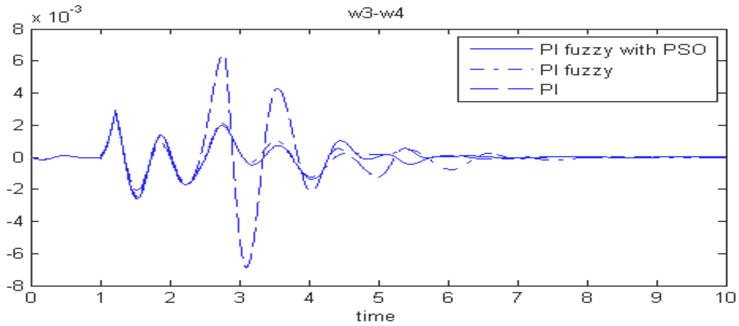

FIGURE 13 Local-Area Mode of Oscillation for $\omega_3 - \omega_4$ with Three-Phase Fault 200 ms

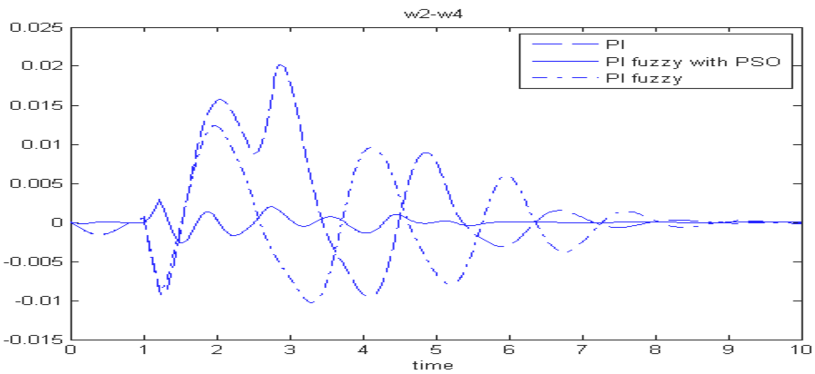

FIGURE 14 Inter-Area Mode of Oscillation for $\omega_4 - \omega_2$ with Three-Phase Fault 200 ms

CONCLUSION

This paper presents a novel development of a fuzzy logic controlled power system using UPFCs to damp the oscillations in a FACTS based integrated multi-machine power system. Oscillations in power systems have to be taken a serious note of when the fault takes place in any part of the system; else this might lead to the instability mode & shutting down of the power system. UPFC based PI controllers can be used to suppress the oscillations upon the occurrence of a fault at the generator side or near the bus side. In this paper, a nonlinear variable gain fuzzy PI controller for UPFC based on PSO has been proposed.

With Particle Swarm Optimization approach, for the best selection parameters of PI-Fuzzy controller of UPFC has been introduced. The simulation results show that the adaptive controller can damp power oscillation more effective than the conventional PI controller and it is not sensitive to the loading conditions and the changes in power system topology.

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