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Coordinated design of UPFC and PSS to improve power system stability

***Abstract**. A modified particle swarm optimization is proposed and used for coordinated designing of the power system stabilizer and unified power flow controller as a damping controller in the multi-machine power system. For evaluation of the effectiveness and robustness of the proposed controllers, their performances have been tested on a weakly connected power system subjected to different disturbances. The results of these studies show that the proposed coordinated controllers have an excellent capability in damping power system inter-area oscillations and enhance greatly the dynamic stability of the power system.*

***Streszczenie.** W artykule opisano metodę projektowania struktury sterowania układem elektrycznym wielomaszynowym, gwarantującej stabilność pracy i jednostkowy współczynnik mocy. W metodzie wykorzystano zmodyfikowaną optymalizację rojem cząstek. Analizy skuteczności i odporności polegała na poddaniu zakłóceniom systemu przy połączeniu słabym. Wyniki badań potwierdzają skuteczność proponowanego rozwiązania. (**Projektowanie struktury UPFC i PSS dla zwiększenia stabilności mocy w systemie**).*

Keywords: UPFC, PSS, Low frequency oscillation, PSO.
Słowa kluczowe: UPFC, PSS, oscylacje niskiej częstotliwości, PSO.

Introduction

The stability of the power system is the core of power system security, which has been researched by electrical engineers. The most common way to control power system stability is to control the excitation of the generator by means of the automatic voltage regulator. Unfortunately, the high performance of these voltage regulators sometimes causes a destabilizing phenomenon in the power system. Most of the problems are associated with the low frequency oscillations in interconnected power systems, especially in the deregulated paradigm. Small magnitude and low frequency oscillation often remained for a long time in power systems [1]. As the most cost effective damping controller, the power system stabilizer (PSS) has been widely applied to suppress the low frequency oscillation and enhance the system dynamic stability [2, 3]. PSSs contribute in maintaining reliable performance of the power system stability by providing an auxiliary signal to the excitation system. PSSs have been used for many years to add damping to electromechanical oscillations [4]. However, using only conventional PSS may not provide sufficient damping for the inter-area oscillations. Hence, new developments in the field of power electronic devices led the Electric Power Research Institute to introduce a new technology known as flexible alternating current transmission systems (FACTS) in the late 1980s [5-8]. The recently appeared FACTS-based controller offers an alternative way in damping power system oscillation. FACTS power oscillation damping (POD) controllers can provide effective damping for the inter-area modes. Among these FACTS devices, the unified power flow controller (UPFC) is a multi-functional FACTS controller with the primary function of power flow control plus possible secondary duties of voltage support, transient stability improvement and oscillation damping, etc [9, 10]. This stability enhancement depends on applying suitable control strategies in UPFC converters. When the UPFC is applied to the interconnected power systems, it can provide significant damping effect on tie-line power oscillation through its supplementary control. However, uncoordinated local control of UPFC controller and PSSs may cause unwanted interactions that may further result in system destabilization. To improve overall system performance, many studies were made on the coordination among PSS and FACTS POD controllers [11-17]. In recent years, extensive studies have been carried out employing different optimization methods for the solution. Recently, a new subset of heuristic algorithms have been developed and successfully applied to a number of benchmarks and real-world problems. Particle swarm optimization (PSO) is a subset of the heuristic algorithm has been developed and successfully applied to a number of benchmarks and real-world optimization problems [18]. Compared with other heuristic algorithms, PSO has less parameter to be adjusted. It has the ability to escape from local minima, it is easy for computer implementation and coding and it has more effective memory capability. Although the standard version of PSO has many advantages and several attractive features, it is also observed that this technique does not always perform as per expectations, and they will smoothly slip into the local near-optimal solutions when the optimization problem is relatively complex, and it cannot jump over the obstruction. Recently, several investigations have been undertaken to improve the performance of the SPSO [13, 19-30].

In this paper, a novel chaotic PSO with nonlinear time varying acceleration coefficient is introduced. The proposed modified PSO (MPSO) greatly elevates global and local search abilities and overcomes the premature convergence of the original algorithm. In addition, these will be extended to solve coordinated design problem of PSS and UPFC damping controller. The problem of coordinated tuning is formulated as an optimization problem according to the eigenvalue-based multi-objective function for a wide range of the operating conditions and MPSO is used to solve it. The effectiveness of the proposed controller is tested on a New England 16-unit 68-bus standard power system under various system configurations and operation conditions. Simulation results have proved that with the optimized controller settings, the system becomes stable and power system oscillations are well damped.

Particle Swarm Optimization

In a PSO system, multiple candidate solutions coexist and collaborate simultaneously. Each solution called a particle, flies in the problem search space looking for the optimal position to land. A particle, during the generations, adjusts its position according to its own experience as well as the experience of neighboring particles. A particle status on the search space is characterized by two factors: its position (X_i) and velocity (V_i). The new velocity and position of the particle will be updated according to the following equations [31]:

(1) $$V_i(k+1) = w\times V_i(k) + c_1\times Rand(.)\times[p_i(k) - X_i(k)] + c_2\times rand(.)\times[p_g(k) - X_i(k)]$$

(2) $$X_i(k+1) = X_i(k) + V_i(k+1)$$

where w is an inertia weight and is a scaling factor controlling the influence of the old velocity on the new one. c_1 and c_2 are two positive constants known as cognitive and social coefficients, explaining the weight of the acceleration terms that guide each particle toward the individual best (*pbest*) and the swarm best positions (g*best*), respectively. *Rand*(.) and *rand*(.) are two independent random numbers selected in each step according to a uniform distribution in a given interval [0, 1]. The inertia weight, w, is usually evaluated by [31]:

(3) $$w = w_{\max} - \frac{w_{\max} - w_{\min}}{k_{\max}}\times k$$

where w_{max} and w_{min} are maximum and minimum value of w, k_{max} is the maximum number of iteration and k is the current iteration number.

Modified particle swarm optimization

As a member of stochastic search algorithms, PSO has a major drawback. Although PSO constitutes a huge success and converges to an optimum much faster than other evolutionary algorithms, it usually cannot improve the quality of the solutions as the number of iterations is increased. PSO usually suffers from premature convergence in the early stages of the search and henceforth, it is unable to locate the global optimum, especially when high multimodal problems are being optimized. In the current research, to enhance the performance, prevent the premature convergence, and provide a good balance between the global exploration and local exploitation abilities of the original algorithm, a chaotic PSO with nonlinear time-varying acceleration coefficients is introduced. The proposed MPSO introduces the application of chaotic sequences to improve the original algorithm's global seeking ability and prevent the early convergence to local minima. One of the dynamic systems showing a chaotic manner is a logistic map whose equation is described as follows:

(4) $$\theta[k+1] = \mu.\theta[k].(1-\theta[k]), \qquad 0\le\theta[1]\le 1$$

where μ is a control parameter and has a real value in the range of [0, 4], and k is the iteration number. The behavior of the system represented by Eq. (4) is greatly changed with the variation of μ. The value of μ determines whether θ stabilizes at a constant size, oscillates within limited bounds, or behaves chaotically in an unpredictable pattern. Equation (4) displays chaotic dynamics when μ=4.0 and $\theta[1]\notin\{0, 0.25, 0.5, 0.75, 1\}$. The new equation for inertia weight obtained by multiplying Eq. (4) and Eq. (3) reads as follows:

(5) $$w = \theta\times\left(w_{\max} - \frac{w_{\max} - w_{\min}}{k_{\max}}\cdot k\right)$$

Although the conventional inertia weight decreases monotonously from w_{max} to w_{min}, the new inertia weight decreases and oscillates simultaneously for total iteration when μ=4.0 and θ[1]=0.55. In addition, to further balance between global exploration and local exploitation abilities, nonlinear time-varying acceleration coefficients are introduced. In this approach the acceleration coefficients change according to the following equations:

(6) $$c_1 = (c_{1i} - c_{1f})\times\exp[-(4\times\frac{k}{k_{max}})^2] + c_{1f}$$

(7) $$c_2 = (c_{2i} - c_{2f})\times\exp[-(4\times\frac{k}{k_{max}})^2] + c_{2f}$$

where c_{1i} and c_{2i} are the initial values of the acceleration coefficient c_1 and c_2, and c_{1f} and c_{2f} are the final values of the acceleration coefficient c_1 and c_2, respectively. In the nonlinear time-varying acceleration coefficients strategy, the cognitive coefficient (c_1) is nonlinearly decreased during the course of run, however, the social coefficient (c_2) is nonlinear and it is inversely increased. The MPSO provides a larger value for the cognitive component and a smaller value for the social component at the beginning of the optimization procedure, which allow particles to move around the search space instead of moving toward the population best (*pbest*). In the later part of the optimization, the MPSO provides a smaller cognitive component and a larger social component, which allow the particles to converge to the global optimum. Consequently, the new velocity update equation for the proposed MPSO can be expressed as follows:

(8) $$\begin{aligned} V_i[k+1] &= \theta\times\left(w_{\max} - \frac{w_{\max}-w_{\min}}{k_{\max}}\times k\right)\times V_i[k] \\ &+ \left((c_{1i}-c_{1f})\times\exp[-(4\times\frac{k}{k_{\max}})^2] + c_{1f}\right)\times Rand(.)\times(pbest_i[k] - X_i[k]) \\ &+ \left((c_{2i}-c_{2f})\times\exp[-(4\times\frac{k}{k_{\max}})^2] + c_{2f}\right)\times rand(.)\times(gbest[k] - X_i[k]) \end{aligned}$$

Exciter and PSS

The excitation system model (IEEE type-ST1) is given in Fig. 1.

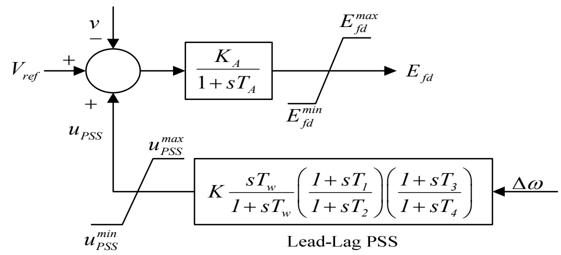

Fig. 1. The block diagram of the excitation system

This includes a static exciter containing an AVR and a PSS that contains a washout circuit and a lead-lag block in addition to a limiter. The conventional lead-lag PSS is installed in the feedback loop to generate a supplementary stabilizing signal u_{pss}. The AVR dynamics can be given by:

(9) $$\dot{E}_{FD} = (K_A(V_{\mathrm{Re}f} - V_T + U_{PSS}) - E_{FD}) / T_A$$

where K_A and T_A are the gain and time constant of the excitation system, respectively; E_{fdi} is the excitation field voltage, and V_T and V_{refi} are the terminal voltages and the reference voltages of the machine, respectively and u_{PSS} is the PSS control signal.

The dynamic model of the UPFC

The UPFC consists of an excitation transformer (ET), a boosting transformer (BT), two three-phase GTO based voltage source converters (VSCs), and a DC link capacitors. The four input control signals to the UPFC are m_E, m_B, δ_E, and δ_B, where, m_E is the excitation amplitude modulation ratio, m_B is the boosting amplitude modulation ratio, δ_E is the excitation phase angle, and δ_B is the boosting phase angle. The dynamic model of the UPFC is required in order to study the effect of the UPFC for enhancing the small-signal stability of the power system. By applying Park's transformation and neglecting the resistance and transients of the ET and BT transformers, the UPFC can be modeled as:

$$\frac{dv_{dc}}{dt}=\frac{3m_E}{4C_{dc}}\begin{bmatrix}\cos\delta_E & \sin\delta_E\end{bmatrix}\begin{bmatrix}i_{Ed}\\ i_{Eq}\end{bmatrix}+\frac{3m_B}{4C_{dc}}\begin{bmatrix}\cos\delta_B & \sin\delta_B\end{bmatrix}\begin{bmatrix}i_{Bd}\\ i_{Bq}\end{bmatrix}$$

(10) $$\begin{bmatrix}v_{Etd}\\ v_{Etq}\end{bmatrix}=\begin{bmatrix}0 & -x_E\\ x_E & 0\end{bmatrix}\begin{bmatrix}i_{Ed}\\ i_{Eq}\end{bmatrix}+\begin{bmatrix}\dfrac{m_E\cos\delta_E v_{dc}}{2}\\ \dfrac{m_E\sin\delta_E v_{dc}}{2}\end{bmatrix},$$

$$\begin{bmatrix}v_{Btd}\\ v_{Btq}\end{bmatrix}=\begin{bmatrix}0 & -x_B\\ x_B & 0\end{bmatrix}\begin{bmatrix}i_{Bd}\\ i_{Bq}\end{bmatrix}+\begin{bmatrix}\dfrac{m_B\cos\delta_B v_{dc}}{2}\\ \dfrac{m_B\sin\delta_B v_{dc}}{2}\end{bmatrix}$$

UPFC based Damping Controller

The damping controller is designed to produce an electrical torque in-phase with the speed deviation according to phase compensation method in order to improve damping of the system oscillations. UPFC control adopts the Proportional plus Integral control law. The four control parameters of the UPFC (*δ_B, m_B, m_E and δ_E*) can be modulated in order to produce the damping torque. The structure of UPFC based damping controller is shown in Fig. 2, where u could be δ_B, m_B, m_E and δ_E. This controller may be considered as a lead/lag compensator. It comprises gain block, signal-washout block and lead/lag compensator.

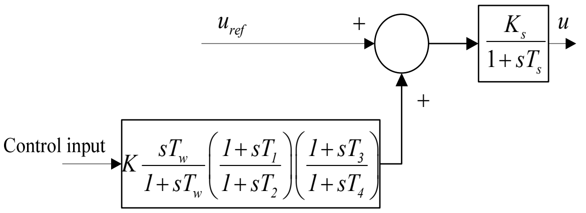

Fig. 2. UPFC with lead-lag controller

Linearized model

The system analyses and controller design to improve small signal stability margin may be carried out by means of linear models. Since the early 1970s, linear analysis techniques have been used to study the dynamic behavior of power systems. After linearizing the system model equations around an operating point, a single linear time invariant model, in the Form

(11) $$\dot{x}=Ax+Bu \qquad y=Cx$$

where $\boldsymbol{x}\in\Re^{\boldsymbol{n}}$ is a vector composed by the deviations of the system state variable (with respect to a nominal operating point), $\boldsymbol{u}\in\Re^{\boldsymbol{p}}$ is a vector with the system control input, and $\boldsymbol{y}\in\Re^{\boldsymbol{p}}$ is the vector with the system outputs. Controller design for power systems are usually based on output feedback, since not all the model state variables are available for direct measurement in the real system. For this reason, the proposed damping controllers (PSS-type and UPFC-based) are founded on the dynamic output feedback structure. The controller is a lead/lag type described by:

(12) $$V(s)=K(s)y(s)$$

where *K(s)* is the transfer function of the controller, *y(s)* is the measurement signal and *V(s)* is the output signal from the controller which will provide additional damping by moving modes to the left. Such control structure can be represented by a linear equation set, in state space form, given by Eq. (13)

(13) $$\dot{x}_c=A_cx_c+B_cy \qquad u=C_cx_c$$

where $\boldsymbol{x_c}\in\Re^{\boldsymbol{n}}$ is the state vector of the controller. The closed loop description of the controlled system may be represented by

(14) $$\dot{\tilde{x}}=\tilde{A}\tilde{x},\ \tilde{A}=\begin{bmatrix}A & BC_c\\ B_cC & A_c\end{bmatrix}$$

where $\tilde{x}\in\Re^{2n}$ is a vector containing the states of both the system and the controller. $\boldsymbol{A}\in\Re^{2\boldsymbol{n}}$ is the state matrices of the closed loop system, and A_c, B_c and C_c are the matrix variables to be determined by the design procedure. The goal of the stabilizers design is to place the eigenvalues of matrix Ã in the left half of the complex plane. The eigenvalues (mode) of the total system can be evaluated from the closed loop matrix Ã.

(15) $$\lambda_i=\sigma_i\pm j\omega_i$$

The stability of the linear system is guaranteed if all eigenvalues have negative real parts. The eigenvalues may be real or complex. The imaginary part of the complex eigenvalue (ω) is the radian frequency of the oscillations, and the real part (σ) is the decrement rate. Then, the damping ratio (ξ_i) of the *i*-th eigenvalue is defined by $\xi_i=-\sigma_i/\sqrt{\sigma_i^2+\omega_i^2}$

Design of Objective Functions

For optimization problem in this paper, an eigenvalue based multi objective function reflecting the combination of damping factor and damping ratio is considered as follows:

(16) $$J=\sum_{\sigma_{ij}\ge\sigma_0}\left(\sigma_0-\sigma_{ij}\right)^2+\alpha\sum_{\zeta_{ij}\ge\zeta_0}\left(\zeta_0-\zeta_{ij}\right)^2$$

(17) $$f(\mathbf{X})=\sum_{j=1}^{NP}J_j$$

where *j = 1, 2, 3,...,NP* is the index of system operating conditions considered in this design process, *i = 1, 2,...,N*, is the index of eigenvalues in the system, σ_{ij} and ζ_{ij} are the damping factor and the damping ratio of the *i*th eigenvalue of the *j*th operating condition. The value of α is a weight for combining both damping factors and damping ratios. Finally, σ_0 and ζ_0 are the constant value of the expected damping factor and damping ratio, respectively. By optimizing *F*, closed loop system poles are consistently pushed further left of the $j\omega$ axis with simultaneous reduction in real parts, too. Thus, enhancing relative stability and increasing the damping ratio over the ζ_0 is achieved. Parameters determined by the MPSO procedure are controllers gain *K*, and lead/leg time constants T_1, T_2, T_3 and T_4. Washout time constants were kept fixed during the optimization. In the proposed method, one must tune the PSS and UPFC controllers' parameters optimally to improve the system's overall dynamic stability under different operating conditions and disturbances. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameter bounds:

(18) $$K_i^{\min}\le K_i\le K_i^{\max} \qquad T_i^{\min}\le T_i\le T_i^{\max}$$

The flowchart of the optimization based coordinated design is depicted in Fig. 3.

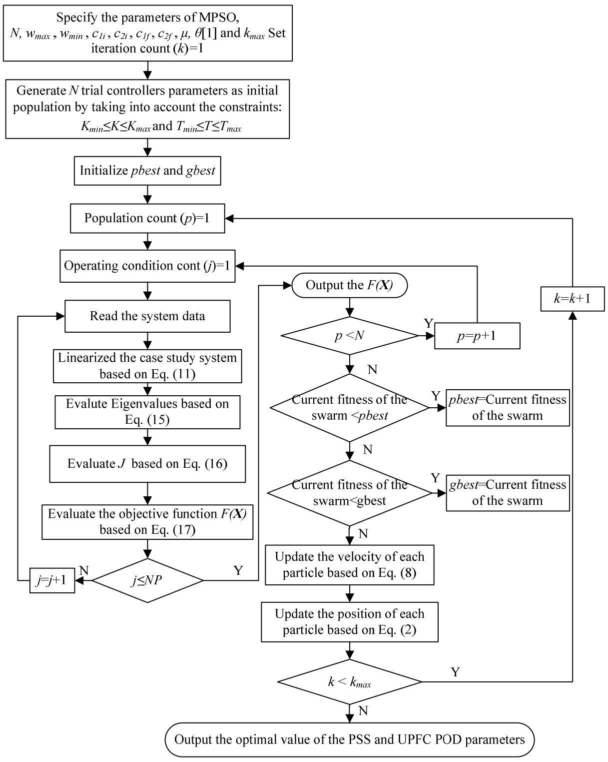

Fig.3. Application of MPSO for coordinated design

Test System

The New England 16-machine, 68-bus system, which is large and close to realistic power systems, is used to illustrate the performance of the proposed method. The system diagram and its relevant data are shown in Fig. 4. It is a reduced order model of the New England and New York interconnected power systems. The entire system can be divided into five areas; (i) New England (G1-G9), (ii) New York (G10-G14), (iii) Generator G14, (iv) Generator G15, and (v) Generator G16. The red lines indicate the major weak tie lines that cause the low-frequency inter-area oscillations. They represent the tie lines between the areas. Areas 1, 2, and 3 each contain a single large generator. These areas represent aggregated equivalents. Area 4 is modeled in more detail, but has one equivalent generator in addition to more normally sized generators. Area 5 has the most detailed modeling.

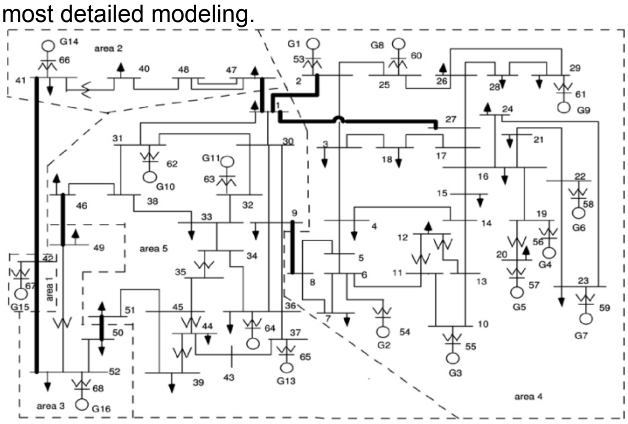

Fig.4. Single line diagram of a 5-area-16-machine system

Controller results and comparisons

In this section, MPSO has been applied to the test system to find the optimal parameters for a PSS and for UPFC controllers. Based on earlier studies, lines 1-27 have been chosen as a candidate for UPFC installation in the 5-area-16-machine system this system is modeled using PST. The supplementary controller for the UPFC and a PSS is to be placed in machine 9 and designed simultaneously by using the MPSO. The results obtained by the algorithm are shown in Table I. The obtained PSS and UPFC controller parameters by MPSO are placed in the 5-area-16-machine system.

Table 1. The optimal parameter settings of the proposed controllers

	Parameters	PSS	UPFC
Uncoordinated design	K	18.10	27.8
	T_1	1.78	0.58
	T_2	1.20	1.56
	T_3	1.73	0.03
	T_4	1.23	0.35
Coordinated design with MPSO	K	26.23	29.77
	T_1	0.177	0.376
	T_2	0.254	0.880
	T_3	1.290	0.93
	T_4	0.380	0.07

A three-phase fault is applied on line 1-2 (tie line between area 5 and area1, at bus 1) at 0.1s, and cleared after six cycles and the behavior of the system was evaluated for 20s. The speed deviation with respect to a particular machine (machine 13) is computed over the simulation period and shown in Fig. 5 to Fig. 7. These figures show that coordinated design of the PSS and UPFC controller by MPSO provides good damping for the study system. Once again, to show the robustness of the designed controllers, a three-phase to ground fault is applied in line 29-28 (on bus 29). The dynamic behavior of the system was evaluated for 20s. The speed deviation is computed over the simulation period and shown in Figs. 8-10. Again, these responses are similar to the responses in Fig. 5 to Fig. 7 for a three-phase to ground fault in line 1-2, showing the robustness of the designed controllers. It can be seen that the damping of the oscillation is much faster with the coordinate control. The proposed coordinating controller thus enhances the stability of the system by providing better damping of power oscillations. The proposed method has successfully increased system damping under small perturbation stability by the proper design of PSS and UPFC parameters. Simulation results have proved that with the optimized controller settings, the system becomes stable and power system oscillations are well damped.

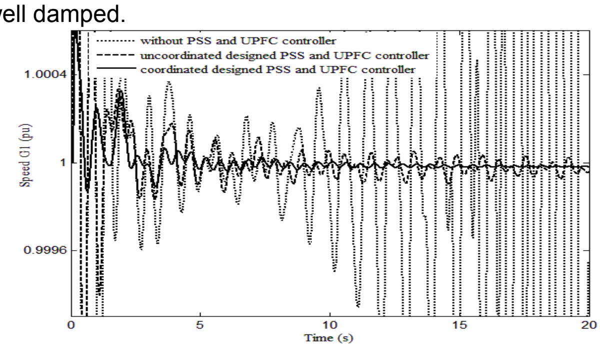

Fig.5. Response of G1 to a three phase to ground fault on bus 1

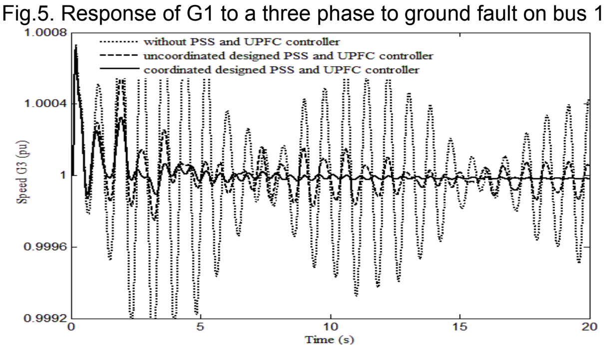

Fig.6. Response of G3 to a three phase to ground fault on bus 1

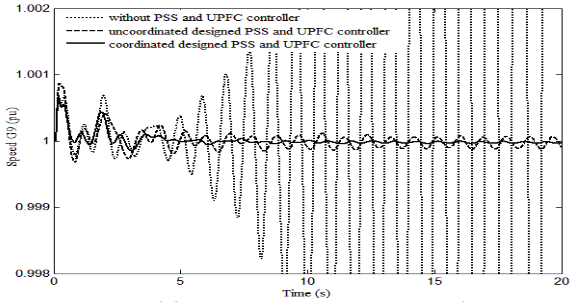

Fig.7. Response of G9 to a three phase to ground fault on bus 1

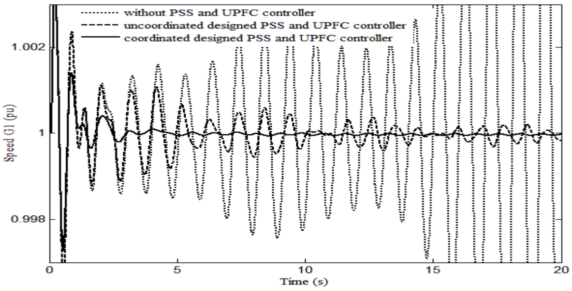

Fig.8. Response of G1 to a three phase to ground fault on bus 29

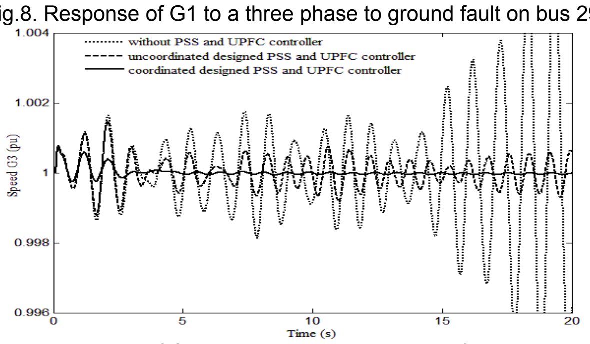

Fig.9. Response of G3 to a three phase to ground fault on bus 29

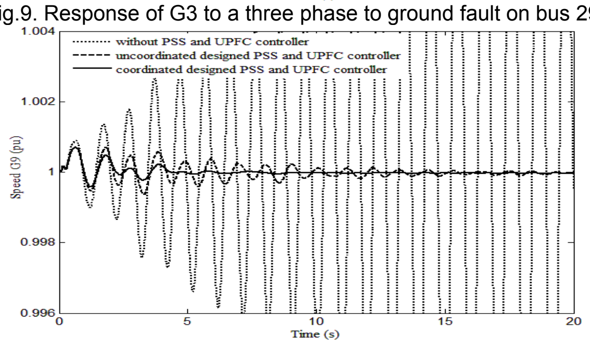

Fig.10. Response of G9 to a three phase to ground fault on bus 29

Conclusion

A modified particle swarm optimization (MPSO) is developed for the simultaneous coordinated tuning of the UPFC damping controller and PSS in multi-machine power system in this study. A novel chaotic PSO with nonlinear time varying acceleration coefficient is introduced. The proposed MPSO greatly elevates global and local search abilities and overcomes the premature convergence of the original algorithm. The proposed method is extended to solve coordinated design problem of PSS and UPFC damping controller. The problem of coordinated tuning is formulated as an optimization problem according to the eigenvalue-based multi-objective function for a wide range of the operating conditions and MPSO is used to solve it. The effectiveness of the proposed controller is tested on a 5-area-16-machine system under various system configurations and operation conditions. The proposed method has successfully increased system damping under small perturbation stability by the proper design of PSS and UPFC parameters. Simulation results have proved that with the optimized controller settings, the system becomes stable and power system oscillations are well damped.

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REFERENCES

[1] Kundur P., Balu N.J., Lauby M.G. Power system stability and control. 1994, 141.
[2] Larsen E., Swann D., Applying power system stabilizers part I, II, III, *IEEE Trans. Power Apparatus. Syst.,* 100(1981), No. 6, 3017-3046.
[3] Eslami M., Shareef H., Mohamed A., Application of artificial intelligent techniques in PSS design: a survey of the state-of-the-art methods, *Prz. Elektrotechniczny ,* 87(2011), No. 4, 188-197.
[4] Eslami M., Shareef H., Mohamed A. Power System Stabilizer Design Based on Optimization Techniques. In 4th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), pp. 1-7.
[5] Eslami M., Shareef H., Mohamed A., Application of PSS and FACTS Devices for Intensification of Power System Stability, *Int. Rev. Electr. Eng.,* 5(2010), No. 2, 552-570.
[6] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., A Survey on Flexible AC Transmission Systems (FACTS), *Prz. Elektrotechniczny*, 88(2012), No. 1A, 1-11.
[7] Eslami M., Shareef H., Mohamed A. Coordination of PSS and FACTS damping controllers in power systems for dynamic stability improvement: A Review. In The 2nd International Conference on Engineering and ICT (ICEI), Melaka, Malaysia, pp. 30-36.
[8] Hingorani N.G., Gyugyi L., El-Hawary M. Understanding FACTS: concepts and technology of flexible AC transmission systems. 2000.
[9] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., Design of UPFC Damping Controllers using Modified Particle Swarm Optimization, *Lecture Notes in Information Technology*, 13(2012), 441-447.
[10] Wang H., Applications of modelling UPFC into multi-machine power systems, *IEE Proceedings-Generation, Transmission and Distribution*, 146(1999), No. 3, 306-312.
[11] Eslami M., Shareef H., Mohamed A. Coordinated design of PSS and TCSC controller for power system stability improvement. In The 9th International Power and Energy Conference (IPEC), Singapore, pp. 433-438, 2010
[12] Eslami M., Shareef H., Mohamed A., Optimization and Coordination of Damping Controls for Optimal Oscillations Damping in Multi-Machine Power System, *Int. Rev. Electr. Eng.,* 6(2011), No. 4, 1984-1993.
[13] Eslami M., Shareef H., Mohamed A., Optimization and Coordination of Damping Controls for Optimal Oscillations Damping in Multi-Machine Power System, *Int. Rev. Electr. Eng.,* 6(2011), No. 4, 1984-1993.
[14] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., Particle Swarm Optimization for Simultaneous Tuning of Static Var Compensator and Power System Stabilizer, *Prz. Elektrotechniczny*, 87(2011), No. 9A, 343-347.
[15] Eslami M., Shareef H., Mohamed A., Khajehzadeh M. Coordinated design of PSS and SVC damping controller using CPSO. In 5th International Power Engineering and Optimization Conference (PEOCO) Shah Alam, Selangor, pp. 11-16, 2011
[16] Eslami M., Shareef H., Mohamed A., Khajehzadeh M. PSS and TCSC Damping Controller Coordinated Design Using GSA. 2011 2nd International Conference on Advances in Energy Engineering, Zeng D (ed), 2012, pp. 763-769.
[17] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., Gravitational search algorithm for coordinated design of PSS and TCSC as damping controller, *J. Cent. South Univ. Technol.*, 19(2012), No. 4, 923-932.
[18] Kennedy J., Eberhart R. Particle swarm optimization. In Proceeding of IEEE international conference on Neural Networks (ICNN'95), Perth, Australia, pp. 1942-1948.

[19] Khajehzadeh M., Taha M., El-Shafie A., Reliability analysis of earth slopes using hybrid chaotic particle swarm optimization, *J. Cent. South Univ. Technol.*, 18(2011), No. 5, 1626-1637.
[20] Khajehzadeh M., Taha M.R., El-Shafie A., Eslami M., Modified particle swarm optimization for optimum design of spread footing and retaining wall, *J. Zhejiang Univ.-Sci. A*, 12(2011), No. 6, 415-427.
[21] Khajehzadeh M., Taha M.R., El-Shafie A., Eslami M., Locating the general failure surface of earth slope using particle swarm optimisation, *Civil Eng. Environ. Syst.*, 29(2012), No. 1, 41-57.
[22] Khajehzadeh M., El-Shafie A., Taha M.R., Modified particle swarm optimization for probabilistic slope stability analysis, *Int. J. Phys. Sci.*, 5(2010), No. 15, 2248-2258.
[23] Khajehzadeh M., Taha M.R., El-Shafie A., Eslami M., Economic design of retaining wall using particle swarm optimization with passive congregation, *Australian Journal of Basic and Applied Sciences*, 4(2010), No. 11, 5500-5507.
[24] Eslami M., Shareef H., Mohamed A. Optimal tuning of power system stabilizers using modified particle swarm optimization. In Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, pp. 386-391.
[25] Eslami M., Shareef H., Mohamed A., Power system stabilizer design using hybrid multi-objective particle swarm optimization with chaos, *J. Cent. South Univ. Technol.*, 18(2011), No. 5, 1579-1588.
[26] Eslami M., Shareef H., Mohamed A., Ghoshal S.P., Tuning of power system stabilizers using particle swarm optimization with passive congregation, *Int. J. Phys. Sci.*, 5(2010), No. 17, 2574-2589.
[27] Eslami M., Shareef H., Mohamed A., Khajehzadeh M. A hybrid PSO technique for damping electro-mechanical oscillations in large power system. In IEEE Student Conference on Research and Development (SCOReD) pp. 442-447.
[28] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., Improved particle swarm optimization with disturbance term for multi-machine power system stabilizer design, *Australian Journal of Basic and Applied Sciences*, 4(2010), No. 12, 5768-5779.
[29] Eslami M., Shareef H., Mohamed A., Khajehzadeh M. Optimal location of PSS using improved PSO with chaotic sequence. In International Conference on Electrical, Control and Computer Engineering (INECCE), Kuantan, Malaysia, 21-22 June, pp. 253-258.
[30] Eslami M., Shareef H., Mohamed A., Khajehzadeh M., An Efficient Particle Swarm Optimization Technique with Chaotic Sequence for Optimal Tuning and Placement of PSS in Power Systems, *Int. J. Electr. Power Energy Syst.*, 43(2012), No. 1, 1467-1147.
[31] Shi Y., Eberhart R. A modified particle swarm optimizer. In IEEE World Congress on Evolutionary Computation, pp. 69-73.

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