Journal of Artificial Intelligence in Electrical Engineering, Vol. 3, No. 9, June 2014

Load Frequency Control in Power Systems Using Improved Particle Swarm Optimization Algorithm

Milad Babakhani Qazijahan

Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran
Email: babakhani.milad@yahoo.com

ABSTRACT

The purpose of load frequency control is to reduce transient oscillation frequencies than its nominal value and achieve zero steady-state error for it.A common technique used in real applications is to use the proportional integral controller (PI). But this controller has a longer settling time and a lot of Extra mutation in output response of system so it required that the parameters be adjusted as appropriate . In this paper, we aim to design a system based on PI controllers using improved particle swarm optimization algorithm for load frequency control.Multi-population approach and local search to improve the optimization algorithms is used and displayed. That this approach will lead to accelerating the achievement of results, preventing entrapment in a local minimum, and get better system output compared with similar methods.

KEYWORDS: Load Frequency Control, proportional integral control, improved particle swarm optimization algorithm

1. INTRODUCTION

Frequency power in the network represents a balance between production and consumption power .If this balance is present, the system frequency will remain constant .Frequency deviation from the nominal value as a signal to the excitation control system is automatically selected. Frequency regulation in power systems that will be remembered by the name of Frequency Control, is considered as one of the major control issues in the design and operation of power systems.Constant frequency deviation from the nominal value directly affects the operation and reliability of the power system.Excessive frequency deviation can damage the equipment, degrade the performance of network loads, establish Overload on lines of communication and stimulation of protection devices on the network and may result in network collapse in adverse conditions.Therefore, it is important to keep the frequency at nominal value.

Today, in many parts of the controlling areas, the proportional integral controllers with fixed parameters are used to control the load frequency. However, the proportional integral control systems have long settling time and relatively large Extra mutations in frequency transient response [1].

In [2] a comprehensive overview of LFC methods proposed in previous research is provided .In most of the research on LFC, centralized control strategy is considered for solving the LFC problem [6-3]. The problem with this approach is that it is necessary for the information to be exchanged from the remote to controlling area. To solve this problem, decentralized LFC control methods have been proposed [7]. In [8] the application of neural networks to the LFC problem is studied .Where feed forward neural network to control the steam turbine valve, thereby regulating the nominal frequency trained and then employed as a controller. Utilizes a reinforcement learning method based on genetic algorithms for LFC is suggested in [9].

To design such a system, several parameters are determined and the safest way to such a problem is an optimization method. In this paper, the algorithm of particle swarm optimization [*](PSO) is used.This algorithm is intuitive and simple to implement and is typically faster than a genetic algorithm.Also, unlike the genetic algorithm is easy to operate with continuous and discrete variables.In recent years, the algorithm is modified and developed in many different ways and approaches.Enjoying the advantages of PSO achieve greater computational speed, ease of implementation, direct actions on continuous variables and also greatly improvement that facilitate the generalization of the method.PSO performance is to optimize based on the mass of the particle motion in optimization variables space and tend to choose the location of the space that is better fitness.The weakness of the conventional PSO algorithm enables the particles in the local extremes that various modifications can be used to overcome this problem. A brief outline of this paper is as follows:

In Section 2, we provide a mathematical model of the power system. We introduce a proposed improved particle swarm optimization algorithm in Section 3, and in Section 4 describe how to achieve optimal parameters of the PI controller for load frequency control based on particle swarm optimization algorithm. And at the end of Section 5 we will review the results of the simulation.

2. THE MATHEMATICAL MODEL OF THE POWER SYSTEM

The power system used in this study consists of two interconnected control areas, which each represent a thermal power plant or water .As shown in Figure 1, each control area has its own load frequency control .The power system is modeled as a Contiguous, while the control signals are sent to the equipment as discrete-time. It is assumed that the power of the control area 1 is water, while the control area 2 is a thermal power plant .Linear mathematical model of the CA model can be described by the following equation [13]:

$$\begin{aligned}\mathbf{x}_i(t) &= \mathbf{A}_i\mathbf{x}_i(t) \\ &\quad + \sum_j \mathbf{A}_{ij}\mathbf{x}_j(t) + \mathbf{B}_i\mathbf{u}_i(t) + \mathbf{F}_i\mathbf{d}_i(t) \qquad (1)\\ \mathbf{y}_i(t) &= \mathbf{C}_i\mathbf{x}_i(t)\end{aligned}$$

---

[*] Particle Swarm Optimization (PSO)

In which:

System state vector, $\mathbf{x}_i \in R^n$

Neighboring system state vector, $\mathbf{x}_j \in R^p$

Vector control signal, $\mathbf{u}_i \in R^m$

Disturbance vector, $\mathbf{d}_i \in R^k$

And the vector output, $\mathbf{y} \in R^l$

The above matrix has the following dimensions:

$\mathbf{A}_i \in R^{n\times n}$ ، $\mathbf{A}_{ij} \in R^{n\times p}$ ، $\mathbf{B}_i \in R^{n\times m}$ ، $\mathbf{F}_i \in R^{n\times k}$ $\mathbf{C}_i \in R^{l\times n}$.

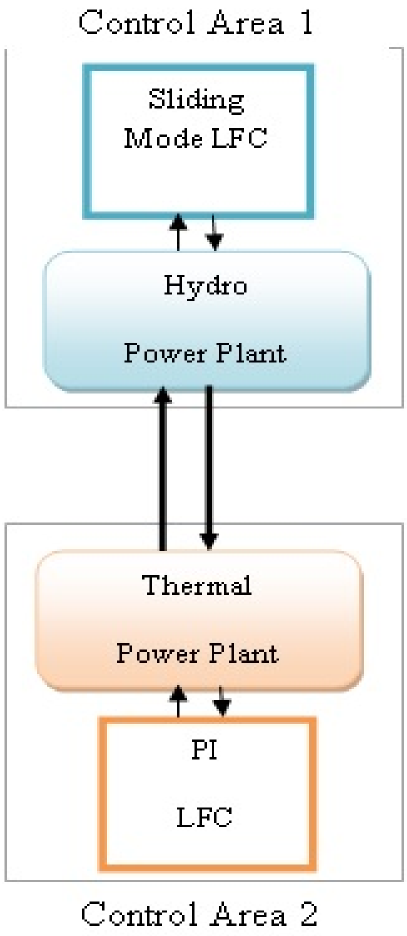

Fig1. Two interlocking control areas

For the hydroelectric plant, state and disturbance vectors as follows:

$$\mathbf{x}_i(t) = \begin{bmatrix} \Delta f_i(t) \\ \Delta P_{tiei}(t) \\ \Delta P_{gi}(t) \\ \Delta x_{gi}(t) \\ \Delta x_{ghi}(t) \end{bmatrix}, \quad \mathbf{d}_i(t) = \Delta P_{di}(t) \tag{2}$$

Matrices in (1) are as follows:

$$\mathbf{A}_i = \begin{bmatrix} -\frac{1}{T_{Pi}} & -\frac{K_{Pi}}{T_{Pi}} & \frac{K_{Pi}}{T_{Pi}} & 0 & 0 \\ \sum_j K_{Sij} & 0 & 0 & 0 & 0 \\ 2\alpha & 0 & -\frac{2}{T_{Wi}} & 2\gamma & 2\beta \\ -\alpha & 0 & 0 & -\frac{1}{T_{2i}} & -\beta \\ -\frac{1}{T_{1i}R_i} & 0 & 0 & 0 & -\frac{1}{T_{1i}} \end{bmatrix} \tag{3}$$

$$\mathbf{B}_i = \begin{bmatrix} 0 \\ 0 \\ -2R_i\alpha \\ R_i\alpha \\ \frac{1}{T_{1i}} \end{bmatrix}, \quad \mathbf{F}_i = \begin{bmatrix} -\frac{K_{Pi}}{T_{Pi}} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

And Coefficients:

$$\alpha = \frac{T_{Ri}}{T_{1i}T_{2i}R_i}$$
$$\beta = \frac{T_{Ri} - T_{1i}}{T_{1i}T_{2i}} \tag{4}$$
$$\gamma = \frac{T_{2i} + T_{Wi}}{T_{2i}T_{Wi}}$$

$\mathbf{A}_{ij}$ Matrices in (1) to describe the relationship depending on the water - heating or water – water have 5×4 or 5×5 dimensions. All elements are zero, except the elements in (1.2) which is equal to $-K_{Sij}$

For thermal model state and confusion vectors are according to Equation 5:

$$\mathbf{x}_i(t)=\begin{bmatrix}\Delta f_i(t)\\ \Delta P_{tiei}(t)\\ \Delta P_{gi}(t)\\ \Delta x_{gi}(t)\end{bmatrix},\quad \mathbf{d}_i(t)=\Delta P_{di}(t) \tag{5}$$

And the state-space matrices are as follows:

$$\mathbf{A}_i=\begin{bmatrix}-\frac{1}{T_{Pi}} & -\frac{K_{Pi}}{T_{Pi}} & \frac{K_{Pi}}{T_{Pi}} & 0\\ \sum_j K_{Sij} & 0 & 0 & 0\\ 0 & 0 & -\frac{1}{T_{Ti}} & \frac{1}{T_{Ti}}\\ -\frac{1}{T_{Gi}R_i} & 0 & 0 & -\frac{1}{T_{Gi}}\end{bmatrix} \tag{6}$$

$$\mathbf{B}_i=\begin{bmatrix}0\\0\\0\\\frac{1}{T_{Gi}}\end{bmatrix},\quad \mathbf{F}_i=\begin{bmatrix}-\frac{K_{Pi}}{T_{Pi}}\\0\\0\\0\end{bmatrix}$$

Here, too, depending on whether the matrix $\mathbf{A}_{ij}$ represents the relationship between thermal-thermal or thermal- water. The dimensions are 4×4 or 4×5 .All elements are equal to zero, except for the element in position (1, 2) which is equal to $-K_{Sij}$.

Signals and power system model parameters are shown in Table 1. An area control signal error has been introduced as a measure of the deviation of the control from its proposed treatment. ACE is defined as a combination of frequency deviation in a CA and active power flow deviations in the lines by the CA and its neighboring areas. LFC aim is to compensate ACE distortions in each area .Thus, the output of the system is defined as follows:

$$\begin{aligned}\mathbf{y}_i(t)&=\mathbf{C}_i\mathbf{x}_i(t)\\ &=ACE_i(t)\\ &=K_{Bi}\Delta f_i(t)+\Delta P_{tiei}(t),\end{aligned} \tag{7}$$

Where, the parameters are adjusted to ensure that the ACE is zero only when a disturbance occurs in CA. ACE signal values of all other CAs are specifically not affected by the disturbance.$\mathbf{c}_i$ Matrix in (7) for a CA with hydro power plant equipment is $\mathbf{C}_i=[K_{Bi}\quad 1\quad 0\quad 0\quad 0]$ and for a CA with a thermal power plant equipment is $\mathbf{C}_i=[K_{Bi}\quad 1\quad 0\quad 0]$.

3. IMPROVED PARTICLE SWARM OPTIMIZATION ALGORITHM

Optimization algorithms based on a random search of problem solutions space play an important role in solving various problems in various fields of science and engineering; especially to solve problems that they have a very large number of variables and variation ,as well as ones that function cannot be maintained as a simple analytical relation between variables. Using optimization methods based on random search such as genetic algorithms and algorithm particle swarm optimization methods are the best.

Particle swarm optimization algorithm (PSO) is one of the most widely used optimization methods based on the collective intelligence of a population of agents (particles) [10] .In recent years, this algorithm has been used for solving several optimization problems [11].

One of the problems that search-based optimization algorithms like PSO may be encountered is caught in a local trap in the search space. That is to find a locally optimal solution, the algorithm converges to the solution and all particles are concentrated around it .The global optimum solution may not to be seen by the particles and the issue may not be the final answer .Another possible problem for these methods, is the uncertainty of parallel search in the answer space .On the other hand, could not find a better solution in the neighborhood of solutions which have been investigated because of the Particles larger steps than the distance between adjacent points of the in the solution space

In this paper, using a multi-population PSO algorithm and also add the possibility of local search to try to improve the method to use for designing load frequency control of our power network. Although the multi-population of the algorithm means that instead of considering only a single population of particles, the whole particles can be divided into several subpopulations. Each particle's next velocity and position is related to their own previous locations, the best observed location of the corresponding population, and the best place in the entire population of particles.

In this paper, a multi-population approach combined with local search methods, is used to improve the PSO techniques to better deal with the problem of designing optimal control of load-frequency.

Table1. Signal and power system parameters

Parameter / variable	***Description***	***Unit***
$\Delta f(t)$	Frequency deviation	Hz
$\Delta P_g(t)$	Deviation of power generator output	p.u. MW
$\Delta x_g(t)$	Diversion valve position of generator	p.u.
$\Delta x_{gh}(t)$	The head valve engine deviation of generator	p.u.
$\Delta P_{tie}(t)$	Deviation of active power communication line	p.u. MW
$\Delta P_d(t)$	Turbulent times	p.u. MW
$\Delta\delta(t)$	The tilt-rotor	rad
K_P	Operation of the power system	Hz / p.u. MW
T_P	Time constant of the power system	s
T_W	Since the beginning of the water	s
T_1, T_2, T_R	Water governor time constant	s
T_G	Governor time constant of water	s
T_T	Turbine time constant	s
K_S	The interest connection between the control areas	p.u. MW
K_B	Frequency bias factor	p.u. MW / Hz
R	Droop speed because of the governor act	Hz / p.u. MW
ACE	Control area error	p.u. MW

In this regard the update of particle speed is defined as follows; which is a generalization of the corresponding relationship in PSO.

$$v_i^k(t+1) = w\, v_i^k(t) + c_1 r_1.\left(gbest^k - x_i^k(t)\right) + c_2 r_2.\left(pbest_i^k - x_i(t)^k\right) + c_3 r_3.\left(gbest - x_i^k(t)\right). \quad (8)$$

Where the index k represents the k cells have And subscript i is the ith particle. The correlation coefficient w inertia, c_1 Is the Acceleration factor of the best places to visit in the subpopulation. $gbest^k$ ،$c_2$is the acceleration coefficient caused by the location of the particlei.e. $pbest_i^k$، And$c_3$is acceleration coefficient caused by the best location of the all particles of all subpopulations, i.e.$gbest$. $x_i^k(t)$ is the position vectorofparticlei from k subpopulations at time t. $r_1$tor_3 are random numbers with uniform distribution between zero and1. According to equation (8) particles of sub populations in addition to their best previous location and the best location of the all particles, are affected by the best place of the subpopulation in which cells member.

The flow chart in Figure 2 is an improved particle swarm algorithm.

Local Search means that for each possible answer, the available answers in the neighborhood of the search space are studied. If you find an answer in the neighborhood with better fitness, the answer would be a better alternative.

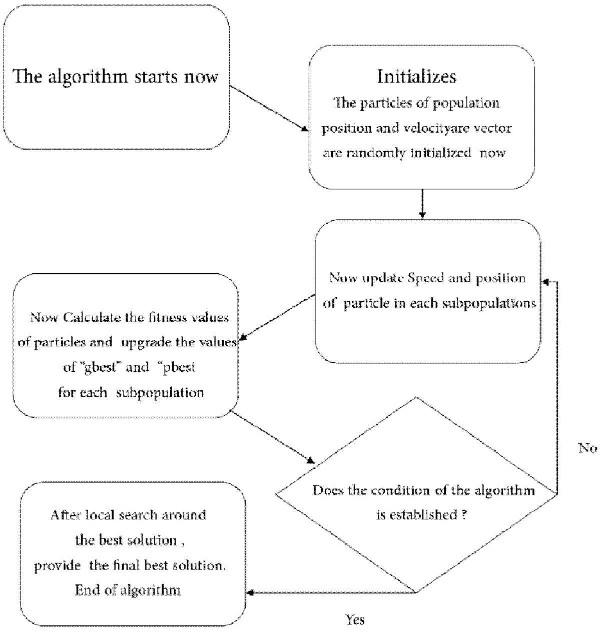

Fig.2. Flowchart of improved particle swarm algorithm

4. APPLICATION OF PSO ALGORITHMS FOR CONTROLLER PARAMETERS OF LFC

PI controller with proportional and integral coefficients is used for the load frequency control of a PI block in each area .The number of parameters necessary for the design of the control system load frequency is doubled .In this paper, we have benefited from an improved particle swarm optimization algorithm for the optimal values for these parameters.

Fitness function used in this algorithm, is modified square integral signal of ACE:

$$J = \int_0^{T_{stop}} \left(ACE^2(t)\right) dt \quad (9)$$

Table (2) shows an improved PSO algorithm

Parameters used in this paper as below:

Table2. Improved particle swarm algorithm parameters

The amount	
1	w
1	c_1
1	c_2
3	c_3
5	Number of cells
10	The number of particles per population
50	the number of occurrences of updated populations
50	The number of local search iterations

5. SIMULATION

To test the proposed algorithm, simulation of interconnected power systems includes two controlling area, as in Figure 1, we see, is executed .A control area (CA1) of the hydroelectric plant and the control area (CA2) is related to the thermal power in which load frequency control uses a PI controller . Simulation system parameters can be seen in Table 3.$\tau = 1s$ is sampling time and $T_{stop} = 120s$ is the duration of the simulation.

During the simulation, we entered two stepping turbulence into the system. One in the control area CA1 and time $t = 1s$ with amount of$P_{d1} = 1\%$ p.u.MW, and one in the control area CA2 in the$t = 30s$ with amount of $P_{d2} = -5\%$ p.u.MW

In order to optimize the parameters of PI controllers, simple PSO and improved PSO algorithm is used to compare the results with each other and system without a controller. For optimization, the objective function is considered as the sum of timed integrals of ACE error signal in two areas

In Figure 3 the ACE error signal in area 1 for three modes: without the controller, the controller designed by PSO and also by designing controller of improved PSO are shown .Similarly, the ACE error signal in area 2, for the three modes is shown in Figure 4.

As can be seen from Figures 3 and 4, error control of the system without controller does not converge to zero and in section 2 has reached a specified nonzero value .Load frequency control posed by PSO has a persistent error to zero, however, seen that the solution found by the improved PSO is better than PSO and has an integral time less then ACE .The answer comes from the improved PSO shows the maximum error less than the PSO, however, the answer is more transient fluctuations.

Table3. Parameters of power system simulation

parameter	unit	CA1	CA2
K_P	[Hz/p.u.MW]	80	120
T_P	[s]	13	25
R	[Hz/p.u.MW]	2.4	2.7
K_B	[p.u.MW/Hz]	0.43	0.38
T_R	[s]	6	_
T_1	[s]	5	_
T_2	[s]	48.7	_
T_W	[s]	1	_
T_G	[s]	_	0.072
T_T	[s]	_	0.33
K_{S12}	[p.u.MW]	0.5	0.5

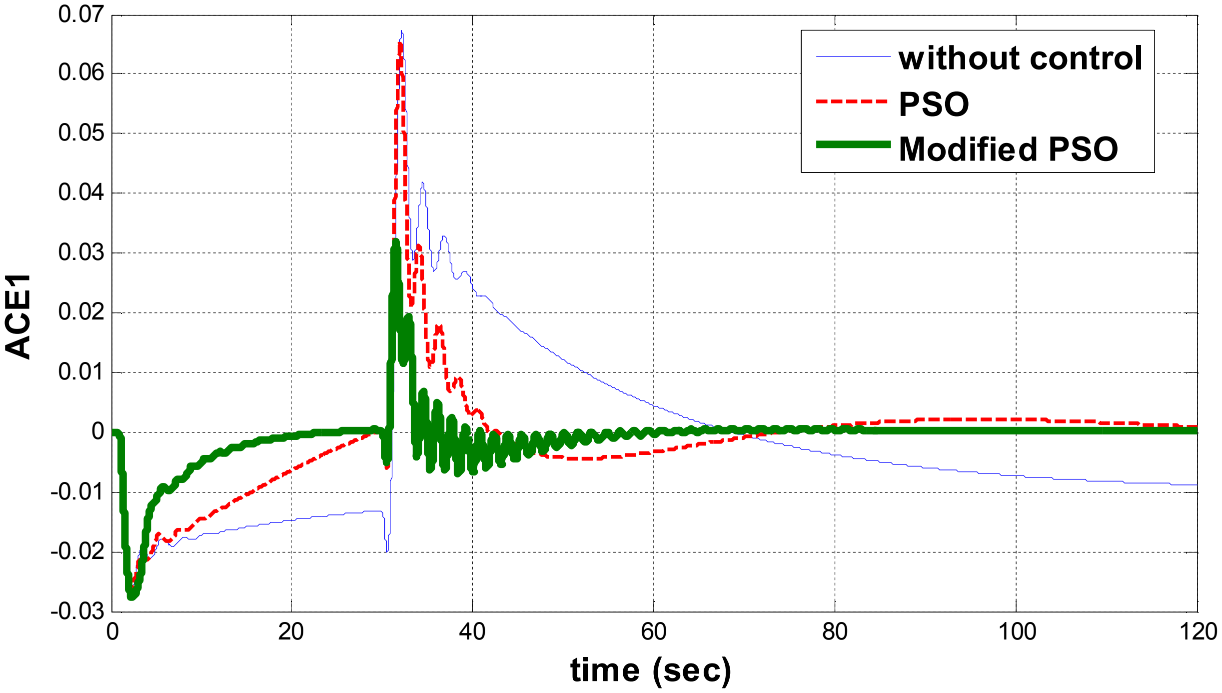

Fig.3. The error signal of area 1 for systems without controller, the controller designed by PSO and design with improved PSO controller

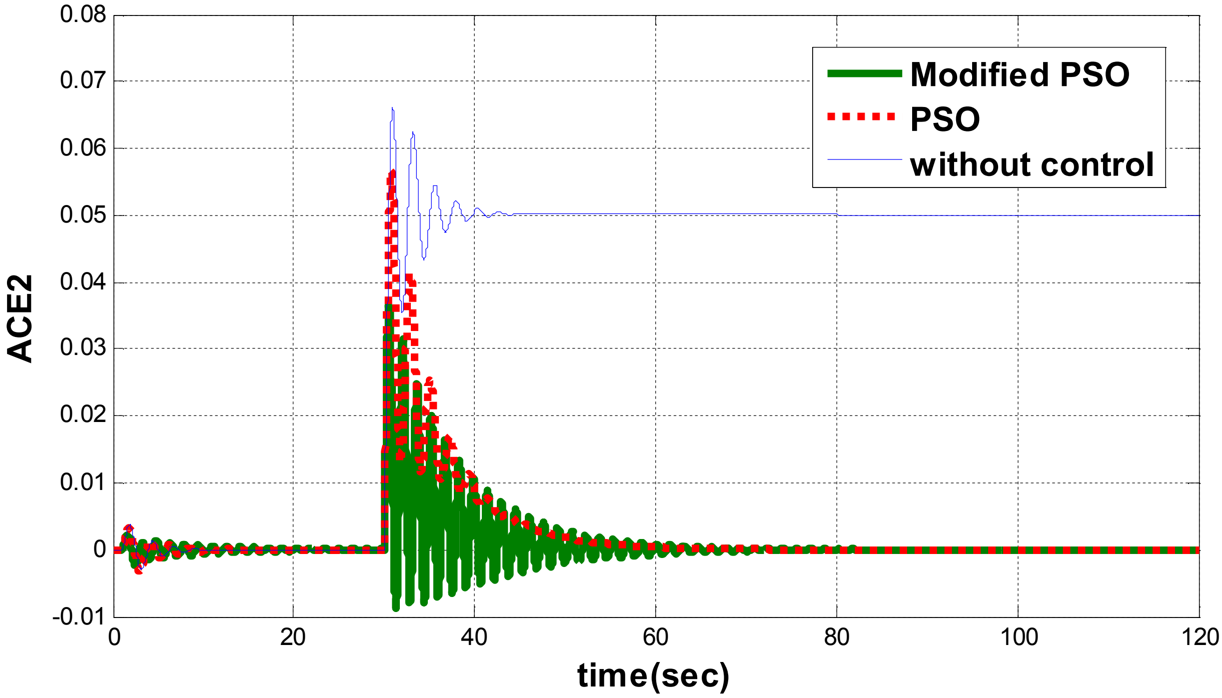

Fig.4. The error signal of area 2 for systems without a controller, the controller designed by PSO and design with an improved PSO controller

6. CONCLUSIONS

In this paper, an improved particle swarm optimization method was the acting to design load frequency control in two area power system .The power system for simulation consists of two water and heat units .To control the load, frequency of each area once a proportional integral control block was considered .With regard to the control error as the objective function for the problem of minimizing, appropriate parameters for proportional integral controllers were determined by using the proposed parameter optimization algorithm. In this paper, several approaches in population and local search have been taken to improve greatly the particle swarm algorithms. In comparing the results indicated that the improved particle swarm algorithm has a lower maximum error and also lower timed integral error than resulting solution obtained from a typical particle swarm algorithm

REFERENCES

[1] Al-Musabi, Naji A. *"Design of optimal variable structure controllers: applications to power system dynamics"*. Diss. Master's thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, 2004.

[2] H. Shayeghi, H. Shayanfar, A. Jalili, *Load frequency control strategies: a stateof-the-art survey for the researcher*, Energy Conversion and Management 50(2) (2008) 344–353.

[3] Demiroren A, Sengor NS, Zeynelgil HL. Automatic generation control by usingANN technique. Electr Power ComponSyst 2001;29(10):883–96.

[4] Shayeghi H, Karrari M, Menhaj MB. Theory of l synthesis for power systemsload frequency control. J Electron Eng 2000;51:258–63.

[5] Shayeghi H, Shayanfar HA. Application of ANN technique based on lsynthesisto load frequency control of interconnected power system. ElectrPower Energy Syst 2006;28:503–11.

[6] Ibraheem , Kumar P. A novel approach to the matrix Riccati equation solution:an application to optimal control of interconnected power systems. J ElectrPower ComponSyst 2004;32(1):33–52.

[7] Yang TC, Ding ZT, Yu H. Decentralized power system load frequency controlbeyond the limit of diagonal dominance. Electr Power Energy Syst2002; 24(3):173–84.

[8] F. Beaufays, Y. Abdel-Magidand B. Widrow, "Application of neural network to load frequency control in powersystems," Neural Networks vol.7, no.1, 183-194,1994.

[9] F. Daneshfar and H. Bevrani, "Load–frequency control: a GA-based multi-agent reinforcement learning," *IET generation, transmission & distribution*, vol. 4, no. 1, pp. 13–26, 2010.

[10] J.Kennedi ,R.Eberhart , ' A Discrete Binary of the Particle Swarm Algorithm' , in IEEE Int . Conf .Vol4 ,No2 , 1995, PP 1942-1948.

R. C. Eberhart and Y. Shi, "Particle swarm optimization: developments, applications and resources," in *Proc. 2001 Congr. Evolutionary Computation*, vol. 1, 2001.