Improved Particle Swarm Optimization Based Load Frequency Control In A Single Area Power System

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***Abstract*— In this paper, an improved particle swarm optimization (IPSO) based load frequency control (LFC) of a single area power system is presented. Although the Particle Swarm Optimization approaches have several advantages, they can still have drawbacks like local optimal trapping due to premature convergence(i.e. exploration problem). This paper proposes an improved PSO framework adopting a crossover operation scheme to increase exploitation capability of PSO.The study has been realized for control of a single area interconnected power system with IPSO optimized self-tuning PID controller. The comparison between a conventional Proportional-Integral (PI) controller and the proposed PSO based controller showed that the proposed controller can generate a better transient response for a step load change. For this application, MATLAB-Simulink software is used.**

***Keywords*— Load Frequency Control, A single Area Power system, Particle Swarm Optimization, Transient Response, PID controllers**

I. Introduction

The dynamic behavior of many power systems and resulted in industrial loads heavily depends on disturbances and in particular on changes in the operating point [1]. Load frequency control in power systems is very important in order to supply reliable electric power with good quality. The goal of the LFC is to maintain stable system frequency which has zero steady state errors, and to provide load sharing between areas in a multi area interconnected power system. In addition, the power system should fulfill the proposed dispatch conditions. Power systems are divided into control areas connected with tie-lines. All generators are supposed to constitute a coherent group in each control area. From the experiments on the power system, it can be seen that each area needs its system frequency to be controlled [2].

Generally, ordinary LFC systems are designed with Proportional-Integral (PI) controllers. However, since the “I” control parameters are usually tuned, it is incapable of obtaining good dynamic performance for various load and system change scenarios. Many studies have been carried out in the past about the load frequency control. In literature, some control strategies have been suggested based on the conventional linear control theory [3]. These controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. According to some authors, variable structure control [4] maintains stability of system frequency. However, this method needs some information for system states, which are very difficult to know completely. Also, the growing needs of complex and huge modern power systems require optimal and flexible operation of them. The dynamic and static properties of the system must be well known to design an efficient controller. On the other hand, to handle such a complex system is quite complicated [5]. According to [6], conventional PID control schemes will not reach a high of control performances. Since the dynamic behavior even for a reduced mathematical model of a power system is usually nonlinear, time-variant and governed by strong cross-couplings of the input variables, special care has to be taken for the design of the controllers. For this reason, recently, a lot of artificial intelligence based robust controllers such as genetic algorithm, tabu search algorithm, fuzzy logic and neural networks are used for PID controller parameters tuning in LFC by authors [7, 8, 16, 17]. Since, Particle Swarm Optimization algorithm is an optimization method that finds the best parameters for controller in the uncertainty area of controller parameters and obtained controller is an optimal controller, it has been used in almost all sectors of industry and science. One of those areas is the load frequency control as shown in [10].

In this study, it is used to determine the parameters of a PID controller according to the system dynamics changing with daily period. In addition, for different applications, this method does not require a certain model [3]. In the integral controller, if the integral gain, Ki, is very high, undesirable and unacceptable large overshoots will be occurred [3]. However, adjusting the maximum and minimum values of proportional (Kp) and integral (Ki) gains respectively, the outputs of the system (voltage, frequency) can be improved. In this simulation study, Kp is made equal a regulation constant “R” to obtain robustness, and it is shown that the overshoots and settling times with the proposed Improved PSO tuned PID controller are better than the outputs of the other controllers.

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II. LOAD FREQUENCY CONTROL

The objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. Basically, single area power system consists of a governor, a turbine and a generator with feedback of regulation constant. System also includes step load change input to the generator. This work mainly related with the controller unit of a single area power system. Simple block diagram of a single area power system with the controller is shown in Figure 1.

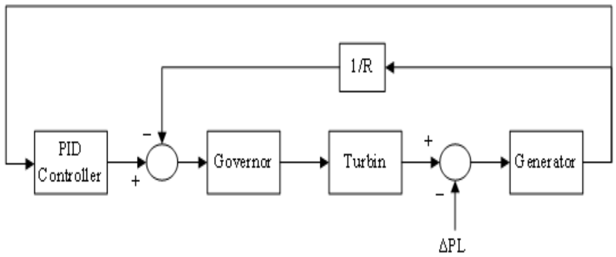

Fig.1. A single area power system with the controllers ($\Delta PL = 0.01$)

So far, PID controllers have widely been used in process control. With simple structure, they yet can effectively control various large industrial processes. There are many tuning approaches for these controllers, but each has own disadvantages or limitations. As a result, the design of PID controllers still remains a remarkable challenge for researchers. In simple words, the PID controller is used to improve the dynamic response as well as reduce or eliminate the steady-state error. The derivative term normally adds a finite zero to the open loop plant transfer function and can improve the transient response in most cases. The integral term adds a pole at origin resulting in increasing the system type and therefore reducing the steady-state error. Furthermore, this controller is often regarded as an almost robust controller. As a result, they may also control uncertain processes. The well-known PID controller transfer function is as follows :

$$K_p + \frac{K_i}{s} + K_d \times s \qquad (1)$$

III. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

Kennedy and Eberhart developed a PSO algorithm based on the behavior of individuals (i.e., particles or agents) of a swarm [11]. Its roots are in zoologist's modeling of the movement of individuals within a group. It has been noticed that members of the group seem to share information among them, a fact that leads to increased efficiency of the group [12]. The PSO algorithm searches in parallel using a group of particles. Each particle corresponds to a candidate solution to the problem. A particle moves toward the optimum based on its present velocity, its previous experience, and the experience of its neighbors. In an -dimensional search space, the position and velocity of particle are represented as vectors.

In a physical n-dimensional search space, the position and velocity of individual i are represented as the vectors $X_i = (x_i, \ldots, x_{in})$ and $V_i = (v_i, \ldots. v_{in})$ in the PSO algorithm. Let $Pbest_i = (x_{i1}^{pbest}, \ldots. x_{in}^{pbest})$ and $Gbest_i = (x_i^{gbest}, \ldots x_n^{gbest})$ be the best position of individual i and its neighbors' best position so far, respectively. Using the information, the updated velocity of individual i is modified under the following equation in the PSO algorithm:

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 \times (Pbest_i^k - X_i^k) + c_2 r_2 \times (Gbest_i^k - X_i^k) \qquad (2)$$

Where,

V_i^k : velocity of individual i at iteration k,
ω : inertia weight parameter,
c_1, c_2 : acceleration coefficients,
r_1, r_2 : random numbers between 0 and 1,
X_i^k : position of individual i at iteration k,
$Pbest_i^k$: best position of individual i until iteration k,
$Gbest_i^k$: best position of the group until iteration k.

In this velocity updating process, the values of parameters such as ω, c_1 and c_2 should be determined in advance. In general, the weight ω is set according to the following equation [9]:

$$\omega = \omega_{max} - (\omega_{max} - \omega_{min}) \times iter/Iter_{max} \qquad (3)$$

where,

$\omega_{max}, \omega_{min}$ initial and final weights,
$Iter_{max}$ maximum iteration number,
$Iter$ current iteration number.

Each individual moves from the current position to the next one by the modified velocity in (2) using the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad (4)$$

Fig. 2 shows the concept of the searching mechanism of PSO using the modified velocity and position of individual i based on (2) and (4) if the values of ω, c_1, c_2, r_1, r_2 are 1.

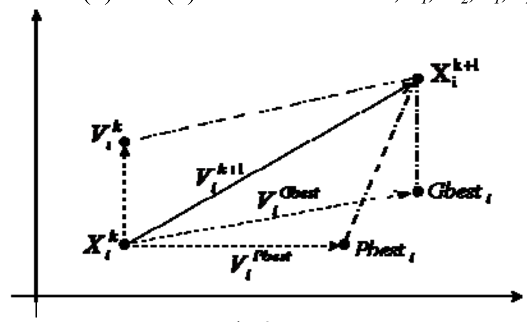

Fig. 2

IV. IMPROVED PARTICLE SWARM OPTIMIZATION WITH CROSSOVER OPERATION

In order to increase the diversity of a population, the crossover operation is newly introduced to the PSO mechanism[14], thereby can effectively explore and exploit promising regions in a search space. The position of particle i, $X_i = (x_{i1}, \ldots. x_{in})$, obtained in (4) is mixed with $Pbest_i$ to generate a trial vector $\hat{X}_i = (\hat{x}_{i1} \ldots, \hat{x}_{in})$ as follows :

$$\hat{X}_{ij}^{k+1} = x_{ij}^{k+1}, \quad \text{if } r_{ij} < CR$$
$$= x_{ij}^{p,k}, \quad \text{otherwise} \qquad (5)$$

For j=1,2,….n, where r_{ij} is a uniformly distributed random number between [0,1], and *CR* is the crossover rate in the range of [0,1]. When the value of *CR* becomes one, there is no crossover like in the conventional PSO. If the value of *CR* is zero, the position will always have the crossover operation similar to the GA mechanism.A proper crossover rate *CR* can be determined by empirical studies to improve the diversity of a population. Fig. 3 gives an example of the crossover mechanism for an individual *i*.

The trial vector $\hat{X}_{ij}^{k+1}$ is used to update the $Pbest_i$ and $Gbest_i$ at iteration $k+1$ using the greedy selection. $Pbest_i^{k+1}$ is set to $\hat{X}_{ij}^{k+1}$ if the fitness value of $\hat{X}_{ij}^{k+1}$ is better than that of $Pbest_i^k$. The developed crossover operation is applied for the improvement of $Pbest_i$ while the PSO evolution process of each particle is conserved by (4).

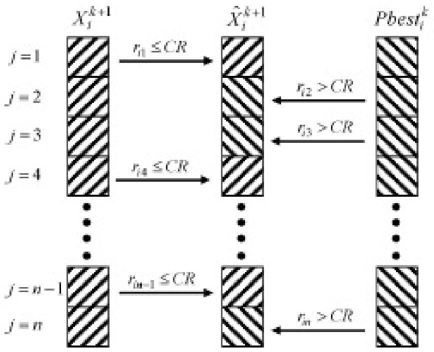

Fig.3. Illustration of crossover operation

V. IMPLEMENTATION OF IPSO FOR PID TUNING IN LOAD FREQUENCY CONTROL

A. Model with proposed PID controller

The framework of PSO based self-tuning PID controller is depicted as Figure 3. To find the optimum parameters (Kp, Ki, Kd) of PID controller, PSO program should search in 3-dimensional search space. In an ordinary load frequency control systems, since a regulation constant R is used as Kp parameter in PID controller, especially I (integral) controller is used in LFC systems. At the proposed system, Kp is made equal regulation constant R, and ID (integral-derivative) controller is used in LFC system. Thus, for robustness, regulation constant is tuned according to load and system changes, too. With the optimized parameters based on PSO algorithm, the proposed PID controller of the LFC can achieve optimal properties. The block diagram of a single area power system with this controller is shown in Figure 4.

B. Performance index for IPSO

During the simulation study, error signal which is required for the controller is transferred to PSO software with error.mat component. All positions of particles on each dimension are clamped in limits which are specified by the user, and the velocities are clamped to the range [V_{max} V_{min}].

In this simulation, the objective is to minimize the error and the maximum overshoot. For this reason the objective function is chosen as the Integral Square Error (ISE). The ISE squares the error to remove negative error components [13].

$$ISE = \int_0^T e^2(t)dt$$

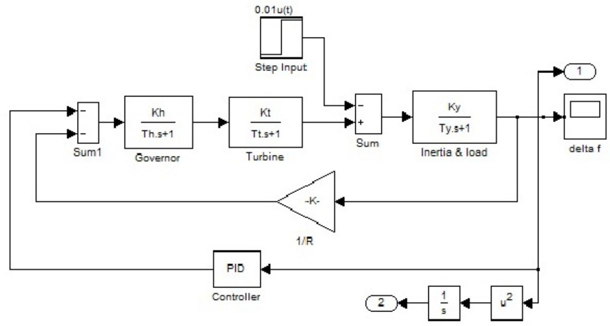

Fig. 4. A single area power system with proposed IPSO-PID controller.

VI. SIMULATION RESULTS

The ordinary single area power system parameters consisting of the speed governor, turbine and generator are given in Table 1. Here the governor free operation is assumed and load demand $\Delta PL = 0.01$.

TABLE I

Description	Parameter	Value
Governer Gain	K_h	1
Governer Time Constant	T_h	80e-3
Turbine Gain	K_t	1
Turbine Time constant	T_t	0.3
Load Model Gain	K_y	120
Load Time constant	T_y	20

At the simulation, the population size is taken 10. c_1 *and* c_2 constants are taken 2. $\omega_{max} = 0.9$ and $\omega_{min} = 0.4$. CR is taken to be 0.6. For conventional PI controllers Ki is taken as 0.65 and R = 2.4 .The values of PID Parameters as obtained by IPSO optimization :

$K_p = R = 3.935$;
$K_i = 8.1472$;
$K_d = 1.5761$;

TABLE III

Controllers	Settling Times(sec)	Maximum Overshoot(Hz)
Conventional PI controller	13.5 sec	0.0264
Proposed IPSO-PID controller	8 sec	0.003330

Simulation results for the single area power system are shown in Table 2. As can be observed, the settling time and overshoots(around 10 times) with the proposed PSO-PID controller are much shorter than that of with the conventional PI controller. Therefore, the proposed PSO-PID controller provides better performance than conventional PI controller for the single area power system.

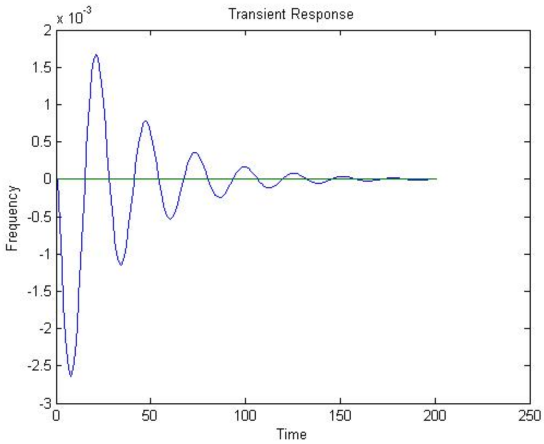

Fig.5 Transient Response with PI controller

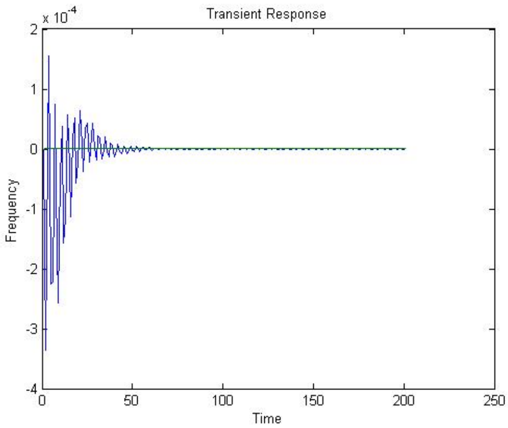

Fig.6 Transient Response with IPSO-PID controller

VII. CONCLUSIONS

In this study, a new particle swarm optimized LFC has been investigated for automatic load frequency control of a single area power systems. For this purpose, first, to obtain more adaptive tuning mechanism for the PID controller parameters and sensitivity of the system is increased. It has been shown that the proposed control algorithm is effective and provides significant improvement in system performance. Therefore, the proposed IPSO-PID controller is recommended to generate good quality and reliable electric energy. In addition, the proposed controller is very simple and easy to implement since it does not require many information about system parameters. Two area power systems operation will be investigated in future. In addition, comparison of the proposed IPSO-PID controller with PID tuning by Differential Evolution and Genetic Algorithm will be subject to the future work. Further research on checking the robustness of multi-area systems and on decentralized PID tuning considering the tie-line interchange power is under progress.

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