IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified

Vol. 4, Issue 12, December 2016

Method & Implementation of PSO Based Load Frequency Control in Multi Area Connected System

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Abstract: This paper presents a function of load frequency control (LFC) in single and two interconnected power systems. It is based on PSO concept. It presents Load Frequency Control problem related to single-area and two-area power systems is studied for uncontrolled case and then with the application of the integral controller, PSO based controller using MATLAB SIMULINK/Workspace software. In case of a single-area system, under uncontrolled case, steady state frequency error exists. The integral controller improves the system's dynamic performance by removing this steady state frequency error. In case of two-area power system, integral controller is used in both the areas to overcome system's steady state frequency errors and thereby enhancing system's dynamic performance. The integral controller is optimized using PSO based controller and is shown that the PSO based integral controller provides better dynamic performance than integral controller in terms of lesser settling time and peak overshoots. Then a PSO based PI controller is developed to control two-area power systems.

Keywords: PSO, Load Frequency, Single Area, Multi Area System etc.

I. INTRODUCTION

For large scale power systems which consists of inter-connected control areas, load frequency then it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately.

The load frequency control mainly deals with the control of the system frequency and real power whereas the automatic Voltage regulator loop regulates the changes in the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of the large scale control of the power system.

Automatic Generation Control can be sub divided into fast (primary) and slow (secondary) control modes. The loop dynamics following immediately upon the onset of the load disturbance is decided by fast primary mode of AGC. This fast primary mode of AGC is also known as "Uncontrolled mode" since the speed changer position is unchanged. The secondary control acting through speed changer and initiated by suitable controller constitutes the slow secondary or the "Controlled modes" of AGC. The overall performance of AGC in any power system depends on the proper design of both primary and secondary control loops. Literature survey shows that a lot of work pertaining to secondary control aspect of AGC has been reported. Secondary controllers are designed to regulate the area control errors to zero effectively. So the overall performance of AGC in any power system depends on the proper design of both primary control loop (selection of R) and secondary control loops (selection of gain for supplementary controller). Among the various types of load frequency controllers, the most widely employed are integral (I), proportional plus integral (PI), integral plus derivative (ID) and proportional plus integral plus derivative (PID) controllers. Their use is not only for their simplicity, but also due their success in large industrial applications.

Power systems are used to convert natural energy into electric power. They transport electricity to factories and houses to satisfy all kinds of power needs. To optimize the performance of electrical equipment, it is important to ensure the quality of the electric power. It is well known that three-phase alternating current (AC) is generally used to transport the electricity. During the transportation, both the active power balance and the reactive power balance must be maintained between generating and utilizing the AC power. Those two balances correspond to two equilibrium points: frequency and voltage. When either of the two balances is broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation. For North America, the standard values for the frequency and voltage are 60 Hertz and 120 Volts respectively. However, the users of the electric power change the loads randomly and momentarily. It will be impossible to maintain the balances of both the active and reactive powers without control.

As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values. Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled. The frequency is highly dependent on the active power while the voltage is highly dependent on the reactive power. Thus the control issue in power systems can be decoupled into two independent problems. One is about the active power and frequency control while the other is about the reactive power and voltage control. The active power and frequency control is referred to as load frequency control (LFC) [1].

The paper is ordered as follows. In section II, it represents related work with proposed system in Load Frequency Control System. In Section III, It defines proposed system. Finally, conclusion is explained in Section IV.

II. RELATED WORK

Nour EL Yakine Kouba et. al. [1] described an application of Artificial Bee Colony (ABC) to load frequency control (LFC) in single, two and multi-area interconnected power systems. The proposed ABC algorithm is used to obtain the optimal values of the proportional-integral-derivation (PID) controller parameters based load frequency control (LFC). The principal function of the LFC loop is to control the frequency and active power. The main aim of this work is to suppress all the fluctuations of the system due to the disturbance and get back the frequency at nominal value. In order to analyze the system frequency and the tie-line power flow with the varying of the load, the simulation is performed under load disturbances. Simulation results showed good performance in terms of settling time and peak overshoot of the proposed approach compared to the traditional Ziegler Nichols, Genetics Algorithm (GA), Particle Swarm Optimization (PSO) and Bacterial Foraging Optimization (BFO) methods.

Miaomiao Ma et. al. [2] integrated the wind turbines (WTs) into the interconnected power system and designs a distributed model predictive control (DMPC) controller for the primary frequency regulation problem. The WTs have been treated as a part of the power system to take part in primary frequency regulation with load disturbances. A frequency response model of multi-area power system including WTs is introduced, in which the physical constraints of the governors and turbines are considered. The distributed model predictive controller is designed by posing the primary frequency regulation problem as disturbance rejection problem of large system with state and input constraints. Analysis and simulation results for a two-area interconnected power system with WTs show possible improvements on closed-loop performance, while respecting physical hard constraints. Comparisons had been made between the DMPC controller with and without WTs.

Hesam Parvaneh et. al. [3] proposed an optimum load frequency control (LFC) of a multi-area power system is developed based on a powerful optimization technique called seeker optimization algorithm (SOA). SOA capabilities for solving difficult practical optimization problems had proven and therefore it has gained a massive consideration by researchers. This paper presents a SOA-based load frequency controller for elimination of the power system oscillations. A two-area power system based on thermal power plants (TPPs) is considered, in which every area is equipped with PID controllers. SOA is used for meeting the optimum parameters of the PID controller, which are acquired by time domain minimization of the objective function. Performance of the proposed controller is compared with genetic algorithm (GA) based PID controller and particle swarm optimization (PSO) based PID controller to indicate the excellence of the proposed algorithm for PID parameters regulation.

K. Jagatheesan et. al. [4] proposed the Automatic Generation Control (AGC) of multi-area hydrothermal interconnected power system with conventional controller. Multi-area power system consists of four power generating units (Two Hydro and two thermal). The thermal power generating is equipped with appropriate single stage re-heater unit and the hydro power generating unit is equipped with a suitable mechanical governor. All four areas are interconnected through tie-line. The conventional integral controller is employed into power system to improve the dynamic performance. The gain value of the integral controller is tuned using trial and error method with three different objective functions (Integral Time Square Error (ITSE), Integral Time Absolute Error (ITAE)) and one percent Step Load Perturbation (1%SLP) in area 1.

Dr. T. Anil Kumar et. al. [5] presented the coordinated control of HVDC link with optimal sliding mode control and HVDC link with H-infinity controller has been proposed to solve load frequency control of multi area power system in open market environment. The performance of proposed coordinated control strategies such as HVDC-OSMC, HVDC-H-infinity has been demonstrated on two area deregulated thermal power system under one possible contact scenario. The superiority of proposed new coordinated (HVDC-H-infinity) control strategy demonstrated over HVDC-OSMC (HVDC-Optimal sliding mode controller), HVDC-

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PI (HVDC-Conventional PI Controller) and without any controller.

Steven Rosen et. al. [6] integrated a 210 MW photovoltaic (PV) plant into a two-area four-machine power system. Due to the output variations of the PV plant, especially during cloudy conditions, the system frequency will significantly fluctuate. The objective of this paper is the optimal tuning of governors on synchronous generators in order to damp and mitigate frequency deviations as fast as possible. The governor parameters are tuned using a heuristic optimization method to provide the least number of frequency events and minimum frequency deviation with varying penetration levels of PV power. With optimally tuned governor parameters, a multi-area power system can operate reliably while maximizing the utilization of clean power generation sources.

Pouya Babahajiani et. al. [7] presented that Frequency control is one of the most important issues in a power system due to increasing size, changing structure and the complexity of interconnected power systems. Increasing economic constraints for power system quality and reliability and high operational costs of generation side controllers have inclined researchers to consider demand response as an alternative for preserving system frequency during off-normal conditions. However, the main obstacle is calculating the accurate amount of load related to the value of disturbances to be manipulated, specifically in a multi-area power system. Dealing with this challenge, this paper made an attempt to find a solution via monitoring the deviations of tie-line flows. The proposed solution calculates the magnitude of disturbances and simultaneously determines the area where disturbances occurred, to apply demand response exactly to the involved area. To address communication limitations, the impact of demand response delay on the frequency stability was investigated.

III. MODEL DERIVATION OF ISOLATED POWER SYSTEM

To understand the load frequency control problem, let us consider a single turbo-generator system supplying an isolated load.

1. Turbine Speed Governing System Model

The system consists of the following components:

1. Fly ball speed governor: This is the heart of the system which senses the change in speed (frequency). As the speed increases the fly balls move outwards and the point B on linkage mechanism moves downwards. The reverse happens when the speed decreases.
2. Hydraulic amplifier: It comprises a pilot valve and main piston arrangement. Low power level valve movement is converted into high power level piston valve movement. This is necessary in order to open or close the steam valve against high pressure steam.
3. Linkage mechanism: ABC is a rigid link pivoted at B and CDE is another rigid link pivoted at D. This link mechanism provides a movement to the control valve in proportion to change in speed. It also provides a feedback from the steam valve movement.
4. Speed changer: It provides a steady state power output setting for the turbine. Its downward movement opens the upper pilot valve so that more steam is admitted to the turbine under steady conditions (hence more steady power output). The reverse happens for upward movement of speed changer.

Let the point A on the linkage mechanism be moved downwards by a small amount Δy_A. It is a command which causes the turbine power output to change and can therefore be written as eq. 1.1:

$$\Delta y_A = K_C \Delta P_C \qquad (1)$$

Where ΔP_C is the commanded increase in power:

The command signal ΔP_C (i.e. Δy_E) sets into motion a sequence of events - The pilot valve moves upwards, high pressure oil flows on to the top of the main piston moving it downwards; the steam valve opening consequently increases, the turbine generator speed increases, i.e. the frequency goes up. Let us model these events mathematically. Two factors contribute to the movement of C:

1. Δy_A contributes- $\left(\frac{L_2}{L_1}\right)\Delta y_A$ or $-K_1\Delta y_A$ (i.e. upwards) of $-K_1 K_C \Delta P_C$
2. Increase in frequency Δf causes the fly balls to move outwards so that B moves downwards by a proportional amount $K'_2\,\Delta f$. The consequent movement of C with A remaining fixed at Δy_A is $+\left(\frac{L_2+L_2}{L_1}\right)K'_2\,\Delta f = +K_2\Delta f$ (i. e. downwards).

The net movement of C is therefore

$$\Delta y_C = -K_1 K_C \Delta P_C + K_2 \Delta f \qquad (2)$$

The movement of D, Δy_D, is the amount by which the pilot valve opens. It is contributed by Δy_C and Δy_E and can be written as

$$\Delta y_D = \left(\frac{L_4}{L_3+L_4}\right)\Delta y_C + \left(\frac{L_3}{L_3+L_4}\right)\Delta y_E$$
$$= K_3\Delta y_C + K_4\Delta y_E \qquad (3)$$

The movement Δy_D depending upon its sign opens one of the ports of the pilot valve admitting high pressure oil into the cylinder thereby moving the main piston and opening the steam valve by Δy_E.

The volume of oil admitted to the cylinder is proportional to the time integral of Δy_D. The movement Δy_E is obtained by dividing the oil volume by the area of the cross section of the piston. Thus

$$\Delta y_E = k_5 \int_0^t (-\Delta y_D)\, dt \qquad (4)$$

The equation can be represented in the form of a block diagram in Fig. 1.

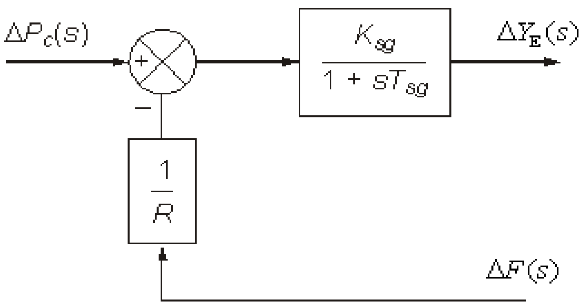

Figure 1: Block Diagram Representation of Speed Governor System

2. Turbine Model

The dynamic response is largely influenced by two factors, (i) entrained steam between the inlet steam valve and first stage of the turbine, (ii) the storage action in the re-heater which causes the output if the low pressure stage to lag behind that of the high pressure stage. Thus, the turbine transfer function is characterized by two time constants. For ease of analysis it will be assumed here that the turbine can be modelled to have a single equivalent time constant as given in Fig. 2.

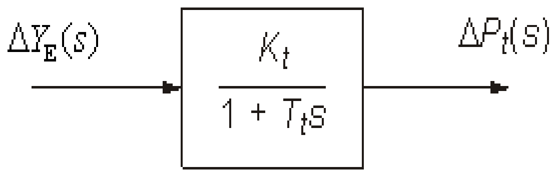

Figure 2: Turbine Transfer Function Model

Where, K_t = Gain of turbine, T_t = Time constant of turbine

3. Generator Load Model

The increment in power input to the generator-load system is

$$\Delta P_G - \Delta P_D$$

Where $\Delta P_G = \Delta P_t$, incremental turbine power output (assuming generator incremental loss to be negligible) and ΔP_D is the load increment. This increment in power input to the system is accounted for in two ways:

1. Rate of increase of stored kinetic energy in the generator rotor. At scheduled frequency (f^o), the stored energy is

$$W^0_{ke} \square H \times P_r \text{ kW = sec (kilojoules)}$$

Where P_r is the kW rating of the turbo-generator and H is defined as its inertia constant

As the frequency changes, the motor load changes being sensitive to speed, the rate of change of load with respect to frequency, i.e. $\partial P_D/\partial f$ can be regarded as nearly constant for small changes in frequency Δf and can be expressed as

$$\left(\frac{\partial P_D}{\partial f}\right)\Delta f = B\Delta f \qquad (5)$$

IV. PROPOSED WORK

The problem of load frequency control has been one of the most accentuated topics in the operation of interconnected power systems. The LFC of an interconnected power system has two principal aspects such as maintenance of frequency and power exchange over tie-lines on scheduled values. The objective of LFC is to maintain the area generation-demand balance by adjusting the outputs on regulating units in response to deviations of frequency and tie-line exchange. In steady state, the output of the generators at any instant will exactly equal the load on the system and all the generating units operate synchronously at the same frequency. Immediately after a change in the total power demand, the flywheel governor of the synchronous machine try to return the system to the initial frequency but it is unable to do that. The main objective of this dissertation is to study the load frequency control problem associated in single and multi-area electrical power systems. In the present work some attention is given to single and two-area power system. At first uncontrolled system is studied and then improvement of its response is learnt on the application of integral controller and PSO.

Conventional method of controller tuning is a trial and error based method. This makes it difficult to be implemented in all kind of problems. Because this requires continuous tuning of parameters values and observing the response which consumes a lot of time and requires effort, which is tedious method. Here no certainty is there that the result obtained after so much variation will be the optimum one. That means all the time given to particular problem and effort will all go in vain. These all demerits encourage us to go for other developed techniques to get optimum values.

The large-scale power systems are normally composed of control areas (i.e. multi-area) or regions representing coherent groups of generators. The various areas are interconnected through tie-lines. The tie-lines are utilized for contractual energy exchange between areas and provide inter-area support in case of abnormal conditions. Without loss of generality we shall consider a two-area case connected by a single line as illustrated. The concepts and theory of two-area power system is also applicable to other multi-area power systems i.e. three-area, four-area, five-area etc.

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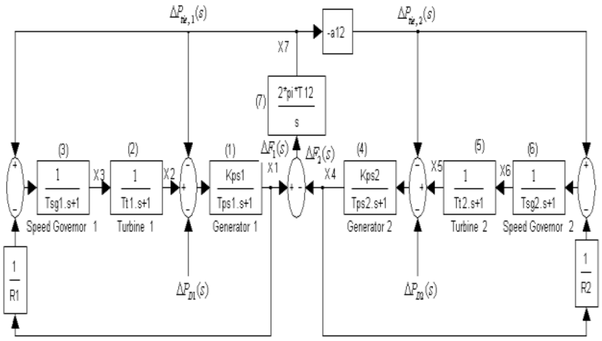

Figure 3: Block Diagram of Two-Area Load Frequency Control without Controller

Here each area consists of controller (which is to be tuned) governor, turbine and generator load model. Each unit's output depends on the input it obtains from the previous block or unit. Single Area System with and without PSO is shown.

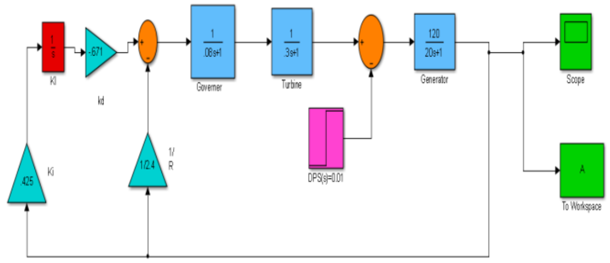

Figure 4: Single Area System Model

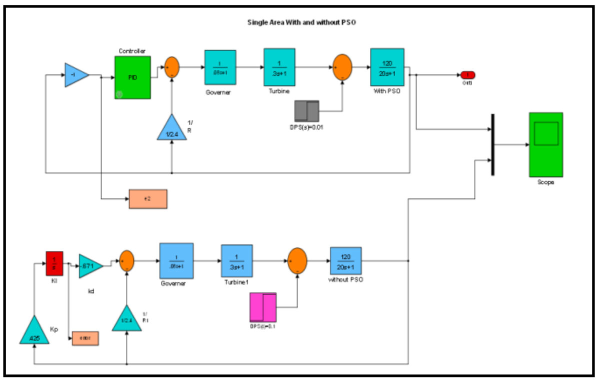

Figure 5: Controller Based Single Area System

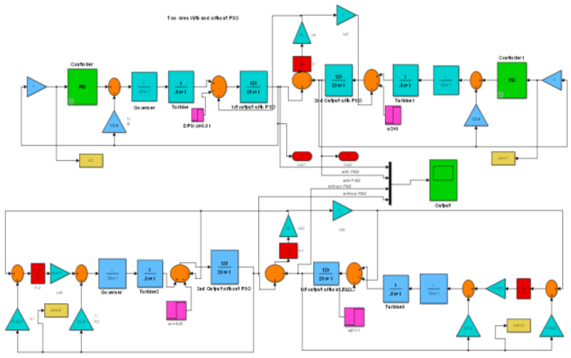

Figure 6: Two Area System with Controller

4.1 Performance Parameters of System

1. Settling Time

Settling time (t_s) is the time required for a response to become steady. It is defined as the time required by the response to reach and steady within specified range of 2 % to 5 % of its final value. Steady-state error (e_{ss}) is the difference between actual output and desired output at the infinite range of time.

2. Peak Overshoot

In control theory, overshoot refers to an output exceeding its final, steady-state value. For a step input, the percentage overshoot (PO) is the maximum value minus the step value divided by the step value. In the case of the unit step, the overshoot is just the maximum value of the step response minus one.

V. RESULTS & DISCUSSION

Power system is used for the conversion of natural energy to electric energy. For the optimization of electrical equipment, it is necessary to ensure the electric power quality. It is known three phase AC is used for transportation of electricity. Good quality of electrical power system means both the voltage and frequency to be fixed at desired values irrespective of change in loads that occurs randomly. It is in fact impossible to maintain both active and reactive power without control which would result in variation of voltage and frequency levels.

To cancel the effect of load variation and to keep frequency and voltage level constant a control system is required. Simulations Model was performed with no controller, with integral controller. PSO based controller is applied to single and two-area electrical power system. The Simulations were also performed with PSO based controller applied to single and two-area power system. Control error of each area consists of linear combination of tie line flows and frequency. ACE represents a mismatch between area generation and load (AGC).

The objective of LFC is to minimize the error in frequency of each area as well as to keep the tie-line error to scheduled value which is quite difficult in presence of fluctuating load. If we control the error in frequency back to zero, any steady state errors in the frequency of the system would result in tie-line power errors because the error in tie-line power is the integral of the frequency change between each pair of areas.

Therefore it is needed to consider the information of the tie-line power deviation in control input. The table 5.1 describes the parameters for PSO algorithm used in the system. The iterations may change and depends upon the user.

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Table 1: Parameters for PSO Algorithm

Parameters	Values
Population Size	10
Iterations	50
Inertia Weight (w)	0.9
Cognitive Coefficient (C1)	2
Social Coefficient (C2)	2

The ordinary single area power system parameters consisting of the speed governor, turbine and generator are given. At the simulation, the population size is taken 10. c1 and c2 constants are taken 2. The simulation results for the single area power system are shown.

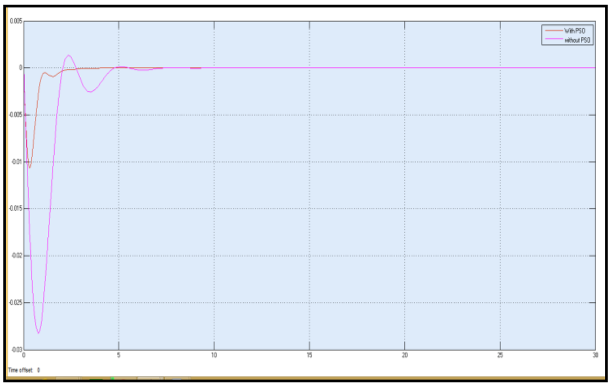

Figure 7: Single Area Power System with and without PSO Method

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.

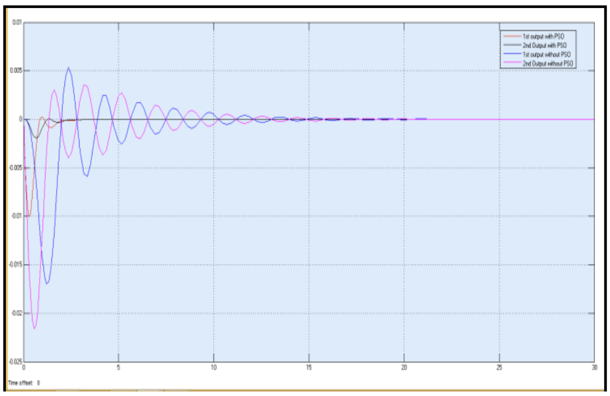

Figure 8: Two Area Power System with and without PSO Method

Bird generally follows the shortest path for food searching. Based on this behaviour, this PSO algorithm is developed. It uses a number of particles where every particle is considered as a point in N-dimensional space. Each particle keeps on accelerating in the search space depending on the knowledge it has about the appreciable solution comparing its own best value and the best value of swarm obtained so far. Once the calculation for velocity of each particle is done then position can be updated using equation of position modification.

VI. CONCLUSION

In this work, it presents on Load frequency control system based on PSO and PID controller. In this dissertation LFC problem related to single-area, two-area power systems are studied for uncontrolled case and then with the application of the integral controller, PSO based controller using MATLAB SIMULINK. In case of a single-area system, under uncontrolled case, steady state frequency error exists. The integral controller improves the system's dynamic performance by removing this steady state frequency error. In case of two-area power system, integral controller is used in both the areas to overcome system's steady state frequency errors and thereby enhancing system's dynamic performance.

The integral controller is optimized using PSO based controller and is shown that the PSO based integral controller provides better dynamic performance than integral controller in terms of lesser settling time and peak overshoots. Then a PSO based PI controller is developed to control two-area power systems. In the case of PSO based controller applied to two areas, settling times, overshoots performance criteria are utilized for the comparison. The simulation results show that proposed PSO based controller for load frequency control of two-area power system is giving reduction in settling time and peak overshoots when compared with other controllers.

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