

Load Frequency Control Optimization using PSO Based Integral Controller



Vandana Dhawane, Rajankumar bichkar

Abstract: This paper presents Automatic Generation Control (AGC) of a power system using integral controller. In the present day power systems, it has become absolutely essential to maintain the quality of the power generated indicating the need of a robust system that can handle parameter uncertainties neglecting disturbances. Although, extensive research has been done in this area, design of an efficient and robust system still remains one of the important issues that need to be addressed. Hence in this paper an integral controller has been designed for a single-area thermal power system without reheat turbine. The optimum controller gain is obtained by Particle Swarm Optimization (PSO) based on Integral of Absolute Error (IAE) and Integral of Square Error (ISE) criterion. The second part of the investigation includes robustness testing of the designed controller against different load conditions and plant parameter variations. The results obtained are compared to those obtained by other control methodologies presented in the recent literature. The results of the simulation validate the superiority of the approach in terms of improvement in the transient response and robustness to plant parameter variations.

Keywords: AGC, single-area thermal power plant, optimization, robustness, PSO.

I. INTRODUCTION

In India the main source of power generation is thermal power plant. Nearly 54% of the total energy in India is generated by coal fired thermal power plants. A power generation system as a whole can be subjected to various kinds of disturbances such as sudden increase in load demand during peak hours. At the same time there are various non-linearities introduced in the system due to variation in system parameters. All this can result in deviation in the supply frequency thus deteriorating the quality of the power generated [1]. Also modern power systems are complex and interconnected, so that disturbance in one area can affect the other area. Similarly modeling errors due to increased complexity of a power system can further degrade the quality of power delivered by the power system. Taking into account all these possibilities, it has become necessary to develop a robust system that can tackle all these problems and still maintain the supply quality [2].

The technique used for maintaining the supply frequency in spite of the disturbances is named as AGC [3]. Unlike other countries such as England, USA and Australia, we do not have reserve provision for contingency condition due to imbalance between load and generation. Hence a frequency associated regulatory method identified as unscheduled interchange is practiced [4].

In June 2017 secondary control has been introduced where both 500MW units of Dadri stage-II power plant are being operated under AGC.

In an isolated power system, functions carried out by a load frequency controller can be summarized as;

1. To improve the robustness of the system to parameter variations.
2. To reduce state deviations in frequency to zero as a result of step load disturbance.

So far numerous techniques have been used by researchers to address the AGC problem. Recent literature study reveals extensive use of variety of optimization algorithms and a wide range of controllers varying from conventional controllers to modern controllers such as fuzzy logic based controllers, integral double derivative controllers, optimal controllers, adaptive and self-tuning controllers that have been used for dealing with the load frequency control problem [5], [6], [7], [8], and [9].

Fractional order Proportional Integral Derivative (PID) controller has been used by Sondhi and Hote [4] wherein the parameters of the controller were optimized using the integral error criterion. The design was also tested for robustness. As per the author's claim, the fractional order controller provides superior disturbance rejection and better stability for a larger range of parameter variations compared to nominal controllers. Tan [5] has proposed a Proportional Integral Derivative (PID) controller for a single-area thermal power system. The gains of the controller were tuned by a two-degree-of-freedom Internal Model Control (IMC)-PID tuning method. To check for robustness of the design, two extreme cases of parameter variations were considered. However the robust performance was found to be inferior to the performance of a state-feedback controller.

In practice, due to nonlinear nature of power systems and approximations made by reducing the order of the models, the mathematical models representing the plants are valid only within a restricted operating range. In the event of operating conditions fluctuations, the control scheme should be able to adopt to changed system parameters. Under such situations, evolutionary computational techniques are found to provide a better solution. Prasad [10] has implemented AGC using a PID controller, optimizing the controller gains using PSO.

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The designed controller was found to be robust in spite of changes in the system parameters. Duman[2] has investigated Gravitational Search Algorithm (GSA) for optimizing the proportional and integral gains of Proportional Integral (PI) controller and PID controller gains. The achievement of the executed technique was analyzed after comparison with that of the conventional PI controller and the technique was found to be superior.

Shiva and Mukherjee [1] have employed Quasi- Oppositional Harmony Search algorithm for Load Frequency Control (LFC) of a single-area thermal power system. The controller used was PID controller with ISE as the objective function. The result analysis showed improvement in the values of the objective function. Shrikant and Yadaiah[11] have used Teaching-Learning Based Optimization (TLBO) algorithm to tune observer and controller gains. The simulation results involving parameter variations, sudden load disturbances and model uncertainties justify the efficacy of the approach.

The use of evolutionary algorithms has shown improvement in the performance of a power system from frequency control point of view. During the analysis of some studied optimization techniques, we have encountered a number of limitations. One of the extensively used recent techniques is Bacterial Foraging Optimization Algorithm (BFOA). The technique relies upon chemotactic movement of the virtual bacteria. The accuracy of the solution obtained by BFOA is affected by delay caused in attaining the global optimum solution as the bacteria move in random direction in the search space as shown by Nanda [12]. Similarly Ant Colony Optimization (ACO) technique has a complex theoretical analysis. Moreover in ACO, probability distribution can change for each iteration. In contrast PSO is simple to implement, its convergence rate is fast and the algorithm can be easily implemented through programming [7]. In addition, researchers have further enhanced the capabilities of PSO by introducing variants of the basic version of PSO to make it more effective.

Apart from conventional control techniques, researchers have explored various advanced control techniques such as fractional order PID controller, fuzzy logic controller, adaptive controller, and internal model controller. Most of the above mentioned methods are effective in achieving the desired objectives, but they suffer from a major drawback of implementation complexity. On the other hand, integral controller is easy to implement and has only a single tuning parameter, hence preferred for this purpose. The integral control action is characterized by zero steady state error and hence the controller suits our requirement as the main aim of our research is to drive the frequency deviation to zero.

The results manifested in the paper clearly authenticate the disturbance rejection capability of the system while simultaneously improving the transient response of the system. The basic outcomes of this paper can be stated as;

1. An integral controller is suggested for AGC of a single-area thermal power system without reheat turbine.
2. The parameters of the said controller are optimized by PSO algorithm using the IAE and ISE criteria.

3. The robustness of the identified approach is verified by variation in system parameters.

II. DYNAMIC MODEL OF A SINGLE-AREA THERMAL POWER SYSTEM WITH INTEGRAL CONTROLLER

The model of a single-area thermal power system in terms of system dynamics is shown in Fig. 1. As shown each block is represented by its equivalent transfer function. There are two inputs to the system, ΔP_d (load disturbance) and ΔP_c (reference power setting) in p.u. MW. The system has a single output Δf in Hz which represents the power system frequency deviation which is the variable of interest to us. R signifies the droop characteristic or speed regulation in Hz/p.u. MW. The equations representing transfer function for governor, turbine and power system are represented by (1) to (3)

$$G_g(s) = \frac{1}{1+T_g s} \quad (1)$$

$$G_t(s) = \frac{1}{1+T_t s} \quad (2)$$

$$G_p(s) = \frac{K_p}{1+T_p s} \quad (3)$$

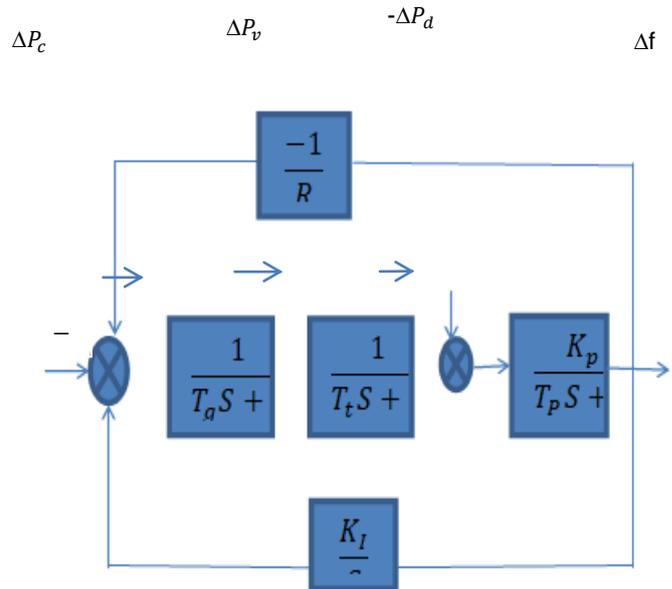


Fig. 1. Dynamic model of a single area thermal power plant

From above equations, it can be noted that T_p , T_g and T_t represent power system, governor and turbine time constants respectively in seconds. Similarly ΔP_v , ΔP_g and ΔP_d represent incremental changes in governor valve position in p.u. MW, generator output in p.u. MW and step load perturbation in p.u. MW. K_p represents gain of the power system in Hz/p.u. MW. The system model can be expressed by the following transfer function:

$$G(S) = \frac{G_g(s)G_t(s)G_p(s)}{1+G_g(s)G_t(s)G_p(s)/R} \quad (4)$$

The transfer function of a single-area thermal power plant without integral controller can be expressed by the following equations:

$$\frac{\Delta F(s)}{-\Delta P_d(s)} = \frac{K_p R(1+T_g S)(1+T_t S)}{R(T_p S+1)(T_g S+1)(T_t S+1)+K_p} \quad (5)$$

Similarly the transfer function of a thermal power plant with integral controller is represented by the following equation:

$$\frac{\Delta F(s)}{-\Delta P_d(s)} = \frac{K_p(1+T_g S)(1+T_t S)S}{S(T_p S+1)(T_g S+1)(T_t S+1)+\frac{K_p}{R}(S+RK_i)} \quad (6)$$

For an uncompensated system, the steady state analysis of the system transfer function by final value theorem gives a static error in frequency for a step load disturbance of magnitude ΔP_d . On the contrary, the system analysis with integral controller proves that frequency is restored back to its nominal value.

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a optimization technique that works on particle population and is developed by Eberhart and Kennedy in 1995. It is a computational method that optimizes solution to a problem through iterative behavior. The algorithm is developed based on the social behavior of flock of birds as demonstrated by Prasad[10]. PSO has been widely used in variety of applications including power quality enhancement and power flow control in microgrid operation [13], load frequency control of hybrid distributed generation system [14], economic load dispatch and low-frequency oscillation damping control [15]. Owing to its ease of application and simplicity, the algorithm has also been used for AGC application. Researchers have reported various variants of basic PSO such as perturbed PSO [16] which works on the principle of perturbed global best, novel PSO wherein the algorithm is adaptive to varying inertia weights when the algorithm is in progress[17] and PSO with chaotic opposition based population initialization[18]. Shiva[1] has implemented Quasi-Oppositional Harmony Search based PID controller for automatic generation control of a single-area thermal power plant. The results obtained were promising with lower values of performance indices but the transient response required more time for the transients to settle down. Thakur and Patra[19] have employed a traditional Zeigler-Nichols tuned PID controller for load frequency control problem. The simulation results proved the ability of the controller to reject the disturbances. However the transient response parameters emphasize the need for transient response improvement. In addition, the robustness of the system has not been verified.

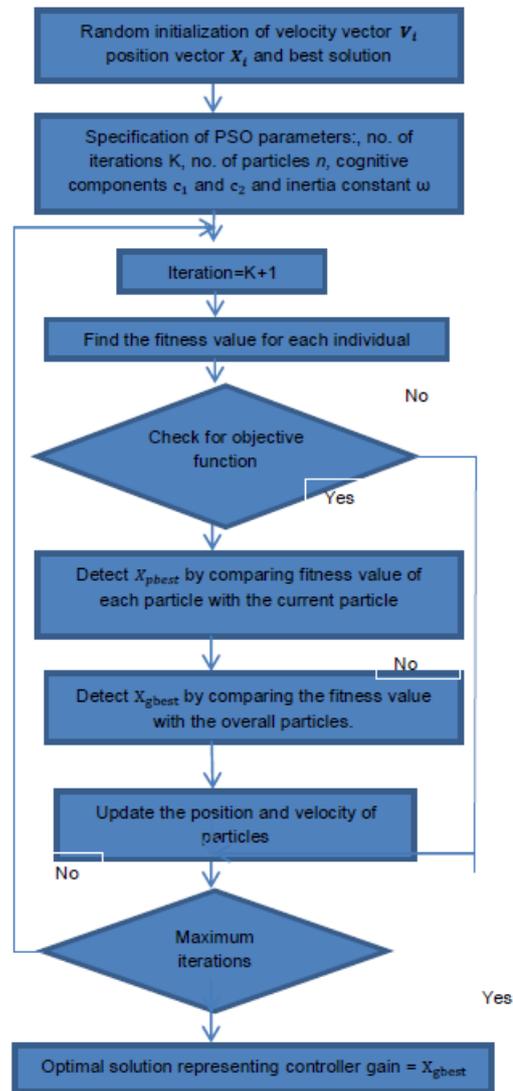


Fig. 2. Flowchart for PSO algorithm

Thus as can be seen from the work carried out by other researchers, the design of a controller can be ascertained to be satisfactory only when the designed controller is able to reject the disturbances efficiently bringing back the system frequency to its original value at the earliest within minimum settling time and provide a robust performance to the system parameter changes. In view of these requirements we have designed an integral controller with gain optimized by PSO, to achieve overall satisfactory transient response with reduced settling time while successfully rejecting the disturbances on the system.

PSO is an iterative algorithm that finds optimal solution for a specified objective function through search space. The algorithm scans the search space and reaches the optimal solution considering the movement of each particle as well as the swarm as a whole. Each particle starts random scan of the search space based on its own best knowledge and the knowledge of the swarm. It is drifted toward the current global best position X_{gbest} and its own best position X_{pbest} . The search process can be represented by simple equations using the position vector $X_i = [x_{i1}, x_{i2}, x_{i3}, \dots, x_{in}]$ and the velocity vector $V_i = [v_{i1}, v_{i2}, v_{i3}, \dots, v_{in}]$ in the search space.

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At every iteration, each particle changes its velocity and attains a new position as expressed by the following equations:

$$V_i^{k+1} = \omega \cdot V_i^k + c_1 \cdot r_1 [X_{pbest}^k - X_i^k] + c_2 \cdot r_2 [X_{gbest}^k - X_i^k] \quad (7)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (8)$$

Where X_i^k , V_i^k are the position and velocity of particle i at iteration k respectively; i is the index of the particle; ω indicates the inertia constant and is in general in the range [0 1]; c_1 and c_2 are coefficients in the range [0 2]; r_1 and r_2 are random values generated during each velocity update; X_{pbest} is the local best position of each particle attained so far based on its own best position. X_{gbest} is the global best position achieved depending upon the swarm's experience.

The terms in (7) and (8) can be defined according to the task they perform:

1. The first term $\omega \cdot V_i^k$ represents inertia component and its function is to maintain the particle search in one direction.
2. The second term $c_1 \cdot r_1 [X_{pbest}^k - X_i^k]$ is called as cognitive component and it indicates the ability of the particle to remember its local best position. The particle has the tendency to return to the area of search space in where it enjoys high individual fitness. The cognitive component c_1 decides the step size of the particle with which it moves towards its local best position X_{pbest}^k .
3. The third term $c_2 \cdot r_2 [X_{gbest}^k - X_i^k]$ is called as social component and it tends to move the particle towards the area in the search space where the swarm has highest fitness. The coefficient c_2 decides the step size of the particle in finding the global best position X_{gbest}^k .

As per (8), each particle's position is updated by using its previous position and new velocity. Thus a search process is renewed and initiated over the changed search space in order to investigate the global optimum solution. The process is repeated until the algorithm iterates through maximum number of iterations or the desired fitness value is reached. Thus regeneration of the swarm through indefinite velocity term and the ability of interpreting the search process produce highly efficient operation to find the global optimum solution. A restricted search space is the only major constraint of the PSO algorithm. This problem can be overcome by use of extended boundaries for the search space but at the cost of increased computation time. Hence more information about the search space boundaries will help to overcome the limitation.

IV. SIMULATION RESULTS AND EVALUATION

In the present study we consider an isolated single-area thermal power system without reheat turbine, supplying a load. The simulation studies are considered for two cases. In the first part of the simulation, we consider the uncompensated system or the system without integral controller as represented by transfer function (5) and study the dynamic behavior of the system for varying load disturbances. In the second part of the simulation, we consider the system assisted by an integral controller as described by (6). The system is tested for disturbance

rejection for different load conditions as well as for robustness.

A. Uncompensated System with Load Variations:

The problem of frequency regulation in a single-area power system with non-reheat turbine dynamics and without integral controller is considered. For execution of the proposed technique, Intel® CORE™ i3 processor is used. The system is simulated in MATLAB2014b environment. The system parameters are; $K_p = 120$, $T_p = 20$, $T_t = 0.3$, $T_g = 0.08$, and $R = 2.4$. A step load perturbation of varying magnitude is applied to the system, and response plot for frequency variation is plotted. The PSO parameters considered are; population size = 40, maximum number of iterations = 100, $\omega = 1$, $c_1 = c_2 = 2.0$. As can be observed from the response shown in fig.3, the step load increase results in drop in the frequency. The final steady state value at which the frequency stabilizes is determined by the regulation R of the governor and the magnitude of step load change. We have considered three variations for step load change and corresponding frequency deviations for uncompensated system are expressed in Table I.

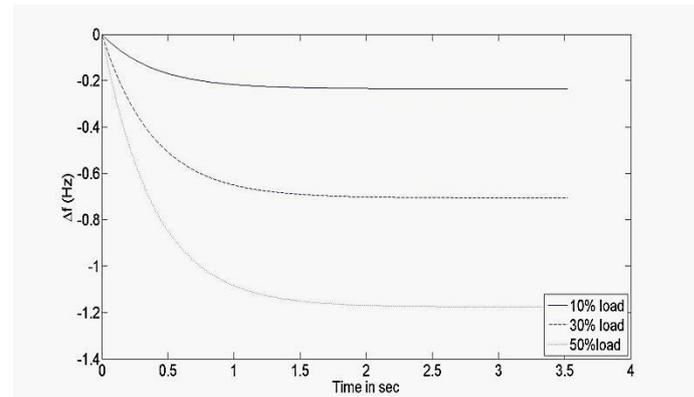


Fig.3. Frequency deviation step response for an uncompensated system for load variations

Table-I: Static variations in frequency with step load change for uncompensated system

Sr. No.	Load Variation	Static error in frequency(Hz)
1	10%	-0.235
2	30%	-0.7058
3	50%	-1.1764

B. System with Integral Controller

In this section the effectiveness of PSO with integral controller is tested for disturbance rejection and robustness. For this, an objective function is considered as a test criterion for testing the computational efficiency of the proposed PSO algorithm. In this paper Integral of Square Error (ISE) and Integral of Absolute Error (IAE) are selected as objective functions. The mathematical expressions are expressed as:

$$IAE = \int_0^t |\Delta f| dt \quad (9)$$

$$ISE = \int_0^t \Delta f^2 dt \quad (10)$$

The aim of minimization of the performance index is to obtain optimal controller gain which may produce the desired performance for the system under study. The constraint for the present optimization problem is the controller gain within some pre-specified limit given by:

$$K_I^{\min} \leq K_I \leq K_I^{\max} \quad (11)$$

In the present work, the controller gain lies within 0 to 5.0 and the optimized value obtained is 4.9986. Assessment of the proposed technique is carried out related to the transient response performance specifications and sensitivity to the parameter variations. With the secondary control action initiated by the integral controller, the system successfully drives the frequency deviations to zero resulting from step load changes as seen from Fig. 4. To verify the transient performance of the system, a step load perturbation of 0.01 p.u. is applied. Under the influence of the disturbance, the system frequency deviation response is plotted shown in Fig. 5 and Fig. 6 taking into account IAE and ISE as error criteria respectively. For asserting the superiority of the proposed approach, we compare the transient response parameter such as settling time and integral error indices with those reported in the recent literature.

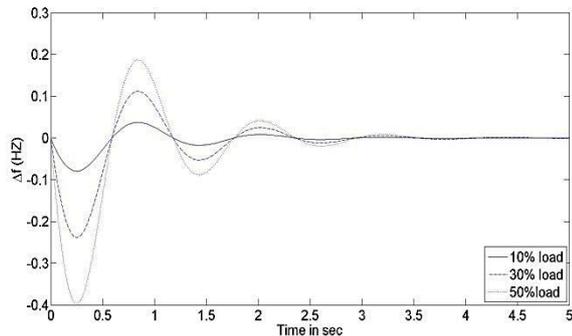


Fig. 4. Frequency deviation step response for system with integral controller for different load variations

Similarly to test for robustness of the applied controller scheme, $\pm 50\%$ uncertainty is added in all the system parameters, i.e., $K_p = [60, 180]$, $T_p = [10, 30]$, $T_t = [0.15, 0.45]$, $T_g = [0.04, 0.5]$ and $R = [1.2, 3.6]$. The results tabulated in Table II, compares the performance of the applied control scheme with the methodologies implemented by other researchers. As can be seen from Table II, the efficiency of the applied technique is verified by value of objective functions. From the observations tabulated in Table II, the values of the IAE performance index obtained are better than those obtained by Sondhi and Hote[3], [20] and Saxena and Hote[21] for nominal system parameters. Similarly improved results are obtained for lower and upper bound system parameters than obtained by Sondhi and Hote[3] and Saxena and Hote[21] considering IAE as the objective function. The objective functions are indicative of the controller optimality. From the values of the IAE criterion obtained for nominal as well as lower and upper bound system parameters, it can be asserted that the

proposed PSO based integral control scheme is optimal in nature as far as IAE criterion is considered.

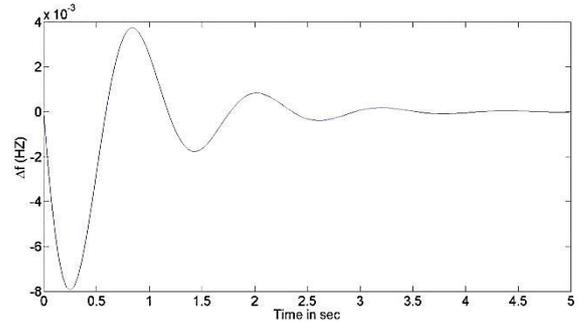


Fig.5. Frequency deviation step response for a system with integral controller with nominal system parameters with IAE as objective function

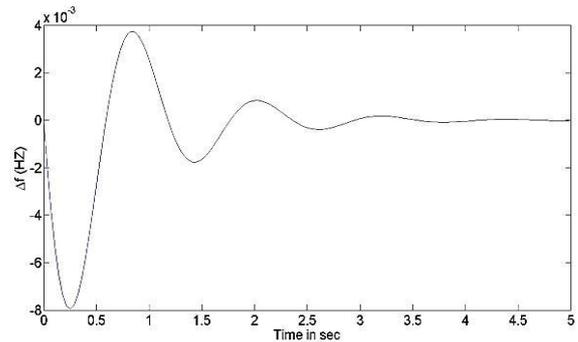


Fig.6. Frequency deviation step response for a system with integral controller with nominal system parameters with ISE as objective function

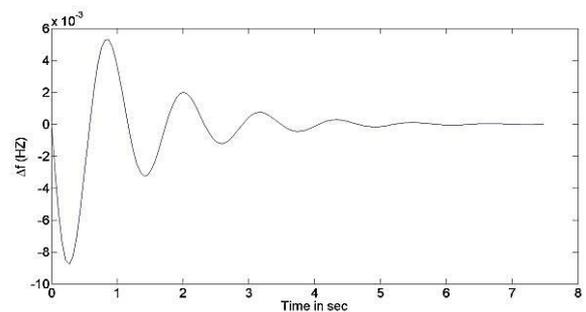


Fig. 7. Frequency deviation step response for a system with integral controller with 50% upper bound system parameters with IAE as objective function

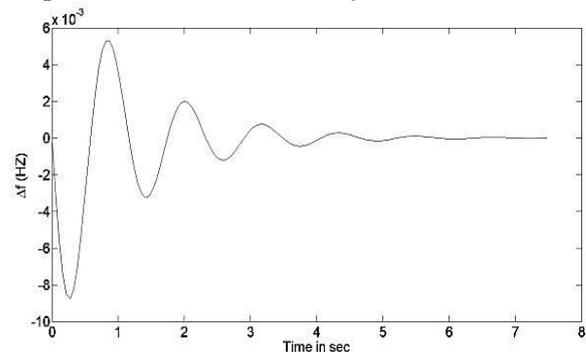


Fig. 8. Frequency deviation step response for a system with integral controller with 50% upper bound system parameters with ISE as objective function

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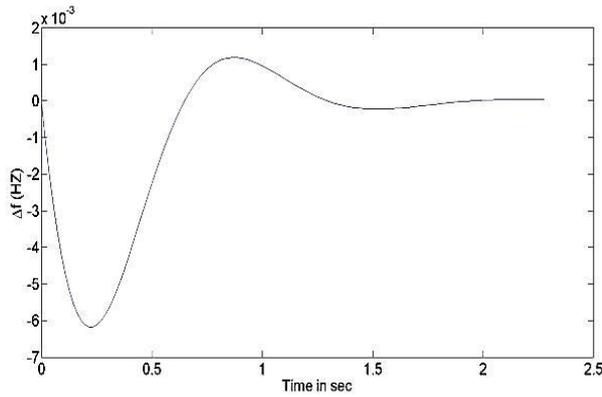


Fig. 9. Frequency deviation step response for a system with integral controller with 50% lower bound system parameters with ISE as objective function

From the point of view of transient response specification, we have considered settling time as it indicates the speed of response of the system or how rapidly the system settles back to its nominal frequency after the system is subjected to disturbances. The observations illustrated in the Table III depict the efficiency of the system in terms of settling time. We have obtained 83% improvement in the settling time over that obtained by Shiva and Mukherjee [5] for nominal system parameters. The variations obtained in the settling time introduced due to parameter uncertainty are found to be within appreciable limits. Thus it can be asserted that the proposed control scheme is optimal in nature considering the ability of the system to nullify frequency fluctuations within minimum settling time resulting from step load change.

Table II: Comparison of the performance indices

	Nominal system parameters		50% parameter change			
			Lower limit		Upper limit	
	IAE	ISE	IAE	ISE	IAE	ISE
Implemented scheme	0.002582	0.004	0.002582	0.004	0.002582	0.004
Shiva & Mukherjee [1]	--	0.00562	--	--	--	--
Sondhi&Hote [20]	0.01014	4.32E-05	--	--	--	--
Saxena [22]	0.00249	0.00061	0.00118	0.000133	0.00406	0.000012
Sondhi&Hote [3]	0.003877	1.36E-05	0.005813	2.21E-05	0.003828	8.91E-06
Saxena&Hote [21]	0.08061	0.000823	0.08247	0.000866	0.07827	0.00081

Table III: Comparison of settling time (Sec)

Design Method	Nominal system parameters	50% upper bound parameters	50% lower bound parameters
Proposed scheme	3.3383	4.5025	1.79
Shiva & Mukherjee[1]	19.81	--	--
Sondhi&Hote [20]	--	--	--
Saxena&Hote [21]	--	--	--
Saxena [22]	--	--	--
Sondhi&Hote [3]	--	--	--

V. CONCLUSION

In a power industry there is a constant need for effective techniques to handle the increasing complexity of large power systems while maintaining the robustness against load changes and system parameter variations. In this context, we have implemented a PSO optimized integral controller to generate a stable control system for a single-area thermal power system. The system achieves good performance in terms of disturbance rejection, robustness against plant parameter uncertainty and settling time. The further progress would be to investigate the current methodology for a two-area thermal power system with and without reheat turbine.

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