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DESIGN OF ARTIFICIAL BEE COLONY BASED LOAD FREQUENCY CONTROLLER FOR A TWO AREA INTERCONNECTED HYDROTHERMAL POWER SYSTEMS

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ABSTRACT

This proposal intends a design of Artificial Bee Colony (ABC) Based load-frequency controller of two-area hydrothermal interconnected power systems. For evaluate the stability of the proposed model, it's mandatorily to introduce a suitable optimizer which optimizes the Proportional- Integral (PI) gain setting by minimizing a quadratic performance index. Now, the mechanical hydro governors are being replaced by Electric Hydro governors so electronic apparatus has been introduced to perform low power functions associated with speed sensing and droop compensation. In general, turbine- governors in any power system has to regulate the turbine-generator speed as primarily and also establish the frequency and the active power on its own system retort to load variation, thus proved in this paper. From the Simulation results, the Hydro Turbines with Electric Governor not only ensures stable output but also provides a good margin of settling time as compared with that of combination of Hydro Turbine with Mechanical Governor. Furthermore, the proposed ABC algorithm is easy to implement without additional computational complexity as compared with conventional Proportional - Integral controller.

Keywords: Load frequency control (LFC), Artificial BEE Colony (ABC), Two-area interconnected hydrothermal power Systems, Hydro Turbines with Electric Governor.

I. INTRODUCTION

Power system operation has to ensure ample power is being distributed to the consumers in reliable and economical style. In ensuring agreeable operation, a challenge comes under assessment, analysis and Modeling of the problem [1]. In addition, unique Simulation methodologies with efficient optimization techniques, outcomes the relationships of various parameters which controls large-scale interconnected power systems. The complexity nature in electric power networks and their interconnections and their control parameters requires a well deserved quality control in power systems. Besides, the interconnected operation enables their utilities to justify its spinning reserve capacities during emergencies and to take benefit of load diversity [2, 3].

In an electric power system, Load Frequency Control (LFC) is a structure to maintain reasonably uniform frequency, to divide the load between the generators, and to control the tie- line interchange schedules. The change in frequency is sensed when the rotor angle ∂ is changed. The error signals are transformed into real power command signal, which is sent to prime mover to call for an increment in the torque. The prime mover then brings change in the generator output by an amount which will change the values of within the specified tolerance [3].Many investigations have been reported that, the problem of LFC meets the following requirements of a power system [4,5] which is otherwise called objectives;

i. Matching generation to load,
ii. Reducing system frequency errors to zero,
iii. Distributing generation among different areas so that tie-line flow is measured within their specified limits.

The objective (i) is achieved by the system governor with a time span of few seconds, but as this alone is not sufficient to take care of (ii) and (iii), a supplementary control is required for the system governor which can be established using Proportional plus Integral (PI) or classy controllers to meet the LFC demands. Likewise, time span of the integral action is also to be considered [2,3].

In the dynamical operation of power systems, it is necessitate for decentralization of control action among individual areas in interconnected power system. Thus, the main performance requirements of decentralized LFC in the interconnected power systems are:

1. Each area regulates its own load variations.
2. Each area contributes to the control of system frequency.
3. At steady state, the Area Control error (ACE), becomes zero or frequency and tie-line power should return to as specified in all areas.
4. Reduces transient frequency oscillations, thereby reducing its magnitude and improves the stability margin of the closed loop system also provides control law independent of disturbance.

From the literature survey, the design of decentralized Load Frequency Controllers to satisfy most of the above requirements using decentralized local system state feedback or output feedback. This feedback control procedure is based on classical Ricatti equation which is analyzed in two different aspects via; closed loop asymptotic stability and sub-optimality degree [5,6,14].

ABC algorithm is one of the most recently introduced swarm-based algorithms which simulate the intelligent foraging behavior of a honeybee swarm. Dervis Parabola [8], have presented their research work with ABC which is used for optimizing a large set of numerical test functions that validates best optimization results as compared with genetic algorithm, particle swarm optimization algorithm and differential evolution algorithm strategies. Results obtained in the present study reveals that the optimal tuning of the gain using Artificial Bee Colony (ABC) algorithm which validates the frequency and tie-line power deviations in all the areas to settle down to zero as quickly as possible.

II. STATEMENT OF THE PROBLEM

The structure of the state, control and disturbance vectors and the transfer function block diagram represented in Figure 2.1. In a two-area interconnected system; area one comprises of thermal reheat unit and area two comprises of Hydro unit. The dynamic model in state variable form can be conveniently obtained from the transfer function model.

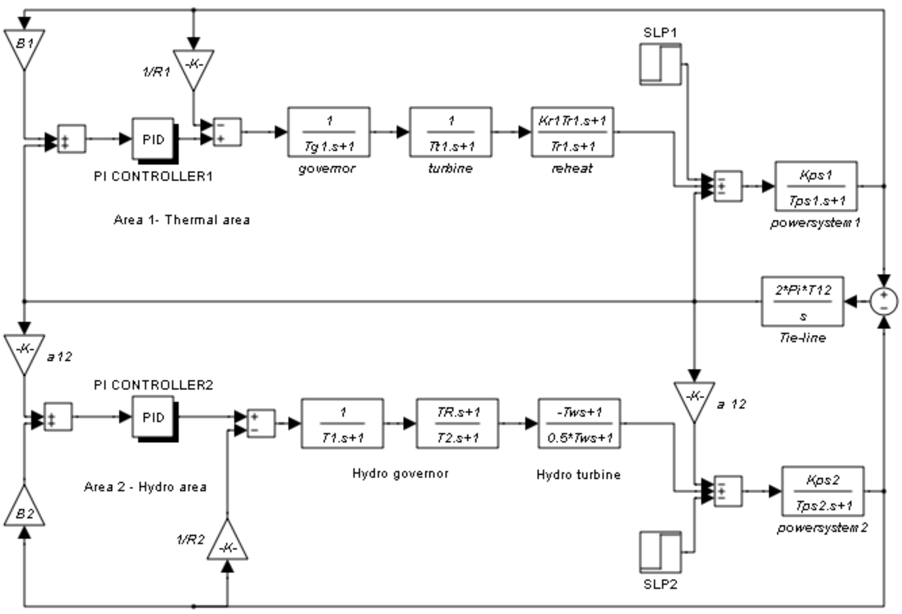

Figure 2.1 represents the transfer function model of a two-area interconnected system with hydro- thermal reheat units

Modeling of a two - area hydrothermal interconnected power system

The transfer function block diagram of LFC model in a deregulated scenario is given in Figure 2.1. Each area comprises of one unit, one reheat and one non-reheat unit.

$$\Delta F_1(s) = \left(\frac{k_{p1}}{1+sT_{p1}}\right)\left(\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{tie,1}(s)\right) \quad (1)$$

$$\Delta P_{G1}(s) = \left(\frac{1+sk_{r1}T_{r1}}{1+sT_{r1}}\right)\left(\Delta P_{T1}'(s)\right) \quad (2)$$

$$\Delta P'_{T1}(s) = \left(\frac{1}{1+sT_{t1}}\right)\left(\Delta X_{E1}(s)\right) \quad (3)$$

$$\Delta X_{E1}(s) = \left(\frac{1}{1+sT_{g1}}\right)\left(\Delta P_{c1}(s) - \frac{1}{R_1}\Delta F_1(s)\right) \quad (4)$$

$$\Delta P_{tie,1}(s) = \left(\frac{T_{12}}{s}\right)\left(\Delta F_1(s) - \Delta F_2(s)\right) \quad (5)$$

$$\Delta F_2(s) = \left(\frac{k_{p2}}{1+sT_{p2}}\right)\left(\Delta P_{G2}(s) - \Delta P_{D2}(s) - a_{12}\Delta P_{tie,1}(s)\right) \quad (6)$$

$$\Delta P_{G2}(s) = \left(\frac{1-sT_w}{1+0.5sT_w}\right)\left(\Delta P_{T2}'(s)\right) \quad (7)$$

$$\Delta P'_{T2}(s) = \left(\frac{1+sT_{R2}}{1+sT_2}\right)\left(\Delta X_{E2}(s)\right) \quad (8)$$

$$\Delta X_{E2}(s) = \left(\frac{1}{1+sT_1}\right)\left(\Delta P_{c2}(s) - \frac{1}{R_2}\Delta F_2(s)\right) \quad (9)$$

Taking L^{-1} of the above equations

$$\Delta \dot F_1 = \frac{k_{p1}}{T_{p1}}\left(\Delta P_{G1} - \Delta P_{D1} - \Delta P_{tie,1}\right) - \frac{\Delta F_1}{T_{p1}} \quad (10)$$

$$\Delta \dot P'_{T1} = -\frac{1}{T_{t1}}\Delta X_{E1} - \frac{1}{T_{t1}}\Delta P'_{T1} \quad (11)$$

$$\Delta \dot P_{G1} = -\frac{1}{T_{r1}}\Delta P_{G1} + \left[\frac{1}{T_{r1}} - \frac{k_{r1}}{T_{t1}}\right]\Delta P'_{T1} + \frac{k_{r1}}{T_{t1}}\Delta X_{E1} \quad (12)$$

$$\Delta \dot X_{E1} = -\frac{1}{T_{g1}}\Delta X_{E1} + \frac{1}{T_{g1}}\Delta P_{c1} - \frac{1}{T_{g1}R_1}\Delta F_1 \quad (13)$$

$$\Delta \dot P_{tie,1} = T_{12}\left(\Delta F_1 - \Delta F_2\right) \quad (14)$$

$$\Delta \dot F_2 = \frac{k_{p2}}{T_{p2}}\left(\Delta P_{G2} - \Delta P_{D2} - a_{12}\Delta P_{tie,1}\right) - \frac{\Delta F_2}{T_{p2}} \quad (15)$$

$$\Delta \dot P_{G2} = -\frac{1}{0.5T_w}\Delta P_{G2} + \left[\frac{1}{0.5T_w} + \frac{2}{T_2}\right]\Delta P'_{T2} + \left(\frac{-2}{T_2} - \frac{-2T_R}{T_1T_2}\right)\Delta X_{E2} + \frac{2T_R}{T_1T_2R_2}\Delta F_2 - \frac{2T_R}{T_1T_2}\Delta P_{c2} \quad (16)$$

$$\Delta \dot P'_{T2} = \left(\frac{1}{T_2} - \frac{T_R}{T_1T_2}\right)\Delta X_{E2} - \frac{1}{T_{t2}}\Delta P'_{T2} + \frac{T_R}{T_1T_2}\Delta P_{c2} - \frac{T_R}{T_1T_2R_2}\Delta F_2 \quad (17)$$

$$\Delta \dot X_{E2} = -\frac{1}{T_1}\Delta X_{E2} + \frac{1}{T_1}\Delta P_{c2} - \frac{1}{T_1R_2}\Delta F_2 \quad (18)$$

$$\dot x = Ax + Bu + \Gamma d \quad (19)$$

Output equation, $y = Cx$ **(20)**

The state vector,

$$x = \left[\Delta F_1, \Delta P_{G1}, \Delta P'_{T1}, \Delta X_{E1}, \Delta P_{tie,1}, \Delta F_2, \Delta P_{G2}, \Delta P'_{T2}, \Delta X_{E2}\right]^T \quad (21)$$

System Control input vector

$$u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{c1} \\ \Delta P_{c2} \end{bmatrix} \quad \textbf{(22)}$$

Disturbance vector $d = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{D1} \\ \Delta P_{D2} \end{bmatrix}$ **(23)**

III. DESIGN OF CONVENTIONAL CONTROLLERS

Proportional Plus Integral Controller

Many investigations in the area of Load Frequency Control (LFC) problem of interconnected power systems have reported over the past six decades. A number of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance. In feedback control systems a controller may be introduced to modify the error signal and to achieve better control action. The efficient incorporation of controllers will modify the transient response and steady state error of the system. Among the various types of load frequency controllers, the most widely employed is the conventional Proportional plus Integral controller (PI). In this work optimum gain values are tuned based on the settling time of the output response of the system (especially the frequency deviation of area1) and with these gain values the performance of the system is analyzed. And here in this case study it is used as a feedback controller which drives the plant to be controlled within a weighted sum of error and integral of that value i.e. it produces an output signal consisting of two terms one proportional to error signal and the other proportional to integral of error signal.
Where,

$$U1 = -K_p\, ACE_1 - K_I \int ACE_1 dt$$
$$U2 = -K_P\, ACE_2 - K_I \int ACE_2 dt \quad \textbf{(24)}$$

Where,

K_P = Proportional gain
K_I = Integral gain
ACE = Area Control Error
U_1, U_2 = Control outputs of the respective areas.

The relative simplicity of this controller is a successful approach towards the zero steady state error in the frequency of the system. The objective of LFC is to reestablish primary frequency regulation, restore the frequency to its nominal value as quickly as possible, and minimize tie-line power flow oscillations between neighboring control areas. In order to satisfy the above requirement, gains (K_{p1},K_{p2}) of proportional controller and gains (K_{i1}, K_{i2}) of integral controller in LFC loop, are to be optimized to have minimum undershoot (US), overshoot (OS) and settling time (ts) in area frequencies and power exchange over tie-line. In the present work, Integral Square Error (ISE) criterion is used to minimize the objective function defined as follows

$$J = \int_0^t \left(\Delta F_1^2 + \Delta F_2^2 + \Delta P_{tie12}^2\right) dt \quad \textbf{(25)}$$

The integral of the square error (ISE) gives the good performance than the other criterions as if requires less computation and more accuracy [4,7]. The Fig shows the block diagram representation of a power system with PI controller

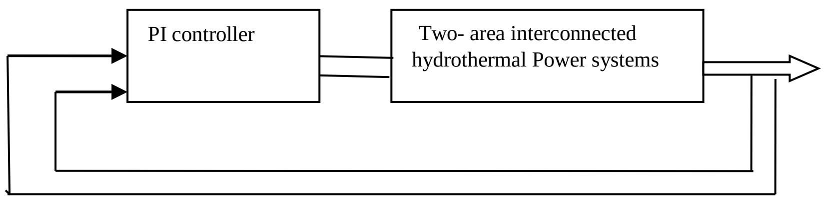

Figure 3.1 shows the block diagram representation of a power system with PI controller

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IV. DESIGN OF ABC ALGORITHM BASED CONTROLLER

The Artificial Bee Colony algorithm which was introduced in 2005 by Karaboga, is used as an optimization search, simulates the intelligent foraging behaviour of a honey bee swarm. It incorporates a flexible and well-balanced mechanism to adapt to the global and local exploration and exploitation abilities within a short computation time. Due to its simplicity and easy implementation, the ABC algorithm has captured much attention and has been applied to solve many practical optimization problems. This method is efficient in handling large and complex search spaces and it has also been found to be robust in solving problems featuring non-linearity, no differentiability and high dimensionality. Compared with the usual algorithms, the major advantage of ABC algorithm lays in that it conducts both global search and local search in each iteration and as a result, the probability of finding the optimal parameters is significantly increased, which efficiently avoid local optimum to a large extent[8,9].

Artificial Bee Colony Algorithm

The main steps of the proposed algorithm are given below:

1. The search process starts with the random initialization of the bee population.
2. According to the numerical objective functions being examined, the non-dominated solution sets are stored in the archive. The archive is used to store the best estimates of the Pareto front and is updated in each search iteration. The archive updating process contains two steps:
   a. Firstly, the newly generated solution sets are combined with the non-dominated solution sets already stored in the archives. Then the dominated solutions are removed.
   b. Secondly, if the archive maximal size is reached, a recurrent truncation method based on crowding distance is utilized to remove the least “promising” non-dominated solutions.
3. The diversity - based performance metric, given by $\alpha n \in [0, 1]$, of the solutions stored in the archive is calculated. α Estimates the level of uniformity in the distribution of solutions in the archive set, i.e., if $\alpha=1$ then the solutions are uniformly distributed, whereas with $\alpha = 0.6$ we may approximate that 40% of the solutions are not evenly distributed. Note that with $\alpha=0$, the archive set is empty.
4. The current stage of food forage is determined according to the diversity of the archive set. Three stages or phases are distinguished: exploration, transition and exploitation.
5. The bee colony structure (i.e., ratios of elite, follower and scout bees) is adjusted according to α. This adjustment aims at maximizing α (i.e., increase the distribution uniformity of the solutions). The goal is to make the solutions in the archive set evenly distributed. Note that the archive size (K) is equal to the population size. The different bee type ratios which were devised according to the following considerations:
   a. In typical experiments, the generated solution sets exhibit low diversity during the initial phase (i.e., α is low). In such cases, the percentage of elite bees performing the waggle dance should be high (i.e., $1-\alpha$ to be high) so that exploration is emphasized. As the search proceeds, the archive set eventually becomes more diversified; the elite bee ratio should then be decreased to facilitate local fine-tuning.
   b. So according to the fitness (i.e., crowding distance) of individual solutions, $(1-\alpha-s)\,K$ of the bees are selected as elite ones. After that, the waggle dance is performed by elite bees. Note that the number of scout bees is fixed throughout the search.
6. The flying patterns (i.e., the bees' search paths) are also subjected to variation. The scout bees use a polynomial mutation operator (promoting an increase in spread) to explore the search space further. The associated mutation probability is fixed. In contrast, elite and follower bees utilize the Simulated Binary Crossover (SBX) method to exploit the near-optimal generated solutions. The adjustment of flying patterns is achieved through the automated tuning of SBX's distribution index. This is being performed in each iteration. The diversity-based performance metric is again utilized to drive this adjustment.
7. Then, based on the adjusted flying patterns, the bees carry out food foraging.

The implementation of above ABC algorithm for tuning of Control parameters in a model network has been implemented in this work and explained in further sections.[8-12]

V. IMPLEMETATION OF ABC ALGORITHM FOR LFC PROBLEM

Step1: Initialize the food source position X_i (solutions population) where $i=1, 2 \ldots D$

$$[X_i=1, 2, 3 \ldots D] \quad (26)$$

Step 2: Calculate the nectar amount of the population by means of their fitness values using:

$$f_i *t_i=1/(1+obj.fun._i J) \quad \textbf{(27)}$$

Where *objective function i* represents equation at a solution *i*

Step 3: Produce neighbor solution V_{ij} for the Employed bees by using the equation

$$V_{ij} = x_{ij} + \varphi_{ij} (x_{ij} - x_{kj}) \quad \textbf{(28)}$$

Where $k = (1,2,3....D)$ and $j =(1,2,3...N)$ are randomly chosen indexes φ_{ij} is a random number between [-1,1] and evaluate them as indicated in step 2.

Step 4: Apply the greedy selection process for the Employed bees.

Step 5: If all Onlooker bees are distributed, Go to step 9.otherwise, Go to the next step.

Step 6: Calculate the probability values P_i for the solution X_i using by equation

$$Pi = \frac{f_i * t_i}{\sum_{n=1}^{N} f_i * t_i} \quad \textbf{(29)}$$

Step 7: Produce the neighbor solution V_i for the Onlookers bee from the solution X_i selected depending on P_i and evaluate them.

Step 8: Apply the greedy selection process for the Onlooker bees.

Step 9: In the ABC algorithm, providing that a position cannot be improved further through a predetermined number of cycles, then that food source is assumed to be abandoned. The value of the predetermined number of cycles is an important control parameter of the ABC algorithm, which is called "limit" for abandonment. Assume that the abandoned source is X_i and $J= (1, 2, 3,..., N)$, then the Scout discovers a new food source to be replaced with X_i. Determine the abandoned solution for the Scout bees, if it exists, and replace it with a completely new solution X_i^j using the equation and evaluate them as indicated in step2.

$$X_i^j=X^j_{min}+rand(0,1)*(X^j_{max}-X^j_{min}) \quad \textbf{(30)}$$

Step 10: Memorize the best solution attained so for.

Step 11: If cycle=Maximum Cycle Number (MCN). Stop and print result, otherwise, follow step 3.[8-12].

VI. SIMULATION RESULTS AND DISCUSSIONS

The optimal gains of Proportional- Integral controllers for two area hydrothermal interconnected power system are determined using ABC algorithm. At the end of the simulation, the tuned parameters of the control system are shown in Table 6.1. These controllers are implemented in a two-area hydrothermal interconnected power system for 1 % step load disturbance in area1. The nominal parameters are given in Appendix. The comparative transient response for two area hydrothermal interconnected power system is shown in Fig 6.1; it can be observed that the oscillations in area frequencies and tie-line power deviation have decreases to a considerable extent as compare to that of the system using conventional controller. Moreover the mechanical hydro governors are being replaced by Electric Hydro governors in which electronic apparatus is used to perform low power functions associated with speed sensing and droop compensation. The comparative transient response for two area hydrothermal power system is shown in Fig 6.2; it can be observed that the oscillations in area frequencies and tie-line power deviation have decreases to a considerable extent as compare to that of the system using mechanical hydro governor. The settling times and peak over/under shoot for the frequency deviations in each area and tie-line power deviations for three case studies are tabulated in Table 6.2. Fig 6.3 shows dynamic responses of the Control input deviations. It is to be noted that two area hydrothermal power systems using electrical governor unit requires lesser control effort.

Table 6.1 Optimized parameters of the Two-area hydrothermal Power system

Two area hydrothermal interconnected power system	**Controller Gain value thermal area-1**	**Controller Gain value hydro area-2**	**Cost function value (J)**
Using conventional controller (mechanical hydro governor)	Kp = 1.213 Ki = 0.365	Kp = 0.016 Ki = 0.069	0.3981

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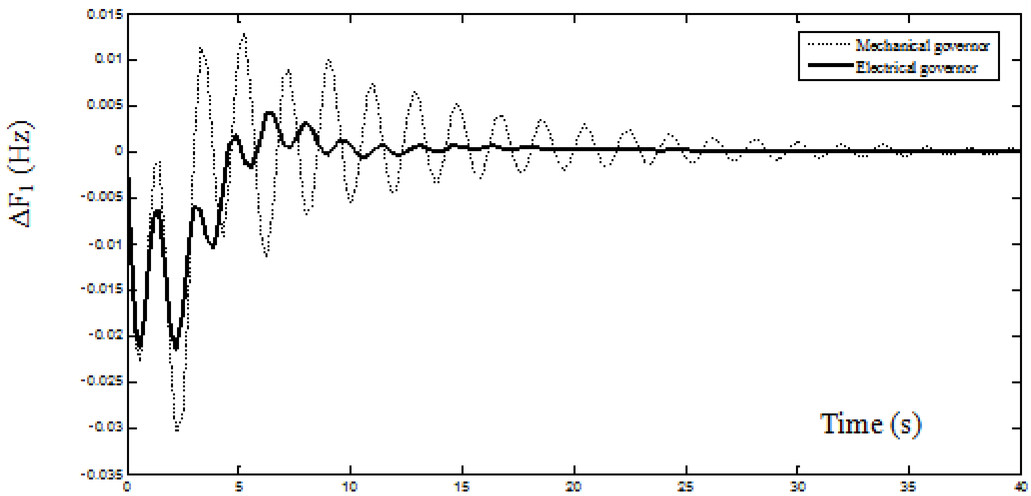
Using ABC algorithm based controller (mechanical hydro governor)	*Kp = 1.012* *Ki = 0.443*	*Kp = 0.008* *Ki = 0.013*	*0.2513*
Using ABC algorithm based controller (Electrical hydro governor)	*Kp = 0.981* *Ki = 0.265*	*Kp = 0.015* *Ki = 0.021*	*0.1636*

From the Table it can be observed that the controller designed using Artificial Bee Colony algorithm for two area hydrothermal interconnected power system using electrical governor have not only reduces the cost function but also ensure better stability, as they possesses less over/under shoot and faster settling time when compare with the output response of the for the two area hydrothermal interconnected power system using mechanical governor units. Moreover the ABC algorithm is easy to implement without additional computational complexity. This algorithm has superior solution quality in satiating the objective. This capability of ABC rises from the greedy selection process and the timely abandonment of used up food sources incorporated in it. These fundamental procedures in the ABC prevent stalling of solutions and make the algorithm more exploitative in nature.

Table 6.2 Comparison of the system performance for the three case studies

Two area hydrothermal interconnected power system	**Setting time (τ_s) in sec**			**Peak over / under shoot**		
	ΔF_1	**ΔF_2**	**ΔP_{tie}**	**ΔF_1 in Hz**	**ΔF_2 in Hz**	**ΔP_{tie} in p.u.**
Using conventional controller (mechanical hydro governor)	38.52	35.15	37.52	0.0414	0.0396	0.0075
Using ABC algorithm based controller (mechanical hydro governor)	33.42	31.54	35.36	0.0306	0.0297	0.0055
Using ABC algorithm based controller (Electrical hydro governor)	15.22	16.42	20.48	0.0212	0.0266	0.0047



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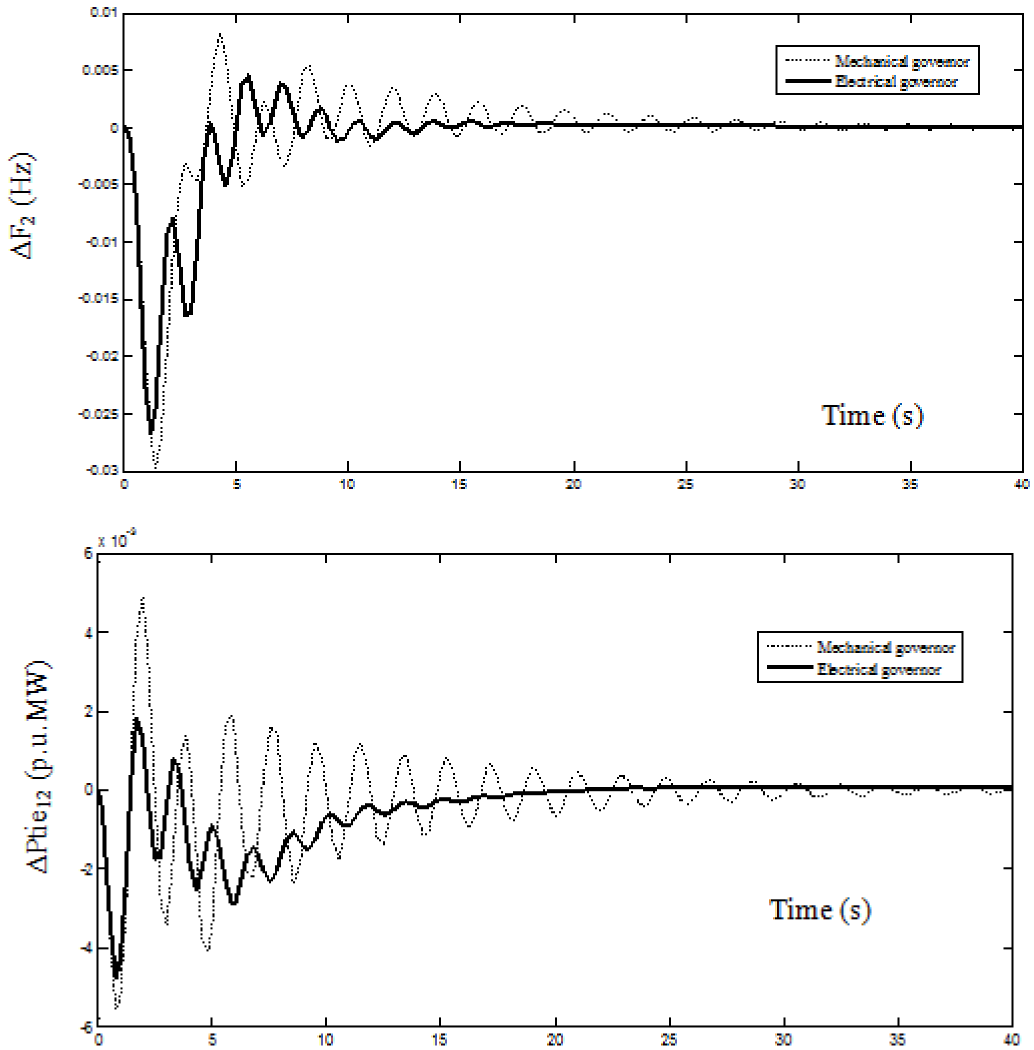
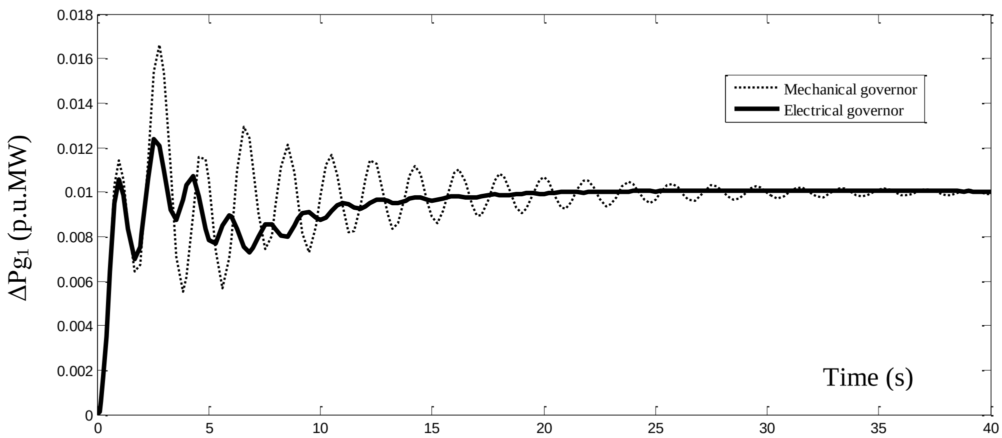


Figure 6.1 Dynamic responses of the frequency deviations and tie- line power deviation in a two- area hydrothermal interconnected Power System considering a step load disturbance of 0.01p.u.MW in area 1 using ABC algorithm



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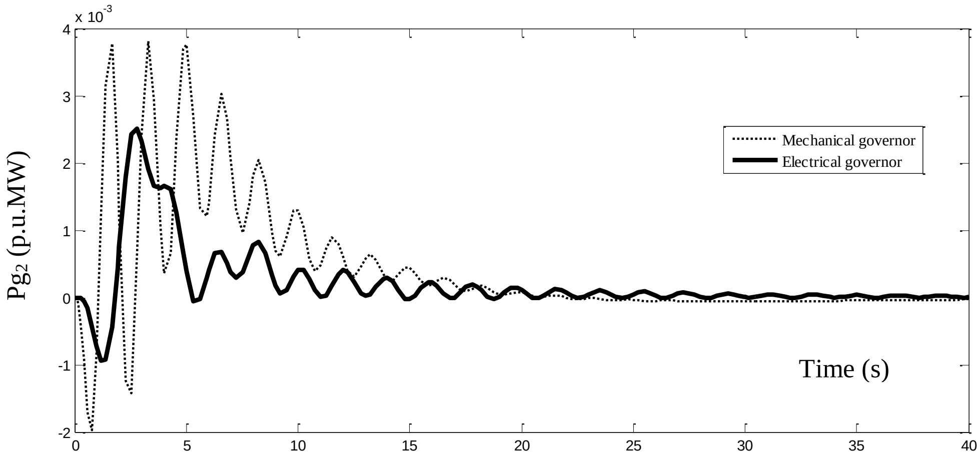

Figure 6.2 Dynamic responses of the required additional mechanical power generation in a two-area hydrothermal interconnected Power System considering step load disturbance of 0.01 p.u.MW in area 1 using ABC algorithm

VII.CONCLUSION

The Artificial Bee Colony algorithm was employed to achieve the optimal parameters of PI controllers for a two area hydrothermal interconnected power system. It has been found that the ABC algorithm is easy to implement without additional computational complexity as compared with conventional controller. The parameter- tuning in conventional method may be unsuitable for some operating conditions. Because the optimization for controller gains is a trial and error method and extremely time consuming when several parameters have to be optimized simultaneously and provides suboptimal result. The ABC algorithm, as an advantage has few controlled parameters. Since initializing a population "randomly" with a feasible region is sometimes cumbersome. Thus ABC algorithm does not depend on the initial population to be in a feasible region. Instead, its performance directs the population to the feasible region sufficiently. With this algorithm quite promising results can be obtained even though the ability to jump out the local optima.

Thus PI controllers are designed and implemented in a Two-Area Hydro Thermal Interconnected Power System. The closed loop system was simulated and comparative studies of the output responses of the system for various step-load conditions were obtained and presented. From the simulated results it is observed that the Hydro Turbines with Electric Governor ensures not only reliable operation but also provides a good margin of stability compared with that of a Hydro Turbine with Mechanical Governor.

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APPENDIX

A.1 Data for the Hydro-Thermal system investigated

$P_{r1} = P_{r2} = 2000$ MW; $H_1 = H_2 = 5$ sec; $K_{r1} = K_{r2} = 0.5$; $R_{11} = R_{12} = R_{22} = 2.4$ Hz/P.U. MW; $T_{r1} = T_{r2} = 10$ sec; $K_{p1} = K_{p2} = 120$ Hz/p.u. MW; $T_{p1} = T_{p2} = 20$sec; $T_{12} = 0.086$ p.u. MW/Radian; f = 60 Hz; $T_w = 1$ sec; $a_{12} = -1$; $T_1 = 48.7$ sec; $T_2 = 0.513$ sec; Tr = 5 sec $Tg_1 = T_{g2} = 0.08$ sec; $T_{t1} = T_{t2} = 0.3$ sec; $\Delta P_{d1} = 0.01$ p.u. MW; $\Delta P_{d1} = 0.04$ p.u. MW; $K_d = 4.0$; $K_i = 5.0$; $D_1 = D_2 = 8.33 \times 10^{-}3$ p.u MW/HZ.