IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

AN OPTIMAL ARTIFICIAL BEE COLONY BASED FREQUENCY CONTROL STRATEGY IN A TWO AREA INTERCONNECTED POWER SYSTEM

Thirunavukkarasu Jayaraman
Assistant Professor, Department of Electrical Engg., Annamalai University, India

ABSTRACT
This paper addresses the design and implementation of a proposed Artificial BEE colony based controller for the load frequency control of two area interconnected power System with AC tie line. The proposed Artificial BEE colony (ABC) controller has designed which concentrates on the deviation of frequency and derivative of frequency variation in a model power system. In addition, the proposed ABC algorithm is used to optimize the optimal integral gain setting by minimizing a quadratic performance index. For the demonstration, this control scheme has been applied to a two area interconnected non-re-heat thermal Power system. It is observed that the ABC based load frequency controller provides very good Transient and steady-state response when compared with Conventional controllers.

KEYWORDS: Load frequency control (LFC), Artificial BEE Colony (ABC), Two-area interconnected power Systems.

INRTODUCTION
Nowadays with the exponential enlargement in size and intricacy of large interconnected power systems. In this regard, the load frequency control (LFC) problem is becoming a very significant one. The basic arrangement of the LFC is to maintain preferred real power output of a generator unit and aid in controlling the frequency of interconnected power systems. Additional, LFC helps to keep the net interchange of power between interconnected areas at pre-specified standards which indirectly satisfies the limit of power system security problems [1, 21, and 22].

LFC plays an important role in power system operation and control for supplying sufficient and reliable electric power with good quality. It will maintain its control only during normal (small and slow) changes in load and frequency of the system. Due to external or internal disturbances, a large real power imbalance occurs throughout the system then an efficient extreme emergency control must be applied. Many control strategies have been already proposed to achieve improved performance of power transactions.

The main objectives of the load frequency control are for a given load perturbation, the following classic requirements are to be met [1,2,3].

- Zero steady-state error of Area Control Error (ACE) which ensures frequency deviation and tie-Line power deviation to zero.
- Ensure good transient response under disturbance
- To provide reliable operation and control of the system.
- Feedback controller should have a simple structure.
- The control law should match with system non-linearity’s
- The controller must be easy for implementation.

LFC is a very important role in power system operation and control for supplying sufficient and reliable electric power with good quality [3]. Many investigations in the area of LFC of isolated and interconnected power systems have been reported [4,5,6] and a number of control strategies have been proposed to achieve improved performance. The proportional plus integral (PI) control approach is successful in achieving zero steady-state error in the frequency of the system, but it exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillation [6]. Moreover, the transient settling time is relatively large. In the application of optimal control technique, the controller design is normally based on a fixed parameter model of the system derived by a linearization process [8]. The non- linear nature of the load frequency control problem make it difficult to ensure stability for all operating points when an integral or a PI control is used [6,7].based on the Simulation results of various controllers, Hence to overcome this crisis, a new and modern intelligent controller been suggested to solve LFC problems. In recent years, modern 'intelligent' methods such as Artificial Neural Network (ANN), Fuzzy Logic (FL) and Genetic Algorithm (GA) [22] have gained increasing interest for application in the LFC problem. In this work, A more recent and computational technique ABC algorithm [9-13] is found to be user-friendly and is adopted here for simultaneous optimization of several parameters for both primary control loops of the governor. These newer methods have promising results. Their notable features are mainly their applicability to a wider range of operating conditions and their model free nature.

MODELLING OF INTERCONNECTED POWER SYSTEMS

For the design of LFC, it is necessary to suitably model the power systems. This work describes the modeling aspects of a two-area thermal non-reheat transfer system with a feedback signal. A procedure for obtaining state equations from the model has already proposed in many literatures. In general, the transfer function method and state variable method are mostly preferred for the design of load frequently control [2, 14].

Transfer function model as State variable Model

The state variable model for the two-area thermal power system without reheat turbine (with feedback) is shown in figure 2.1. The model is valid for small perturbations around a nominal operating point for the time duration of interest in LFC studies. The revise on the excitation system and the effects of the voltage regulator are neglected to evolve a simple model. The feedback of integral of area control error (ACE) as speed changer command signals are scheduled frequency and tie line power.

Table 2.1 Set of equations representing the Transfer function model for two area interconnected system with feedback signal

Transfer function model representations	
$\Delta F_1(s) = \frac{K_{ps1}}{1 + ST_{Ps1}} [\Delta P_{g1}(s) - \Delta P_{d1}(s) - \Delta P_{tie1}(s)]$ $\Delta P_{g1}(s) = \frac{1}{1 + ST_{t1}} [\Delta X_{e1}(s)]$ $\Delta X_{e1}(s) = \frac{1}{1 + ST_{sg1}} [\Delta Pc1(s) - \frac{1}{R_1} \Delta F_1(s)]$ $\int ACE_1 = \int [\beta_1 \Delta F_1(s) + \Delta P_{tie1}(s)]$ $\Delta P_{tie1}(s) = \frac{2\pi T_{12}}{S} [\Delta F_1(s) - \Delta F_2(s)]$ $\Delta F_2(s) = \frac{K_{ps2}}{1 + ST_{Ps2}} [\Delta P_{g2}(s) - \Delta P_{d2}(s) - \Delta P_{tie2}(s)]$ $\Delta P_{g2}(s) = \frac{1}{1 + ST_{t2}} [\Delta X_{e2}(s)]$ $\Delta X_{e2}(s) = \frac{1}{1 + ST_{sg2}} [\Delta P_{c2}(s) - \frac{1}{R_2} \Delta F_2(s)]$ $\int ACE_2 = \int [\beta_1 \Delta F_2(s) + a_{12} \Delta P_{tie1}(s)]$	After taking the Laplace transform, $\dot{\Delta F_1} = \frac{1}{T_{Ps1}} [K_{ps1} \Delta P_{g1} - \Delta F_1 - K_{ps1} \Delta P_{d1} - K_{ps1} \Delta P_{tie1}]$ $\dot{\Delta P_{g1}} = \frac{1}{T_{t1}} [\Delta X_{e1} - \Delta P_{g1}]$ $\Delta X_{e1} = \frac{1}{T_{sg1}} [\Delta P_{c1} - \Delta X_{e1} - \frac{1}{R_1 T_{sg1}} \Delta F_1]$ $ACE_1 = \beta_1 \Delta F_1(s) + \Delta P_{tie1}(s)$ $\dot{\Delta P_{tie1}} = 2\pi T_{12} \Delta F_1 - 2\pi T_{12} \Delta F_2$ $\dot{\Delta F_2} = \frac{1}{T_{Ps2}} [K_{ps2} \Delta P_{g2} - \Delta F_2 - K_{ps1} \Delta P_{d2} - a_{12} K_{ps2} \Delta P_{tie2}]$ $\dot{\Delta P_{g2}} = \frac{1}{T_{t2}} [\Delta X_{e2} - \Delta P_{g2}]$ $\dot{\Delta X_{e2}} = \frac{1}{T_{sg2}} [\Delta P_{c2} - \Delta X_{e2} - \frac{1}{R_2 T_{sg2}} \Delta F_2]$ $ACE_2 = \beta_1 \Delta F_2(s) + a_{12} \Delta P_{tie1}(s)$

The above equations in Table 2.1 are put in the form, $X = Ax + Bu + \gamma d$ (2.1)

And output equation $Y = CX$ (2.2)

Where the system state vector [X], System control input is [u], System disturbance input vector is [d], and system matrix [A].By using the above set of equations in table 2.1, the state variable model for the proposed system has been achieved [2].

DESIGN OF CONVENTIONAL CONTROLLERS:

For efficient operation of a power system, some important conventional controllers have been considered in this work for the control of two area interconnected power systems which helps to compare and discuss its flaws and merits [14].

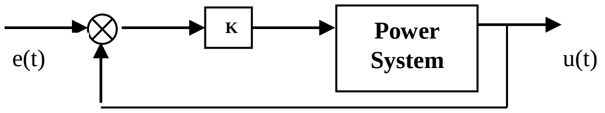


Figure 3.1 Block diagram of Controller with Power system

Proportional Controller

It produces an output signal u(t), which is proportional to the input signal e(t) as shown in fig 3.1.

i.e., u(t) = Kp e(t) (3.1)

Where Kp = proportional gain or constant.

Integral Controller

It produces an output signal u(t) which is proportional to the integral of the input signal e(t) as shown in fig 3.1.

i.e., $u(t) \propto \int e(t)$; $u(t) \propto \frac{K_i}{s} e(t)$ (3.2)

Where Ki = integral gain (or) constant.

Proportional Plus Integral Controller

It produces an output signal, u(t) consisting of two terms, one proportional to input signal e(t) and other proportional to the integral of the input signal e(t) as shown in fig 3.1.

$U(t) \propto [e(t) + \int e(t)\, dt]$; $U(t) = Kp\, e(t) + Ki \int e(t)\, dt$

Where Kp = proportional gain and Ki = integral gain

The output of the PI controller in the load frequency control is given by the expression

$Kp\, ACEi + Ki \int ACEi\, it$ (3.3)

DESIGN OF ARTIFICIAL BEE COLONY (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[18,19,20].

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 α=1 then the solutions are uniformly distributed, whereas with α = 0.6 we may approximate that 40% of the solutions are not evenly distributed. Note that with α=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-α 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-α-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.[18-21]

IMPLEMETATION OF ABC ALGORITHM FOR LFC PROBLEM

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

$$[X_i=1, 2, 3 \ldots D] \quad (5.1)$$

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

$$f_i * t_i = 1/(1+obj.fun._i\, J) \quad (5.2)$$

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

$$V_{ij} = x_{ij} + \varphi_{ij}\,(x_{ij} - x_{kj}) \quad (5.3)$$

Where $k = (1,2,3 \ldots D)$ and $j = (1,2,3 \ldots N)$ 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

$$Pi = \frac{f_i * t_i}{\sum_{n=1}^{N} f_i * t_i} \quad (5.4)$$

ISSN: 2277-9655
Impact Factor: 3.785

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.

$$X_i^j=X^j_{min}+rand(0,1)*(X^j_{max}-X^j_{min}) \quad (5.5)$$

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.[18-20].

SIMULATION RESULTS AND DISCUSSIONS

The proposed ABC algorithm based controller and conventional PI controller are implemented for interconnected power systems and system; responses are obtained for a step load change of 0.01 p. u MW in the system in Fig 6.1. For comparative analysis, the system frequency deviation responses of two controllers are implemented and their responses are plotted as a function of time‘t'.

From the response, it's evident that the proposed controller performance at transient state and at steady state is better than the conventional Integral Controller. The ABC algorithm based controller has a better dynamic response, quick in operation, reduced error magnitude and minimized frequency transients.

Tuning of interconnected power system with conventional controllers

Determination and tuning of the optimal value of gain (K_i) with P, I and Proportional Plus Integral Controller

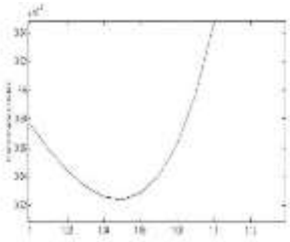
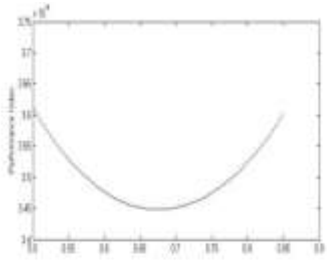
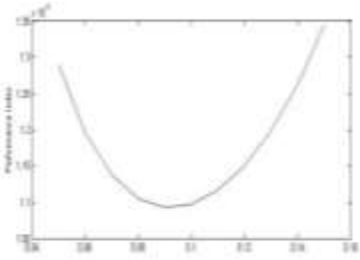
The proportional controller improves steady-state tracking accuracy, disturbance signal rejection and relative stability. The proportional controller is not alone used because it produces constant steady state error. Here we assume that Kp1 = Kp2 = Kp. Since the two areas are identical and the cost curve is shown in Table 5.1. The lowest point on U-curve is considered as an optimum value.

As like a P controller, Here again, Ki1 = Ki2 = Ki has been assumed for the integral controller; from the cost curve drawn between Ki and performance index j, optimum controller gain can be obtained for the integral controller. The lowest point on the U-shaped curve is taken as the optimum value of gain Ki as shown in the cost curve in Table 6.1.

The introduction of PI controller increases the order and type number of the system by 1. The optimum value of Kp is kept constant and performance index j can be obtained for various values of controller gain Ki. the optimum value of Ki can be determined as shown in the cost curve given in table 6.1.

ISSN: 2277-9655
Impact Factor: 3.785

Table 6.1 Simulation results represent the Cost Curve for P, I and Proportional Plus Integral Controller

P Controller	I Controller	PI Controller
		

The conventional PI controller is implemented for interconnected power systems and system responses are obtained for a step load change of 0.01 p. u MW in the system.

Tuning of interconnected power system with proposed abc controller

The simulation results with ABC based tuning are shown in Figures 6.2-6.4 and its comparative results are shown in table 6.2.

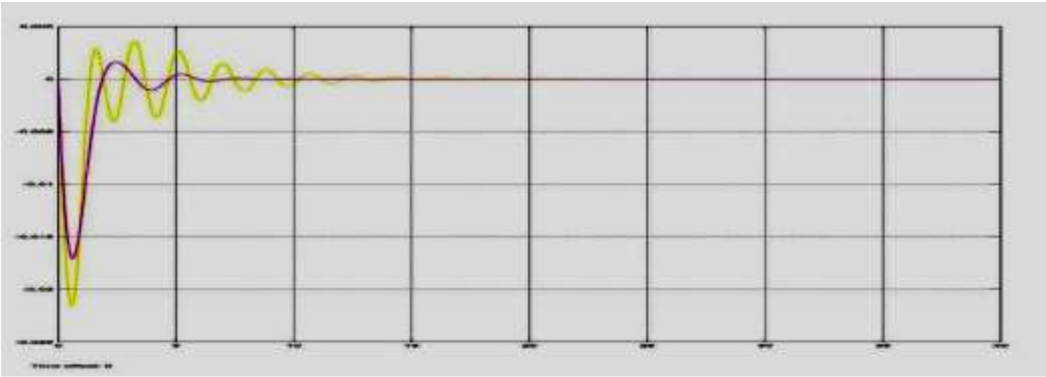


Fig.6.2 Frequency deviation in area 1 of a two area Thermal Power system for a step load disturbance

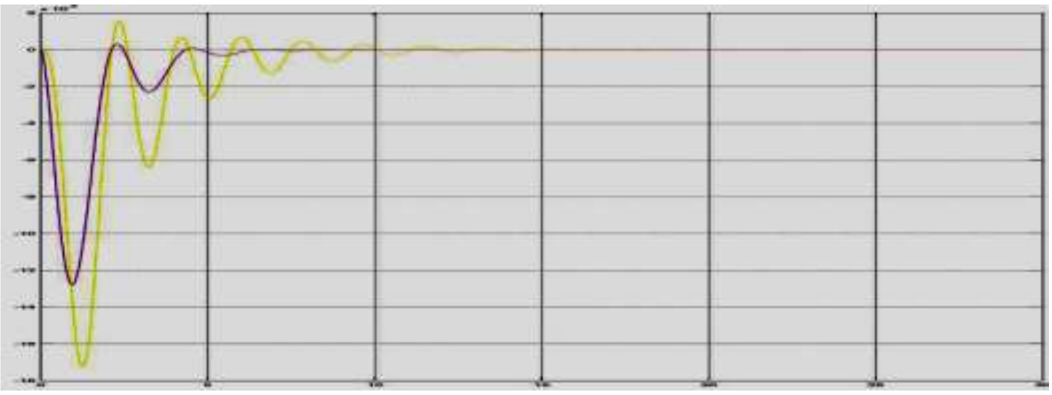


Fig.6.3 Frequency deviation in area 2 of a two area Thermal Power system for a step load disturbance

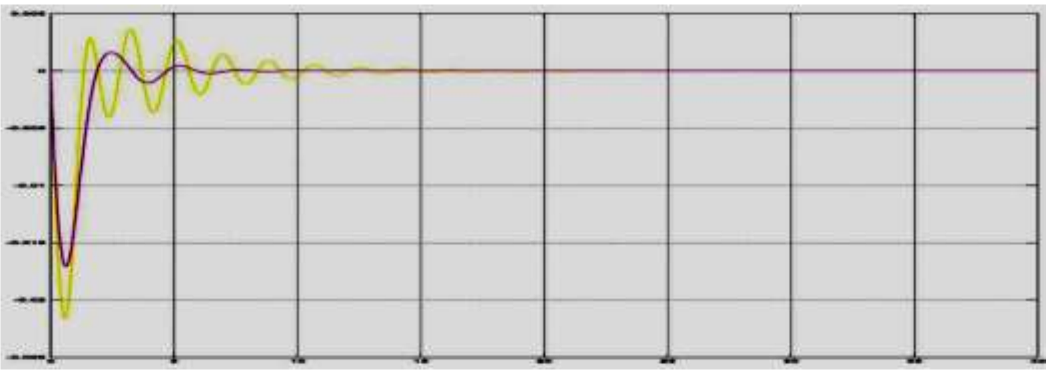


Fig.6.4 Frequency deviation in the tie line of a two area Thermal Power system for a step load disturbance

It is observed that the proposed controller has good damping and reduced transient error and any further improvement in one of the design objectives will lead to degradation in another objective. The area frequency deviations are measured in Hz, tie-line power deviations are measured in p. u MW and settling time in seconds. Table 6.2 presents the comparison of the system performances with conventional and ABC based controllers.

Table 6.2. Comparison of the system performances

Two area thermal Interconnected power system	Setting time (τ_s) in sec			Peak over/under shoot		
	ΔF_1	ΔF_2	ΔP_{time}	ΔF_1 in Hz	ΔF_2 in Hz	ΔP_{time} in
Using Conventional controller	**19**	**18**	**15**	**0.0036 / -0.0216**	**0.005 / -0.017**	**0.0008 / -0.0058**
Using ABC algorithm based controller	**7**	**6**	**5.5**	**0.0016 / -0.017**	**0.0003 / -0.0128**	**0.0001 / -0.0041**

Data for modeled Two Area Interconnected Thermal Power System

The data for the two area interconnected thermal power system are $T_{g1} = T_{g2=}$ 0.08sec;$T_{t1} = T_{t2=}$ 0.3sec; T_{p1} = 20sec;$R_1 = R_{2=}$ 2.4Hz/p.u. M.W;$2\pi T_{12}$ = 0.545sec ;Kp_1 = $Kp2_=$ 120Hz/p.u. MW;A_{12} = -1

ISSN: 2277-9655
Impact Factor: 3.785

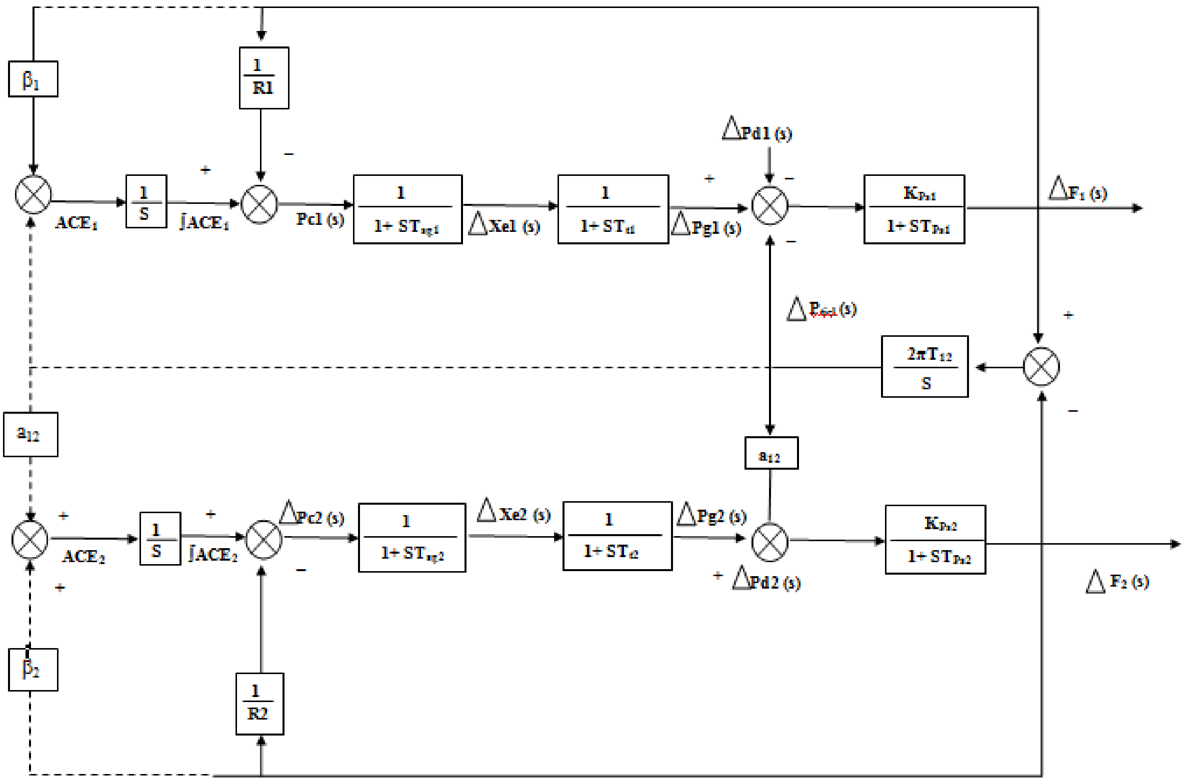


Fig 6.1: Modeling of two area non-reheat thermal power system (with feedback control)

CONCLUSION

An ABC Algorithm based controller is designed for two area thermal power system without reheat. A comparison has been made between the response of the proposed controller and conventional Integral controller. The simulation results show that the proposed ABC algorithm based controller shows good transient and steady state performance. The proposed controller can be designed for two area interconnected thermal power system. In this paperwork, the value of K_1 is chosen as 0.1. The effect of varying K_1 can be carried out and from that, the optimum K_1 value can be found. From the results, it's observed that

- Steady-state frequency error is zero.
- Stability of the system is assured with high-quality transient response distinguished by good steady state and dynamic state characteristics.
- The proposed scheme is simple and effective but also easy to implement for operation and control.

ACKNOWLEDGEMENTS

The author wishes to thank Dr.G.Mohan, Professor, EEE, and Annamalai University for his valuable guidance, and the authorities of Annamalai University, Annamalai Nagar, Tamilnadu, India For the facilities provided to prepare this paper.

REFERENCES

[1] H.Shayeghi, H.A.Shayanfar and A.Jalili, "Load control strategies: A state-of-the-art survey for the researcher", Energy Conversion and Management, Vol. 50, No.2, pp. 344-353, 2009.
[2] Elgerd O.I., "Electrical energy system theory – An introduction", (Mc Graw – Hill, New Delhi, 1983.
[3] O. I. Elgerd and C. Fosha, 'Optimum megawatt frequency control of multi-area electric energy systems,' IEEE Trans. Power App. Syst., vol. PAS-89, no. 4, pp. 556–563, Apr. 1970.
[4] N. Cohn, 'Some aspects of tie-line bias control on interconnected power systems,' Amer. Inst. Elect. Eng. Trans., Vol. 75, pp. 1415-1436, Feb. 1957.
[5] T. Kennedy, S.M. Hoyt, and C. F . Abell, 'Variable, non-linear tie line frequency bias for interconnected systems control ', IEEE Trans. On Power Systems, Vol. 3, No. 3, August 1988, pp. 1244-1253.

[6] K.Ramar and S.Velusami, “Design of Decentralized Load-Frequency Controllers using pole placement Technique”, *Electric Machines and Power Systems*, Vol.16, No.3, pp.193-207, 1989.

[7] D. Das, J. Nanda, M. L. Kothari, and D. P. Kothari, ‘Automatic generation control of Hydrothermal system with new area control error considering generation rate constraint,’ Elect. Mach. Power Syst., vol. 18, no. 6, pp. 461– 471, Nov./Dec. 1990.

[8] R. K. Cavin, M. C. Budge Jr., P. Rosmunsen, ‘An Optimal Linear System Approach to Load Frequency Control’, IEEE Trans. On Power Apparatus and System, PAS-90, Nov./Dec. 1971, pp. 2472-2482.

[9] J. Talaq and F. Al-Basri, “Adaptive fuzzy gain scheduling for load frequency control,” IEEE Trans. Power Syst., vol. 14, no. 1, pp. 145–150, Feb. 1999.

[10] M. F. Hossain, T. Takahashi, M. G. Rabbani, M. R. I. Sheikh, and M. Anower, “Fuzzy- proportional integral controller for an AGC in a single area power system,” in Proc. 4th Int. Conf. Electrical and Computer Engineering (ICECE), Dhaka, Bangladesh, Dec. 2006, pp. 120–123.

[11] B.Venkata Prasad, Dr. S.V Jayaram Kumar (2008) Load frequency control for a two area interconnected power system using robust genetic algorithm controller.

[12] K. De Jong “Adaptive system design: A genetic approach”, IEEE Trans. Systems, Man and Cybernetics, SMC – 10, No.9, 1980,PP. 1566-1574.

[13] J.J Grefenstette, “Optimization of control parameters for genetic algorithms”, IEEE Trans. Systems, Man and Cybernetics, SMC –16, No.1, 1986, PP 122 – 128

[14] H.D.Mathur and S.Ghosh, “A comprehensive analysis of intelligent controllers for load frequency control”, Proceedings of the IEEE Power India Conference, pp.853-857, New Delhi, India, 2006.

[15] Ibraheem, P. Kumar and D.P. Kothari, "Recent philosophies of automatic generation control power systems" IEEE Transactions on Power Systems, Vol. 20, No. 1, pp. 346-357, 2005.

[16] M.L. Kothari and J. Nanda, “Application of optimal control strategy to automatic generation control of a hydrothermal system”, IEE Proceedings, Vol. 135, No. 4, pp.268-274, 1988.

[17] S. K. Sinha, R. N. Patel and R. Prasad, “Application of GA and PSO Tuned Fuzzy Controller for AGC of Three Area Thermal-Thermal-Hydro Power System”, International Journal of Computer Theory and Engineering, Vol. 2, No. 2, pp. 1793-8201, 2010

[18] Dervis Karaboga and Bahriye Akay, “A comparative study of Artificial Bee Colony algorithm”, Applied Mathematics and Computation, Vol. 214, pp.108–132, 2009.

[19] D.Karaboga and B.Basturk, "A Powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm", Journal of Global Optimization, Vol. 37, pp. 459-471, 2007

[20] S.N.Omkar, J.Senthilnath, Rahul Khandelwal, G.Narayana Naik and S.Gopalakrishnan, “Artificial Bee Colony (ABC) for multi-objective design optimization of composite structures”, Applied Soft Computing, Vol. 11, pp.489–499, 2011

[21] R.Thamizhselvan and S.Ganapathy, “Application of Support Vector Machine to Static Security Assessment in Power systems”, International Journal of Applied Engineering Research, Vol.10, pp.38362-38367, 2015.

[22] Thirunavukkarasu Jayaraman, “Load Frequency Control for a two Area Interconnected Power System Using Genetic Algorithm Controller”, International Journal of Engineering Sciences & Research Technology, Vol.4, pp.805-811, 2015.