ISSN No:-2456-2165

Ant Lion Optimization Based Controller Tuning for Automatic Generation Control of Multiarea Interconnected Thermal System

Shweta Yadav
M. E. Scholar, Electrical Engineering
SSTC, SSGI
Bhilai, India

Simardeep Kaur
Assistant Professor.: Electrical Engineering
SSTC, SSGI
Bhilai, India

Abstract:- An AGC maintains the frequency of the system by balancing the active power generation to the load demand. The frequency of the system is dependent on the active power supply of the system according to the load changes. A conventional PID controller is generally employed to achieve AGC. However, proper tuning of controller parameter is required in order to achieve satisfactory controller performance. So, the proper choice of design objectives and the tuning method play very important part in AGC. In this work, a PID controller with derivative term is tuned to control the frequency and tie-line power deviations of a two-area non-reheat thermal system using Ant Lion optimization (ALO) algorithm. ALO is an efficient optimization algorithm which is based on the behavior of ant lions. For optimization purpose, the fitness function is formulated by considering settling times of deviations in frequency and tie-line power deviations and the integral errors. Four different cases of load perturbation conditions in both areas are considered. A comparative assessment of the proposed controller is carried out with PSO based controller and the obtained results are tabulated. Time-domain simulations are carried out to further establish the superior performance of the proposed controller.

***Keywords**:- Automatic generation control; Ant lion optimization; Particle swarm optimization; PID controller; multi-area interconnected system.*

I. INTRODUCTION

The main objective of electric utilities is to supply of reliable power with acceptable quality of power, and the main challenge lies in maintaining the equilibrium between the generation and the supply (1). Because if there is no equilibrium between generation and the supply the whole power system may collapse due the mismatch of frequency between the interconnected system. Automatic Generation Control (AGC) involves the real and the reactive power control in it, reactive power control involves the Automatic Voltage Regulation (AVR) and the real power control involves the load-frequency control (LFC) or AGC. Multi-area power system is generally an interconnected system and in such interconnected systems maintaining the change in frequencies in permissible values in the interconnected areas due to the change in the load demand is done by the AGC system. AGC does this by changing the set-position of the generators for the corresponding change in the load and this change in the demand will go as the error input to the controller in the respective system called as the Area Control Error (ACE). Every time the controller takes the corresponding control action and maintains the frequency and the tie-line power in equilibrium such that the ACE will become zero and hence, the change in the frequencies and the tie-line power becomes zero and the system will be stable (2).

II. PROBLEM FORMULATION

As we know that the effectiveness of the AGC depends not only on the controller, it also depends on the objective function chosen in the problem statement because if we chose a wrong objective function, even if the optimization technique is good it cannot deliver good results. We can choose the change in the frequencies in the interconnected areas i.e., Δf_1 (change in the frequency in area-1) and Δf_2 (change in the frequency in area-2) and the ΔP_{tie} (change in the Tie-line Power change), if it is a two area system, as the objectives to be minimized. These changes (errors) can be converted into numerical values by converting these error signals into the Integral of Squared Error (ISE), Integral of Time multiplied Absolute Error (ITAE), Integral of Absolute Error (IAE), Integral Square Absolute Error (ISAE) etc., and depending on the application and interest we can choose any of these error determination techniques, Here in our application we have chosen the ITAE as the error criteria because it gives the clear picture of the variation of the error output with respect to time and the integral action of ITAE ensures that the integral of the frequency and tie-lines errors are minimized and time multiplier makes certain that the settling times in these deviations are minimized .

As the formulation of the objective function should be selected very carefully, in our work we mainly concentrated on decreasing the settling times of Δf_1, Δf_2 , ΔP_{tie} of line and also the ITAE of these changes due to changes in the load. Here, we should simultaneously achieve two objectives. Hence, we can formulate our problem as the multi-objective problem. This multiple objective problem can be formulated into a single objective problem, by giving certain weights to each individual objective to be met. In this work, half of the weight is given to the sum of settling times of the frequencies and tie-line power deviations and other half of the weight is given to ITAE error of the deviations of the frequencies and tie-line power deviations.

ISSN No:-2456-2165

A. Objective function

The objectives considered in our work are,

- Minimization of the settling times of the Δf_1, Δf_2, and ΔP_{Tie} i.e., the settling times of the change in frequencies in the two areas, tie-line power changes and the area control errors of both the controllers in the both areas.

$$J_1 = (\Delta f_1^{ST} + \Delta f_2^{ST} + \Delta P_{Tie}^{ST}) \quad (1)$$

Here 'ST' denote the settling time of the corresponding parameter.

- Minimization of the integral of time multiplies absolute error of the Δf_1, Δf_2 and ΔP_{Tie}.

$$J_2 = \int_0^{t_{sim}} (|\Delta f_1| + |\Delta f_2| + |\Delta P_{Tie}|)t.dt \quad (2)$$

Above mentioned two objectives are combined to form single objective function with equal weightage assigned to them. And it will be in the form,

$$J = W_1 \times J_1 + W_2 \times J_2 \quad (3)$$

Where $W_1 = W_2 = 0.5$

The constraints to the problem are the minimum and maximum value of the controller coefficients defined as

$$\begin{aligned} K_p^{\min} &\le K_p \le K_p^{\max} \\ K_i^{\min} &\le K_i \le K_i^{\max} \\ K_d^{\min} &\le K_d \le K_d^{\max} \\ n^{\min} &\le n \le n^{\max} \end{aligned} \quad (4)$$

III. PROPOSED WORK

A two-equal area interconnected system with two non-reheat thermal plant with individual area rating of 2000MW with a nominal load of 1000MW in each area is shown in *Fig.1*

The two area system shown in the fig.1 consists of a governor, turbine, and a generator each, and each area has three Inputs and two outputs, error output from the controller (denoted by $\Delta u_1, \Delta u_2$ or $\Delta P_{ref1}, \Delta P_{ref2}$), change in the load (denoted by $\Delta P_{D1}, \Delta P_{D2}$), change in tie-line power (denoted by ΔP_{Tie}) are the inputs and the change in the frequencies in the two areas (denoted by $\Delta F_1, \Delta F_2$) and the area control error (denoted by ACE_1 and ACE_2) are the outputs of the system. The model used in our work has a wide range of usage in the literature for the study of the two-area system.

The input to the controller ACE for the two areas are given as

$$ACE_1 = B_1 \cdot \Delta f_1 + \Delta P_{tie} \quad (5)$$

$$ACE_2 = B_2 \cdot \Delta f_2 + a_{12} \cdot \Delta P_{tie} \quad (6)$$

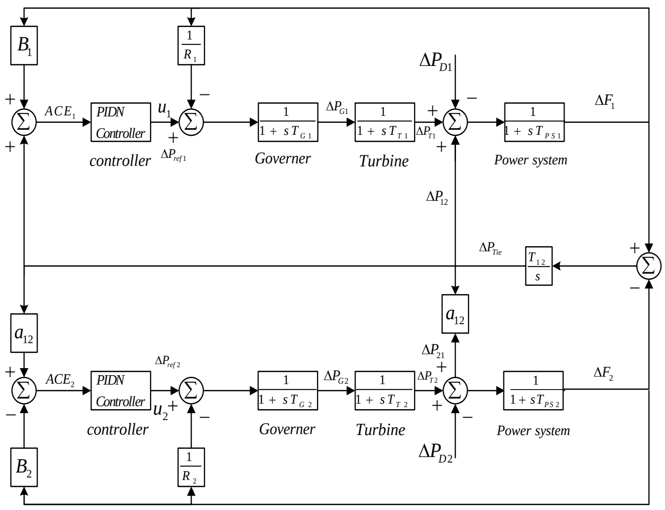

Fig 1:- Block diagram for a two-area non-reheat thermal system.

A. Modelling of the Load Frequency Control Block Diagram

The complete Block diagram of the load frequency control of an isolated power station is shown in the Fig 2.

Now the deviation at the output for corresponding change in the load $-\Delta P_L$ is shown in the Fig.2, the open loop transfer function of the figure is given below.

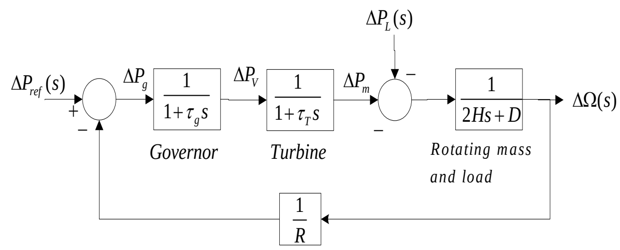

Fig 2:- Block diagram of the load frequency control of an isolated power station.

$$KG(s)H(s) = \frac{1}{R}\frac{1}{(2HS + D)(1 + \tau_g s)(1 + \tau_T s)} \quad (7)$$

The closed loop transfer function relating the change in the frequency to the change in the load is,

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2HS+D)(1+\tau_g s)(1+\tau_T s)+1/R} = T(s) \qquad (8)$$

Or

$$\Delta\Omega(s) = -\Delta P_L(s)T(s) \qquad (9)$$

As we know the load changes in the input, are generally step changes. Therefore, $\Delta P_L(s) = \Delta P_L / s$, by final value theorem the steady state change in the frequency is given by

$$\Delta\omega_{ss} = \lim_{s\to 0} s\Delta\Omega(s) = (-\Delta P_L)\frac{1}{D+1/R} \qquad (10)$$

From the above equation if $D=0$ i.e. if the frequency sensitive load is zero the steady state frequency deviation is determined by the governor speed regulation as

$$\Delta\omega_{ss} = (-\Delta P_L)R \qquad (11)$$

If 'n' number of generators of speed regulations $R_1, R_2, ..., R_n$ are connected in the system the steady state change in the frequency is,

$$\Delta\omega_{ss} = (-\Delta P_L)\frac{1}{D+1/R_1+1/R_2+...+1/R_n} \qquad (12)$$

IV. OPTIMIZATION METHODOLOGY

The selection of the optimization technique plays a vital role in proper tuning of control parameters obtained for control action and hence, it will affect the control mechanism. So, we should select the proper algorithm such that they will result in obtaining the optimal point in our search space rather than trapping in a local optimal point and it will be even better if they converge to the optimal point in less iteration and less time. In this work, particle swarm algorithm (PSO) and antlion optimizer (ALO) is used to tune the controller parameters for AGC. In the following sections, brief discussions of all the algorithms are outlined.

A. Particle Swarm Optimization

This template was designed for two affiliations. PSO algorithm is a swam-intelligence based, approximate, nondeterministic Optimization technique which was first described by James Kennedy and Russell Eberhart in 1995 by the observation of the swarming habits of animals such as birds or fish (24).

The PSO algorithm maintains multiple potential solutions at one time

- During each iteration of the algorithm, each solution is evaluated by an objective function to determine its fitness.
- Each solution is represented by a particle in the fitness landscape (search space)
- The particles "fly" or "swarm" through the search space to find the maximum value returned by the objective function.

The PSO algorithm mainly consists of just three steps

a) Evaluate fitness of each particle
b) Update individual and global bests
c) Update velocity and position of each particle

These steps are repeated until some stopping condition is met

B. Ant Lion Optimization

The ALO algorithm is proposed by Mrijalili *et al.* in 2015 [9]. It imitates the behavior of antlions and ants in the trap. The behavior is mathematically modelled on the basis of random walk of ants in the entire search space and hunting of the ants by the antlions by making traps to get fitter. The ants randomly moves in the search space in order to locate food, therefore, their walk is modelled as a random walk defined as: (3.20)

$$X(r) = \begin{bmatrix} 0, cumsum(2s(r_1)-1), \\ cumsum(2s(r_1)-1), \\ L cumsum(2s(r_G)-1) \end{bmatrix} \qquad (13)$$

(3.21)

where, $cumsum$ is the cumulative sum, G is the maximum number of generation, r is the current generation, and $s(r)$ is a stochastic function calculated as follows:

$$s(r) = \begin{cases} 1 & \text{if } rand(\ ) > 0.5 \\ 0 & \text{otherwise} \end{cases} \qquad (14)$$

where, r is the current iteration and $rand(\ )$ is any random number in the interval [0,1].

The random initializations of ants and antlions within the search space is carried out. The positions of ants and antlions are stored in following matrices:

$$P_A = \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,D} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,D} \\ \vdots & \vdots & \cdots & \vdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,D} \end{bmatrix} \qquad (15)$$

and

$$Q_{AL} = \begin{bmatrix} Q_{1,1} & Q_{1,2} & \cdots & Q_{1,D} \\ Q_{2,1} & Q_{2,2} & \cdots & Q_{2,D} \\ \vdots & \vdots & \cdots & \vdots \\ Q_{N,1} & Q_{N,2} & \cdots & Q_{N,D} \end{bmatrix} \qquad (16)$$

ISSN No:-2456-2165

where, P_A and Q_{AL} is the population of ants and antlions, respectively. N is the population size and D is the dimension of the problem.

V. SIMULATION RESULTS AND DISCUSSION

In this work, controller tuning for automatic generation control (AGC) of two-area interconnected thermal power system is carried out. The parameters of the studied system are listed in Appendix A. A classical PID controller with derivative filter is used. As it is already discussed any change of load in one area affects other area too as both areas are connected with each through tie-line. Ant lion optimization (ALO) algorithm is used to tune the controller parameters. To verify the controller performance, various sets of step load disturbances are created in both areas. The proposed controller is compared to particle swarm optimization (PSO) based controller to validate its superiority. The time-domain simulations are carried out to further validate the superior performance of the proposed controller. The social and cognitive parameter for PSO are taken as 2 and 2, respectively while inertia weight is taken as 0.9. A total of 50 iterations and 10 population size is considered for both ALO and PSO algorithm. All simulations are carried out in MATLAB environment. The boundary conditions of the controller parameters used in this work are defined as follows:

$$\begin{aligned} 0 \le K_p \le 2 \\ 0 \le K_i \le 2 \\ 0 \le K_d \le 2 \\ 100 \le n \le 500 \end{aligned} \quad (17)$$

Following section discusses various case scenarios of the simulations.

C. Test Cases

The case scenarios taken in this work are step load changes in both areas. First set of cases consists of load increase in one area with no load changes in other areas whereas second set of cases consists of load decrease in one area with no load changes in other area. The tabulated results present the simulation results of the studied system. In all tabulated results, the minimum value obtained for objective function and the tuned numerical values of the controller parameters (i.e. K_p, K_i, K_d and n) along with settling times of frequency and tie-line power deviations and minimum ITAE are presented

Case 1: A step load decrease of 0.05 pu in Area 1 at $t = 0$ sec with no load change in Area 2

Parameters		PSO	ALO
Fitness Function Value	J	1.2858	1.2126
Controller parameters	K_p	1.5219	1.9468
	K_i	1.6694	1.9174
	K_d	1.1787	1.5058
	n	307.3381	485.9986
Settling times (sec)	Δf_1	4.5447	4.4235
	Δf_2	4.5448	4.4533
	ΔP_{tie}	4.6815	4.6159
ITAE		0.1265	0.1143

Table 1. Case 1:- Copmare Betweent Pso And Alo

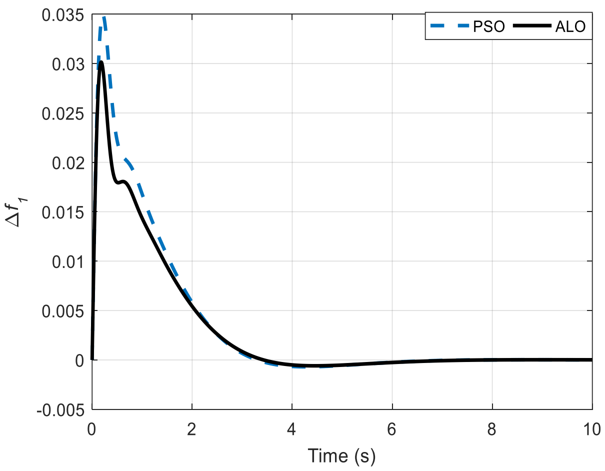

Fig 3:- (A) Frequency deviation of Area 1 for Case 1

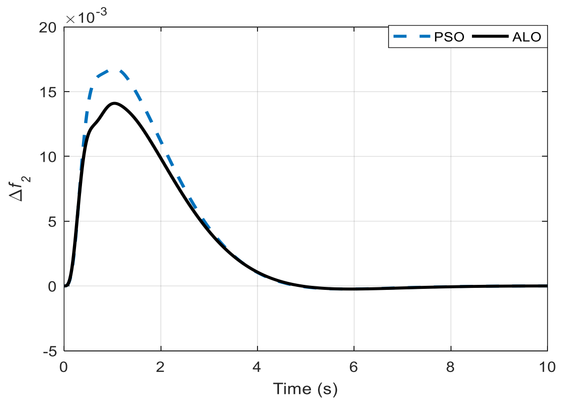

Fig 3:- (B) Frequency deviation of Area 2 for Case 1

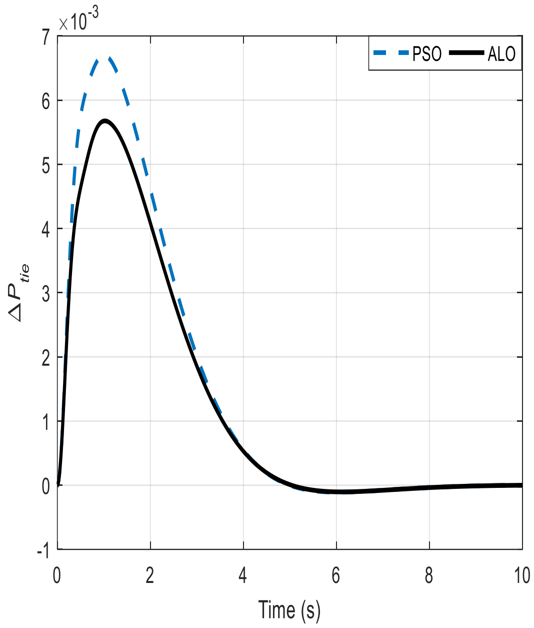

Fig 3:- (C) Tie line power deviation for Case 1

The figures suggest that a load change in area 1 is affecting the frequency of area 2 and tie-line power which is as per our expectations. From the figure, it can easily be identified that proposed controller is better performer in terms of settling times than PSO based controller. From the above discussion, it can be concluded that ALO based controllers are outperforming PSO based controllers in solving AGC problem.

Case 2: A step load decrease of 0.05 pu in Area 2 at $t = 0$ *sec with no load change in Area 1*

Parameter		PSO	ALO
Fitness Function Value	J	1.3349	1.2452
Controller Parameters	K_p	1.3433	0.6458
	K_i	1.2177	1.4416
	K_d	1.6443	0.3489
	n	414.4374	282.7629
Settling times (sec)	Δf_1	5.7832	3.0856
	Δf_2	6.9575	3.0856
	ΔP_{tie}	5.9431	3.6094
ITAE		0.2459	0.1039

Table 2. Case 1:- Copmare Betweent Pso And Alo

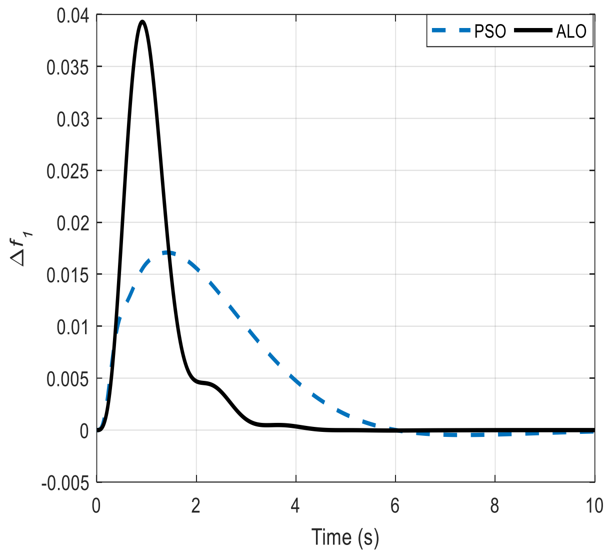

Fig 4:- (A) Frequency deviation of Area 1 for Case 2

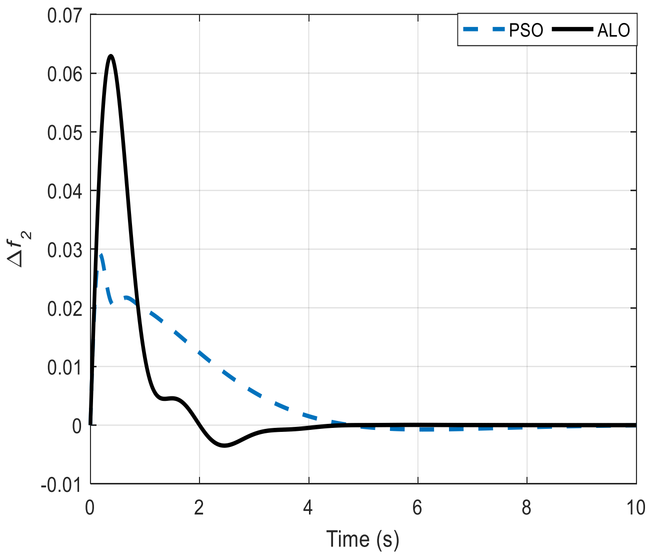

Fig 4:- (B) Frequency deviation of Area 2 for Case 2

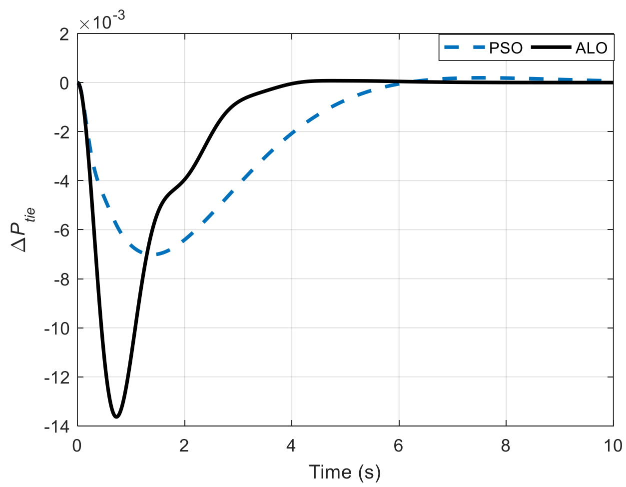

Fig 4:- (C) Tie line power deviation for Case 2

The figures suggest that a load change in area 1 is affecting the frequency of area 2 and tie-line power which is as per our expectations. From the figure, it can easily be identified that proposed controller is better performer in terms of settling times than PSO based controller. From the above discussion, it can be concluded that ALO based controllers are outperforming PSO based controllers in solving AGC problem.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The conclusion derived from this work is outlined below.

- In this work, an equal two-area interconnected power system widely used in the literature is taken for the simulation purpose for automatic generation control (AGC).
- A conventional PID controller with derivative filter is used to be tuned.
- A single objective function is formulated with equal weightage given to the settling times of the frequency and tie-line power deviations and ITAE of frequency and tie-line power deviations.
- Ant lion optimization (ALO) algorithm is applied to tune the controller parameters for AGC.
- Four different cases of step load disturbances are simulated to test the performance of the proposed controller.
- The performance of the proposed controller is established by comparing it with particle swarm optimization (PSO) based controller.
- The simulation results are tabulated and the results suggest that ALO based controller is outperforming PSO based controller for all cases.
- To further validate the superiority of the proposed controller, time-domain simulations of frequency deviations of each areas and tie-line power deviations for all cases are illustrated. From the simulation, the superior performance of ALO based controller is established.

B. Scope for future work

There is further scope of work which is outlined below.

- The work can be extended to a large area interconnected system such as three area and four area interconnected power system with incorporation of non-linearity in the system like governor dead-band and multiple type of fuel options.
- Interconnected power system consisting of renewable energy penetration can be utilized for AGC.
- AGC in deregulated environment can be considered.
- Modern controllers such as the Fractional Order Proportional Integral Derivative (FOPID) controllers in the control action can be used in place of PIDN controller. Modern algorithms for the optimization of the controller parameters can be utilized.

REFERENCES

[1]. H Sadat, Power System Analysis. WBC/McGraw- Hill, 1999.

[2]. P. Kundur, N. J. Balu, and M. G Lauby, Power System Stability and Control. McGraw-Hill New York, 1994.

[3]. K. Padiyar, Power System Dynamics. BS publications, 2008.

[4]. J. Nanda, S. Mishra, and L.C. Saikia, "Maiden application of bacterial foraging-based optimization technique in multiarea automatic generation control", IEEE Transactions on Power Systems, vol. 24, no. 2, pp.602-609, 2009.

[5]. H. Gozde and M. C. Taplamacioglu , "Automatic Generation Control Application with Craziness based Particle Swarm Optimization in a Thermal Power System", International Journal of Electrical Power & Energy Systems, vol. 33, no. 1, pp. 8-16, 2011.

[6]. L. C. Saikia and S. K Sahu, "Automatic Generation Control of a combined cycle gas turbine plant with classical controller using firefly algorithm", International Journal of Electrical Power and Energy System, vol. 53, pp. 27-33, 2013.

[7]. A. Abdelaziz and E. Ali, "Cuckoo Search Algorithm Based Load Frequency Controller Design for Non-Linear Interconnected Power System", International Journal of Electrical Power and Energy System, vol. 73, pp. 632-643, 2015.

[8]. J.J Grefenstette, "Optimization of Control Parameters for Genetic Algorithms", IEEE transactions on systems, man, and cybernetics, vol 16, no. 1, pp. 122-128, 1986.

[9]. S. Mirjalili, "The ant lion optimizer", Advances in Engineering Software, vol 83, pp. 80-98, 2015.

[10]. G. Hou, L. Qin, X. Zheng, and J. Zhang, "Design of PSO-based fuzzy gain scheduling PI controller for four-area interconnected AGC system after deregulation", in The 2011International Conference on Advanced Mechatronic Systems, 2011, pp. 72-76 IEEE.

[11]. M. Tavakoli, A. Khodabakhshian, and R. Hooshmand, "BF-NM optimization algorithm based LFC for interconnected power system", in Electrical Power and Energy Conference (EPEC), 2012 IEEE,2012, pp. 261-266 IEEE.

[12]. S. Biswas and P. Bera, "GA Application to Optimization of AGC in Two-Area Power System Using Battery Energy Storage", in communications, Devices and Intelligent Systems (CODIS), 2012 International conference on, 2012, pp 341-344 IEEE.

[13]. N. Kumari and A. Jha, "Partical Swarm Optimization and Gradient Descent Methods for Optimization of PI Controller for AGC of multiarea thermal-wind-hydro power plant", in Computer Modelling and Simulation (UKSim), 2013 UKSim 15th International Conference on, 2013, pp. 536-541 IEEE.

[14]. K.ChandraSekhar and K. Vaisakh, "An intelligent technique based on code algorithm for determination of optimum gain values of PID controller in an AGC system", in Intelligent systems and signal processing (ISSP), 2013 International Conference on, 2013, pp. 34-41 IEEE.

[15]. S. Panda and N. K. Yegireddy, "Automatic generation control of multi-area power system using multi-objective non-dominated sorting genetic algorithm-II", International Journal of Electrical Power & Energy Systems vol.53, pp. 54-63, 2013.

[16]. N. E.Y. Kouba, M. Menaa, M.Hasni, and M. Boudour, "A novel robust automatic generation control in interconnected multi-area power system based on bat inspired algorithm", in control, Engineering & Information Technology (CEIT), 2015 3rd International Conference on, 2015, pp.1-6 IEEE.

[17]. T. K. Pati and B. K. Sahu, "Application of hybrid DEPSO algorithm to study the performance of different PID controller structures for automatic generation control of a two-area multi-units interconnected power system", in Circuits, Power and Computing Technologies (ICCPCT), 2014 International Conference on, 2014, pp. 787-791 IEEE.

[18]. B. Tyagi and S. Srivastava, "A Decentralized Automatic Generation Control Scheme for Competitive Electricity Markets", IEEE Transactions on Power Systems, vol. 21, no. 1, pp. 312 -320, 2006.

[19]. R. Patel, S. Sinha, and R. Prasad, "Design of a robust controller for AGC with combined intelligence techniques", International Journal of Electrical power and Energy Systems Engineering, vol. 1, no. 2, pp. 95-101, 2008.

[20]. L.C. Saikia, J. Nanda, and S. Mishra, "Performance Comparision of several classical controllers in AGC for multi-area interconnected thermal system", International Journal of Electrical power and Energy Systems, vol. 33, no. 3, pp. 394-401, 2011.

[21]. P. Kumar and D. P Kothari, "Recent Philosophies of automatic generation control strategies of power system", IEEE Transactions on Power Systems, vol. 20, no. 1, pp. 346 -357, 2005.

[22]. I. Ngamroo, "A Stabilization of Frequency Oscillations using a power modulation control of HVDC link in a parallel AC- DC interconnected system", in Power Conversion Conference, 2002. PCC- OSAKA 2002. Proceedings of the, 2002, vol. 3, pp. 1405-1410 IEEE.

[23]. M. Farahani, S Ganjefar, and M. Alizadeh, "PID controller adjustment using chaotic optimization algorithm for multi-area load frequency control", IET Control Theory and Application, vol. 6 no. 13 pp. 1984-1992, 2012.

[24]. R. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory", in Micro machine and human science in 1995. MHS'95., Proceeding of the 6th International Symposium on, 1995, pp. 39-43 IEEE.