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Chaotic Firefly Algorithm for Optimal Tuning of PID Controller Parameters in Single Area Power Systems

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Abstract—*Firefly algorithm is applied to tune PID parameters for load frequency control in electric power system using approximate model matching technique in frequency domain. The difference between the gain and phase margins of the actual and reference model has been considered as the error function to be minimized with the help of the above mentioned algorithm. The results obtained are satisfactory with respect to single area power system. Further chaos has been added to standard firefly algorithm to develop chaotic firefly algorithm. Five different chaotic maps have been used to tune the attractiveness coefficient and the light absorption coefficient of the Firefly algorithm. Thus, a comparison is drawn between various chaotic maps and standard firefly algorithm.*

Index Terms*: Firefly, PID Controller.*

1. INTRODUCTION

Conventional PID controllers are widely used in various industries as a part of control strategy. As these controllers are simple in operation, reliable and can be broadly used therefore they are so popular. Despite of the presence of a lot of control theories and strategies still a PID controller is used in more than 95% of the control loops .

A PID controller comprises of three elements : the proportional, integral and derivative element. A PID control has combined advantages of proportional control, integral control and derivative control.

Proportional Control: For a control action in a system, the Actuating signal is proportional to error signal. And the error signal is the variation between a reference input signal and the feedback signal, which is a part of the output. So the proportional value tells about the reaction to the error at a desired point of time.

Integral Control: For the action of integral control, actuating signal comprises of a proportional error signal added to value of the integration of the error signal. So the integral value tells about the response based on summation of latest errors.

Derivative Control: In this control the actuating signal comprises of derivative of error summed up with proportional error signal. Therefore, derivative value of a PID controller tells about the reaction that depends on the rate at which the error changes.

Nonlinear changes in the overall system tend to change in dynamics of the process therefore the PID is usually poorly tuned. Initially, Hit and Trial methods were used to tune the PID controller then conventional methods were used to optimize the PID parameters like Cohen-coon settings or Ziegler Nichols method. Recently, metaheuristic approaches have also been used in this area. The salient feature of these metaheuristic algorithms is their ability of predicting output values on their own to tune the PID controller.

In this paper an approach of tuning of PID controller parameters is projected. Firefly Algorithm, one of the recent metaheuristic technique has been used to optimize PID controller parameters. It is inspired by the behavior of fireflies. This technique was introduced by Xin-She Yang at Cambridge University and presented in [1] then his comprehensive work was introduced in [2].Firefly Algorithm has been lately modified to solve different problems [3,4,5].

In this paper, firefly algorithm(FA) is used for selecting tuning parameters of a PID controller, which is achieved by FA to minimize the sum of square error. The results obtained by standard firefly algorithm are compared to chaotic firefly algorithm using MATLAB programming. The experiments show that the chaotic FA based approach performed better than standard FA. An improvement in system efficiency, performance and dynamism is observed.

2. BASICS OF FIREFLY ALGORITHM

Scientist Xin-She Yang developed FireFly algorithm in 2007 and published his research in 2008. Firefly Algorithm is build on the flashing patterns of the fireflies and behavior of their movement[6]. In simple words we can describe FA by the following conventions :

- A firefly is attracted towards another firefly despite of their sex; All fireflies are unisex.
- In Fireflies the degree of attraction depends on the firefly's brightness. Thus a firefly which is less brighter will tend to move toward a brighter firefly. The degree of attraction is relative to the brightness of the firefly.The attraction and brightness of a fireflies decreases as the distance between them increases. It will move randomly if there exit no brighter firefly than a specific firefly.
- The landscape of the objective function is also a factor on which the brightness of a firefly is affected.

In Firefly Algorithm, the solutions are obtained on the basis of attractiveness and movement of fireflies.

These factors can be defined as :

- Attractiveness

The degree of attraction of a firefly is proportional to the light intensity detected by its adjacent fireflies.

The function of attraction of a firefly is monotonically decreasing function and is defined as follows:

$$\beta = \beta_o e^{-\gamma r^m}, (m \geq 1) \quad (1)$$

where r is the Cartesian distance between two fireflies. Distance between i^{th} firefly and j^{th} firefly at positions x_i and x_j respectively is stated as :

$$r_{ij} = \left\|x_i - x_j\right\| = \sqrt{\Sigma_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (2)$$

Where, $x_{i,k}$ is the k^{th} element of the spatial coordinate x_i of i^{th} firefly.

- Movement

Considering, firefly i moves towards firefly j on the basis of brightness. A firefly is attracted to a brighter firefly, the movement of firefly i towards further attractive firefly j is given by :

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2} \left(x_j^t - x_i^t\right) + \alpha \varepsilon_i^t \quad (3)$$

Where, the foremost term x_i^t is the existing location of a firefly, the following term tells about firefly's attractiveness towards adjacent fireflies , and the third term tells the random movement or randomization of a firefly. The coefficient of randomization is α.

3. REALIZATION OF CHAOTIC FIREFLY ALGORITHM FOR LOAD FREQUENCY CONTROLLER

Firefly algorithm is comparable to few other metaheuristic optimization techniques. Firefly algorithm follows behavior of fireflies based on flashing of light and attraction characteristics. The algorithm generates early population of the practical solution then the entire population is handled in a search domain or a search space. The best location in the entire search space is found out on using the flashing light(also called as fitness function) of the fireflies and randomness. Each firefly moves in the search domain i.e the number of decision variables based on the attractiveness of its neighboring fireflies. Applying this mechanism of search over a number of iterations , FA finds a optimized value of PID parameters[7].

Chaos into FA introduced to increase its global search and increase the speed of overall searches. To fulfill this five one-dimensional chaotic maps[8] have been used to tune the movement of fireflies in the algorithm.

In this scheme, the chaotic firefly algorithm(CFA)[9] is used to tune PID parameters, which is achieved by minimizing the SSE,ITAE,ISE,ITSE,RMSE etc. In this paper PID parameters have been tuned using sum of square error. Block diagram of chaotic firefly algorithm has been shown below.

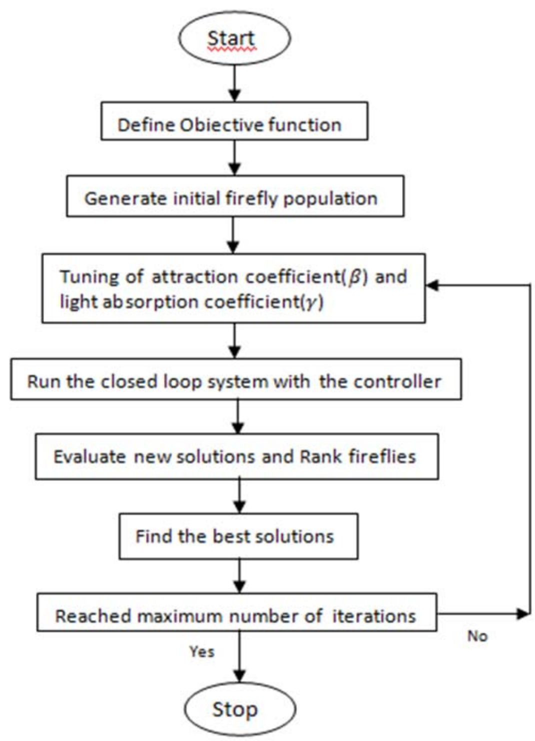

Fig. 1: Block Diagram of CFA

4. PID PARAMETER FORMULATION

We considered the block diagram of a basic PID controller shown in Fig. 1. In the block diagram, the component C*(s)* depicts the controller and G(s) depicts the process to be controlled. The output[10] of the block diagram is given by equation(4),

$$u(t)=K_p e(t)+K_i \int e(t)\,dt + K_d \frac{de(t)}{dt} \quad (4)$$

And the transfer function of C(s) i.e the PID controller is given by equation(2),

$$C(s)= K_p+\frac{K_i}{s}+K_d s \quad (5)$$

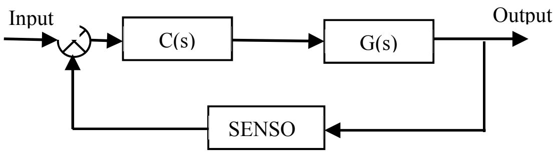

Fig. 2: Block diagram of a basic PID control system

The main goal is to adjust the parameters of the controller as fast as possible as well as getting a desired performance characteristics for a specific process. This is achieved using firefly algorithm and chaotic firefly algorithm. Block diagram for the proposed system[11] is shown is Fig. 2.

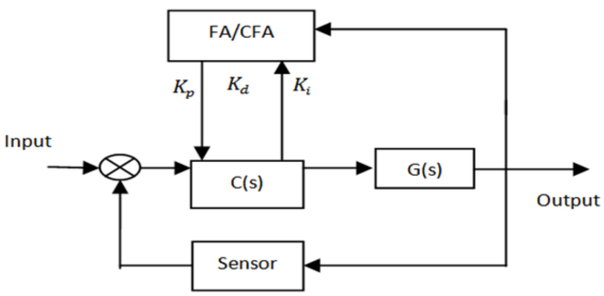

Fig. 3: Tuning of controller using FA and CFA

5. RESULTS FOR SINGLE AREA POWER SYSTEM

Two examples have been considered with a population size of 20 fireflies and 50 number of iterations on which the firefly algorithm and chaotic firefly algorithm for 20 test runs have been performed. Tuning of PID parameters has been done by minimizing sum of square error(SSE).

Example 1. A single-area power system with a non-reheat turbine taken from [12] is considered as given below.

System parameters are given as T_G=0.2,T_T =0.5,K_p= 1.25,T_P=12.5,R=0.005.

The open-loop transfer function of the system is given as

$$\frac{1.25(0.5s+1)(0.2s+1)}{\left((12.5s+1)(0.5s+1)(0.2s+1)+\frac{1.25}{0.05}\right)} \quad (6)$$

The closed loop transfer function of the reference model with one zero at origin is selected as

$$M(s) = \frac{0.01s}{s+1} \quad (7)$$

The optimized values of K_D,K_P,K_I, best value, worst value, average value ,standard value and average time have been displayed in Table 1.

Example 2. A single-area power system with a non-reheat turbine taken as example from [13].

System Parameters :

T_G=0.2, T_T =7, K_P=1,T_P=10, R=0.05

The open-loop transfer function of the system is given by

$$\frac{(7s+1)(0.2s+1)}{(10s+1)(7s+1)(0.2s+1)+\frac{1}{0.05}} \quad (8)$$

Table 1: Results of Example 1

Type of Map	Best Value	Worst Value	Average Value	Standard Deviation	K_D	K_P	K_I
Basic FA	4.68E-03	4.68E-01	4.68E-02	2.16E-05	17.1455	6.88766	18.1384
Iterative Map	4.69E-04	4.75E-04	4.74E-04	3.82E-06	3.79685	9.83775	19.9377
Sine Map	4.76E-04	4.72E-04	4.70E-04	3.73E-06	16.6413	20	19.1769
Singer Map	4.67E-04	4.67E-03	4.67E-03	2.73E-06	4.78948	18.5478	20
Logistics Map	4.50E-04	4.74E-04	4.56E-04	3.64E-07	0.540256	19.9135	19.919
Sinusoidal Map	4.75E-04	4.77E-04	4.76E-04	1.73E-06	4.90422	10.8783	19.9446

TABLE 2: Results of Example 2

Type of Map	Best Value	Worst Value	Average Value	Standard Deviation	K_D	K_P	K_I
Basic FA	3.30E-04	9.01E-04	6.16E-04	4.04E-04	13.8159	12.7581	19.1777
Iterative Map	2.34E-10	2.05E-09	1.14E-09	1.28E-09	14.4521	3.81425	2.48453
Sine Map	7.76E-10	1.14E-09	9.58E-10	2.58E-10	4.3236	3.8261	2.5039
Singer Map	4.41E-12	4.63E-12	4.52E-12	1.54E-13	0.041349	0.69018	2.5321
Logistics Map	4.48E-13	7.82E-13	6.15E-13	2.36E-13	18.7059	0.920509	2.48116
Sinusoidal Map	2.74E-09	2.94E-09	2.84E-09	1.41E-10	11.4453	7.55517	2.44208

The desired closed-loop reference model for load–frequency control is selected with a zero at origin as

$$M(s) = \frac{0.4s}{1.3s+1} \quad (9)$$

The optimized values of K_D,K_P,K_I, best value, worst value, average value ,standard value and average time have been displayed in Table 2.

6. CONCULSION

The parameters of a PID controller have been tuned efficiently in this paper by using firefly algorithm and chaotic firefly algorithm. Two systems have been taken from literature[14].The best value, worst value, average value, standard deviation and average CPU time of the objective function are calculated to draw comparison between standard firefly and chaotic firefly. The controller parameters are identified using approximate model matching technique[15]. The reference model taken up for the systems reflect frequency domain approach[16]. Hence the error function has been chosen as the difference between the bode responses of the actual and the reference models. The results obtained are satisfactory with respect to single area power system. The results reveal system perform better for chaotic maps .The results are better for chaotic algorithm because of the use of deterministic chaotic maps in place of constant values. Statistical results show that chaotic algorithms have enhanced the quality of results.

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