Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 4, Issue 3; April-June, 2017, pp. 212-216

http://www.krishisanskriti.org/Publication.html

Tuning of Load Frequency Controller Parameters using Adaptive Firefly Strategy

Ricky Garg[1] and Souvik Ganguli[2]

[1,2]Thapar University, Patiala
E-mail: [1]rickygarg92@gmail.com, [2]souvik.ganguli@gmail.com

Abstract—*In this paper, an Adaptive Firefly Algorithm has been applied to tune PID parameters of the LFC. Initially analysis is done using basic firefly algorithm and then five new adaptive firefly techniques have been applied to four different problems of single area power system defined in literature. Results obtained using Adaptive firefly technique is better than basic firefly technique as well as various other techniques reported in the literature. Comparison between all the techniques has been shown. Difference between the Nyquist response of the given model and the desired model is used as an error. The design method focuses on minimizing the Integral of Square Error (ISE) criterion.*

1. INTRODUCTION

In a power system, frequency deviation is there when load demand is not equal to the energy generated. Today, with increasing technology need for power is increasing day by day, as industry is growing total demand is increasing very rapidly. Frequency fluctuation is always due to change in the load. If there is an increase in load the load frequency decreases, on the other hand if load decreases the system frequency increases. Both the conditions are very dangerous for our power system and we need to avoid this situation. Changes in the active power demand leads to change in the frequency and change in reactive power demand leads to a change in the Voltage magnitude. Many methods have been proposed to control this change in frequency. The method proposed in this paper is LFC. LFC doesn't work for large changes in the frequency but for small day to day fluctuations. With increasing complexity of Inter connected power system the need for LFC is increasing day by day. Various controller designs reported in the Literature for LFC loop are Classical control [6,7], optimal control[6,9], Adaptive [8,10], robust control[11,14]. In LFC, Proportional Integral Derivative control is preferred due to its simplicity and satisfactory performance. Frequency response matching has been used to design PID controller. In this paper certain examples have been taken from literature and results are calculated using Firefly algorithm (FA) and Adaptive firefly algorithm (AFA) which are further compared with the results reported in literature using other optimization techniques. Basic FA and AFA have better convergence characteristics than other optimization techniques. Methods to make basic FA as AFA certain modification as proposed in the literature have been implemented which show tremendous improvement over Basic FA.

2. THE SYSTEM MODEL

Governor, turbine, generator and load are the main components of a plant of a LFC system. Linearized model of various components are shown fig.

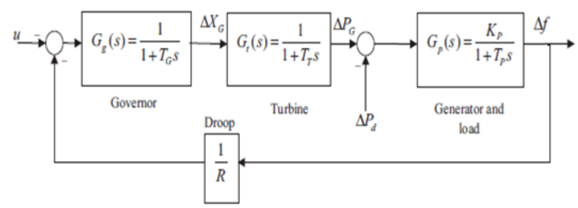

Fig. 1

The transfer function for the above system may be written as

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

ΔP_d	Disturbance in the Load (in p.u.MW)
u	Reference value of the Load
K_p	Gain of Electric system
T_p	Time constant of Electric system(s)
T_t	Time constant of Turbine system(s)
T_g	Time constant of Turbine system(s)
R	Speed regulation (Hz/p.u.MW)
Δf_t	Increase in frequency deviation (Hz)
ΔP_{gt}	Increase in generator output (p.u.MW)
ΔX_{gt}	Change in governor valve position

Various terms used in the block diagram are defined as follows

The terms used to describe the LFC system

3. FIREFLY ALGORITHM (FA)

The flashing of fireflies is a very commonly observed at night. There are about 2000 species of fireflies and each species produce their own rhythmic flashes. The pattern is unique for particular species. There are two fundamental functions of flashing first is to attract mating partners and second is to warn potential prey. Flashing pattern also shows the bitter taste of prey. Females respond to male's unique pattern of flashing and gets attracted accordingly. Now, we know that light intensity varies with the distance between two fireflies as per inverse square law[18].

$$I(r) = \frac{I_s}{r^2} \quad (2)$$

For a given medium there occurs absorption of light also, which varies as per the formula below

$$I = I_0 e^{-\gamma r} \quad (3)$$

Where γ is the absorption coefficient of light and I_0 is the light intensity at origin or zero distance r = 0. We define the attractiveness β of a firefly by

$$\beta = \beta_0 e^{-\gamma r^2} \quad (4)$$

where β_0 is the attractiveness at r = 0. Since it is often faster to calculate 1/(1 + r^2) than an exponential function, this function, if necessary, can conveniently be approximated as

$$\beta = \beta_0 \frac{1}{1+\gamma r^2} \quad (5)$$

In the actual implementation, the attractiveness function β(r) can be any monotonically decreasing functions such as the following generalized form:

$$\beta = \beta_0 e^{-\gamma r^m}, (m \geq 1) \quad (6)$$

For two fireflies i and j placed at x_i andx_j, respectively, the Cartesian distance is given by

$$r_{ij} = \| x_i - x_j \| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (7)$$

Given that, spatial coordinate's kth component is $x_{i,k}$ of ith firefly. In a 2D case, we have

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (8)$$

The movement of a ith firefly attracted to another, more brighter (attractive) firefly j is determined by

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2} \left(x_j^t - x_i^t\right) + \alpha \varepsilon_i^t \quad (9)$$

Where, the second term is due to the attraction. The third term is randomization, with α being the randomization parameter, and ε_i is a vector of random numbers drawn from a Gaussian distribution or uniform distribution. Third term ensures a random movement to the firefly for taking next step. For example, the simplest form is ε_i can be replaced by rand-1/2, where rand is a random-number generator uniformly distributed in [0,1]. For most of our implementation, we can take β_0= 1 and $\alpha \in$[0, 1].

4. ADAPTIVE FIREFLY ALGORITHM (AFA)

In this algorithm certain modification are done to the basic firefly algorithm to minimize the dependency of control parameters.

Strategy S1

Ngaam et al. [1] proposed a memetic FA (MFA), which designed a dynamic strategy to adjust the parameter α as follows

$$\alpha(t) = \left(\frac{e^{\delta}(N_G - t)}{t.\in}\right)^M \quad (10)$$

Where δ is a constant defined by user to clamp α and $\in$ is a constant whose value is 10^{-6}.

Strategy S2

$$\alpha(t) = exp\left(\delta\left(\frac{N_G - t}{t}\right)^{\frac{1}{t}}\right)^M \quad (11)$$

Strategy S3

$$\alpha(t) = \left(e^{\delta}.t^{\frac{-N}{D}}\right)^{\frac{M(N_G - t)}{N_G}} \quad (12)$$

Where, N and D defines the dimension and population size of an optimization problem.

Strategy S4

$$\alpha(t) = \left(t^{(N^p - 1)}.(N_G - t)\right)^M \quad (13)$$

Where, P is the power of population size N.

Strategy S5

$$\alpha(t) = t^{\frac{M(N+D)(N_G - t)}{(N_G)}} \quad (14)$$

In the above mentioned equations 'M' is defined as

$$\alpha(t) = -\exp\left(-\left(\frac{N_G - t}{t}\right)\right) \quad (15)$$

To make the algorithm independent of control parameters, parameters can be made adaptive. We are using α and making it adaptive as per the need or in other words we can say that we are controlling randomization after every iteration. As the iteration is changing the α is reduced resulting in a decreased random movement of firefly.

5. RESULTS AND DISCUSSIONS

Example1. A non- reheat turbine in a single-area power system [16] was considered.

The transfer function of open-loop system from ΔP_d to Δf as in Fig. 1 is given by

$$\frac{120(0.3s+1)(0.08s+1)}{((20s+1)(0.3s+1)(0.08s+1)+120/2.4)} \quad (16)$$

The desired closed-loop reference model for load–frequency control is selected as

$$G(s)=\frac{0.4s}{0.4s+1} \quad (17)$$

The frequency points are selected as W_0=0.03 and W_1=0.06 rad/s.

The PID parameters are identified by approximate model matching listed below:

Table 1: Performance Criteria for example 1

	K_D	K_P	K_I	ISE
Basic FA	0.2172	1.4312	2.4195	4.90E-19
S1	0.26229	1.4039	2.3959	2.27E-25
S2	0.31403	1.5549	2.5252	1.29E-25
S3	0.32813	1.6186	2.5784	1.81E-19
S4	0.24208	1.3424	2.3419	2.66E-25
S5	0.3358	1.6161	2.5764	9.52E-26

Table 2: Performance Comparison for Example 1

Method	K_D	K_P	K_I	ISE
Nishnat Anwar	0.27	1.52	2.5	2.471E-5
Padhan and Majhi	0.235	1.49	1.30	3.635E-5
Tan	0.183	0.40	0.63	13.62E-5

Population size considered is 20 and 50 are the number of iterations on which firefly algorithm and 5 different strategies of Adaptive firefly algorithm has been applied. ISE technique has been used to compare difference between given transfer function and desired transfer function.

Example2. A reheat turbine in a single-area power system [15] was considered. The open loop transfer function is given by

$$G_t(s)=\frac{CT_r s+1}{(T_r s+1)(T_t s+1)} \quad (18)$$

Where T_r is a constant and c is the fraction of total generated power which is generated by the reheat process.

The transfer function of open-loop system from ΔP_d to Δf as in Fig. 1 is given by

$$\frac{120(0.3s+1)(0.08s+1)(4.2s+1)}{\left((20s+1)(0.3s+1)(0.08s+1)(4.2s+1)+\frac{120}{2.4(1.47s+1)}\right)} \quad (19)$$

The desired closed-loop reference model for load–frequency control is selected as

$$G(s)=\frac{0.4s}{1.3s+1} \quad (20)$$

The frequency points are selected as W_0=0.03 and W_1=0.06 rad/s.

The PID parameters are identified by approximate model matching listed below:

Table 3.Performance Criteria for example 2

	K_D	K_P	K_I	ISE
Basic FA	19.9642	12.5745	4.75781	2.90E-16
S1	14.9281	8.67774	3.96774	6.88E-17
S2	20	12.4227	4.72975	1.75E-15
S3	20	12.7029	4.781	8.27E-17
S4	17.484	10.4813	4.35098	5.11E-17
S5	15.8324	10.1682	4.28353	7.31E-18

Table 4.Performance comparison for example 2

Method	K_D	K_P	K_I	ISE
Nishnat Anwar	2.57	10.60	2.50	0.664E-5
Padhan and Majhi	1.16	6.16	1.93	2.003E-5
Tan	0.787	2.79	1.27	5.96E-5

Example3. A non- reheat turbine in a single-area power system [16] is considered.

The transfer function of open-loop system from ΔP_d to Δf as in Fig. 1 is given by

$$\frac{1.25(0.5s+1)(0.2s+1)}{((12.5s+1)(0.5s+1)(0.2s+1)+1.25/0.05)} \quad (21)$$

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

$$M(s)=\frac{0.01s}{s+1} \quad (22)$$

The frequency points are selected as W_0=0.05 and W_1=0.1 rad/s.

The PID parameters are identified by approximate model matching listed below:

Table 5: Performance Criteria for example 3

	K_D	K_P	K_I	ISE
Basic FA	68.64839	149.561	100.1334	2.63E-22
S1	68.78623	149.7026	100.1862	3.62E-23
S2	68.62327	149.5014	100.1118	3.53E-23
S3	68.94215	149.8949	100.2573	3.71E-23
S4	69.66331	150.7822	100.5849	4.15E-23
S5	69.08169	150.0668	100.3208	3.80E-23

Table 6: Performance Comparison for Example 3

Method	K_D	K_P	K_I	ISE
Nishnat Anwar	69.2	149.2	100	0.0693E-7
Padhan and Majhi	28.56	55.21	46.8	0.2937E-7
Khodabakhshian	19.6	36.22	10	1.067E-7

Example4. A non- reheat turbine in a single-area power system taken as example from [17].

The transfer function of open-loop system from ΔP_d to Δf as in Fig. 1 is given by

$$\frac{(7s+1)(0.2s+1)}{(10s+1)(7s+1)(0.2s+1)+\frac{1}{0.05}} \quad (23)$$

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

$$M(s)=\frac{0.4s}{1.3s+1} \quad (24)$$

The frequency points are selected as W_0=0.01 and W_1=0.02 rad/s.

The PID parameters are identified by approximate model matching listed below:

Table 7: Performance Criteria for example 4

	K_D	K_P	K_I	ISE
Basic FA	9.9465	0.42776	2.5159	4.57E-16
S1	8.9389	0.84403	2.558	4.56E-16
S2	9.1103	0.26972	2.5006	4.71E-16
S3	9.9999	0.36553	2.5097	4.91E-16
S4	9.9999	0.17537	2.4904	4.81E-16
S5	9.9996	0.59943	2.5333	5.96E-16

Table 8.Performance Comparison for Example 4

Method	K_D	K_P	K_I	ISE
Nishnat Anwar	9.7	0.267	2.50	0.9625E-5

6. CONCLUSION

Approximate model matching technique has been used to compare the given model with the desired model for single area power system. Response of both the models is seen for small change in frequency to arrive at a set of linear algebraic equations, solutions of which gives the controller parameters. In firefly as well as adaptive firefly algorithm both mathematical simplicity as less computational burden are involved. Various types of models have been considered such as single area non-reheat turbine, single area reheat turbine. Integral of square error has been considered, which is to be minimized using AFA. Different five strategies reported in literature are used to minimize the ISE. Results show substantial improvement compared to the previous methods followed for to reduce error.

7. ACKNOWLEDGEMENT

I express my gratitude to my supervisor Asst. Prof. Souvik Ganguli, EIED, Thapar University for his continuous motivation and support. I whole-heartily value his guidance and encouragement from the beginning till the end of this paper. I am indebted to him for helping me to shape the problem and providing insights to the solution.

REFERENCES

[1] N. Cheung, X. Ding and H. Shen, "Adaptive Firefly Algorithm: Parameter Analysis and its Application", *PLoS ONE*, vol. 9, no. 11, p. e112634, 2014.

[2] M. Jamil and X. Yang, "A literature survey of benchmark functions for global optimisation problems", *International Journal of Mathematical Modelling and Numerical Optimisation*, vol. 4, no. 2, p. 150, 2013.

[3] Y. Diouane, S. Gratton and L. Vicente, "Globally convergent evolution strategies for constrained optimization", *Computational Optimization and Applications*, vol. 62, no. 2, pp. 323-346, 2015.

[4] Z. Gao, T. Xiao and W. Fan, "Hybrid differential evolution and Nelder–Mead algorithm with re-optimization", *Soft Computing*, vol. 15, no. 3, pp. 581-594, 2010.

[5] M. Anwar and S. Pan, "A new PID load frequency controller design method in frequency domain through direct synthesis approach", *International Journal of Electrical Power & Energy Systems*, vol. 67, pp. 560-569, 2015.

[6] Concordia C, Kirchmayer LK. Tie-line power and frequency control of electric power systems. Am Inst Electr Eng Trans Part III 1953;72:562–72

[7] Das D, Nanda J, Kothari ML, Kothari DP. Automatic generation control of a hydrothermal system with new area control error considering generation rate constraint. Electr Mach Power Syst 1990;18:461–71. Int J Electr Power Energy Syst 1986;8(2):93–100

[8] Pan CT, Liaw CM. An adaptive controller for power system load–frequency control. IEEE Trans Power Syst 1989;4(1):122–8

[9] Rubaai A, Udo V. Self-tuning load frequency control: multilevel adaptive approach. IEE Proc Gen Transm Distrib 1994;141(4):285–90

[10] Oysal Y, Yilmaz AS, Koklukaya E. A dynamic wavelet network based adaptive load frequency control in power systems. Electr Power Energy Syst 2005;27:21–9

[11] Wang Y, Zhou R, Wen C. Robust load–frequency controller design for power system. IEE Proc Gen Transm Distrib Part C 1993;140(1):11–6

[12] Azzam M, Mohamed YS. Robust controller design for automatic generationcontrol based on Q-parameterization. Energy Convers Manage 2002;43(13):1663–73

13] Toulabi MR, Shiroei M, Ranjbar AM. Robust analysis and design of power system load frequency control using the Kharitonov's theorem. Electr Power Energy Syst 2014;55:51–8

[14] Ali R, Mohamed TH, Qudaih YS, Mitani Y. A new load frequency control approach in an isolated small power systems

using coefficient diagram method. Electr Power Energy Syst 2014;56:110–6
[15] Tan W. Unified tuning of PID load frequency controller for power systems via IMC. IEEE Trans Power Syst 2010;25(1):341–50
[16] Padhan DG, Majhi S. A new control scheme for PID load frequency controller of single-area and multi-area power systems. ISA Trans 2013;52:242–51
[17] Gundes AN, Chow L. Controller synthesis for single-area and multi-area power systems with communication delays. In: American control conference (ACC), Washington, DC, USA; June 17–19, 2013.
[18] X. S. Yang, “Nature-inspired Metaheuristic Algorithm”, Luniver Press (2008)