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Load Frequency Control of Nonlinear Power System Employing Firefly Algorithm

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Abstract

Background/Objectives: Firefly Algorithm (FA) is employed to for Load Frequency Control (LFC) of nonlinear power system. **Methods/Statistical Analysis:** The supremacy of FA technique is established by comparing the outcomes with Genetic Algorithm (GA). **Findings:** Additionally, sensitivity study is conducted by changing system parameters like time constants of turbine, speed governor and inertia constant as well as generator initial loading condition by +50% to -50% from their normal values in addition to the magnitude and location of load disturbance to illustrate the effectiveness of the suggested design approach. **Application/Improvements:** A nonlinear three area thermal system is taken as the system under study and the parameters of the LFC controller are tuned using FA technique.

Keywords: Firefly Algorithm (FA), Generation Rate Constraint (GRC), Load Frequency Control (LFC), Proportional Integral Derivative Controller, Sensitivity Analysis

1. Introduction

Numerous control schemes have been suggested by investigators for Load Frequency Control (LFC) of power systems. These approaches include traditional approaches like conventional[1,2] and optimal control[3]. Several intelligent approaches like Genetic Algorithm (GA)[4], Particle Swarm Optimization (PSO)[5], Bacteria Foraging Optimization Algorithm (BFOA)[6], Differential Evolution[7], Fuzzy Logic Controller (FLC)[8], Artificial Neural Network (ANN)[9] etc., have been suggested in literature for frequency control. It is found from above study that LFC scheme is influenced by the optimization method used, structure of controller and performance criterion selected. Therefore, novel methods with high new techniques are always welcome to solve the real world complications. Lately, an optimization technique, identified as Firefly Algorithm (FA) has been proposed by Yang[10,11]. FA techniques is motivated by the flashing characteristic of fireflies. FA technique has been effectively used to optimize complex optimization problems[12,13]. Recent investigation demonstrates that FA is a very effective and often provides better results than optimization techniques like ABC, PSO and BFOA[14,15].

In this study, the improvement of FA compared to GA has also been shown Lastly, sensitivity investigation is executed by changing the generator loading and system time constants from their normal values.

2. Materials and Method

2.1 System Under Study

A three area nonlinear power system as shown in Figure 1 is considered as system under study. In the test system, three unequal thermal areas are interconnected[16]. The rating of generating units in each area 1, 2 and 3 are 2000 MW, 4000 MW, and 8000 MW respectively. The nonlinearity due to Generation Rate Constraint (GRC) is included with a GRC of 3% per minute for tall the generators[14]. The system data is provided in Appendix.

2.2 Proposed Approach

Different controller like I/PI/PID are assumed in each area for frequency control. Individual Area Control Errors (ACE) specified by[1], are taken as in puts to the controllers.

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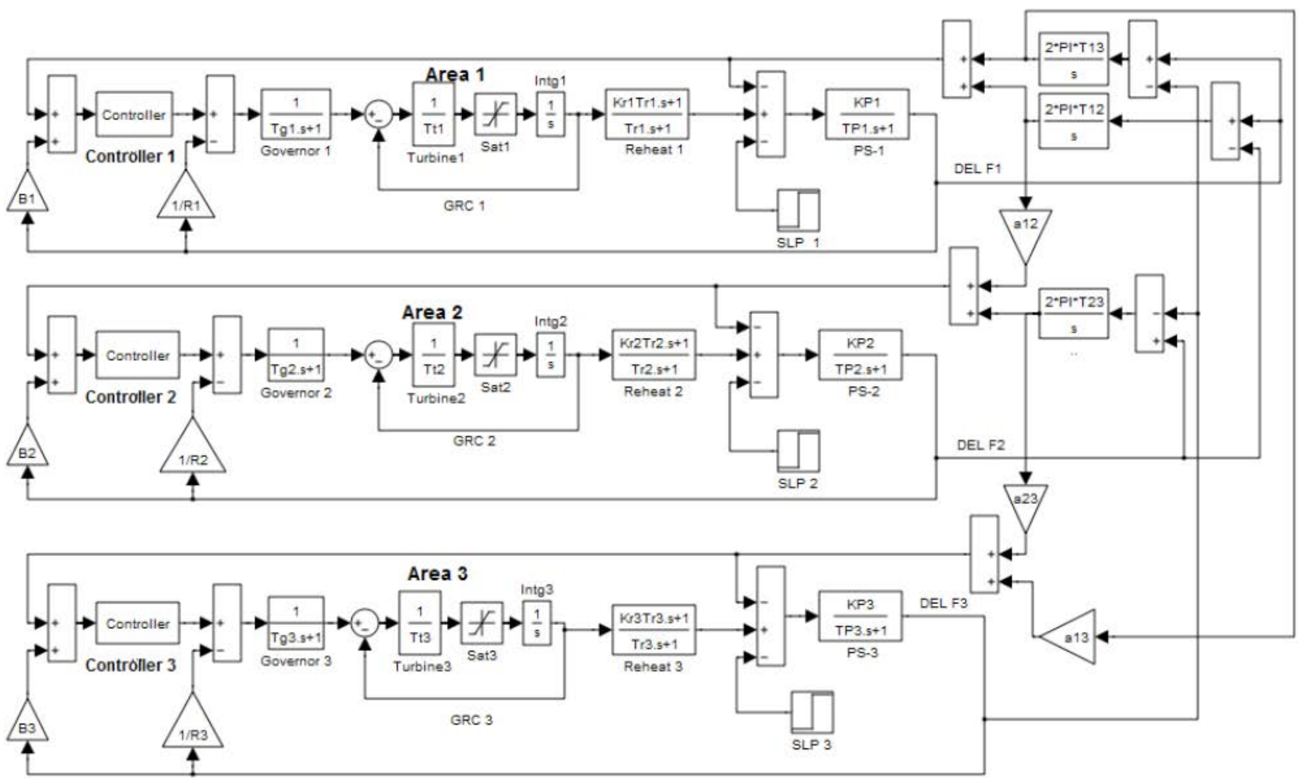

Figure 1. MATLAB/SIMULINK model of three unequal area thermal system.

$$e_1(t) = ACE_1 = B_1\Delta F_1 + \Delta P_{Tie1} \tag{1}$$

$$e_2(t) = ACE_2 = B_2\Delta F_2 + \Delta P_{Tie2} \tag{2}$$

$$e_3(t) = ACE_3 = B_3\Delta F_3 + \Delta P_{Tie3} \tag{3}$$

Where B_i's are the frequency bias parameters, ΔF_i's represent frequency deviations and ΔP_{Tiei} are the deviations in transmission line real power out of areas.

Four kinds of objective functions usually employed for design of any control system. These are ITAE, ISE, ITSE and IAE. ITAE objective function lessens the settling time in system response, but the same cannot be realized using IAE or ISE objective functions. ITAE objective function also decreases the maximum overshoot. ITSE objective function gives huge controller output for an abrupt variation in input and is not desirable. In LFC studies, it is observed that ITAE objective function provides better system performance than others[17]. Thus in the present study ITAE objective function is selected which is expressed in Equation (4).

$$J = ITAE = \int_0^{t_{sim}} \left(\left|\Delta F_i\right| + \left|\Delta P_{Tie\_m-n}\right|\right) \cdot t \cdot dt \tag{4}$$

Where ΔF_i represent the deviation in frequency in area i; $\Delta P_{Tie-m-n}$ represent the deviation in line power linking area m and area n; t_{sim} represent simulation time.

Figure 1. Test system: three unequal thermal area power system

3. Overview of FA Optimization Technique

Firefly Algorithm (FA) optimization technique is developed by Yang[10] for multi-modal optimization.

For efficient operation of FA, two vital parameters should be specified. They are the light intensity (I) and attractiveness (β). For an individual firefly, its attractiveness of is governed by its light intensity which is linked with the cost function[11]. The expression of light intensity $I(r)$ which depends on initial intensity I_0 and its distance r is given in Equation (5).

$$I(r) = I_0 e^{-\gamma r} \tag{5}$$

where I_0 the initial intensity of light and γ represents coefficient of light absorption.

Because the attractiveness of a firefly's is related to the light intensity perceived by neighboring fireflies, the attractiveness β of a firefly is expressed as:

$$\beta = \beta_0 e^{-\gamma r^2} \tag{6}$$

where β_0 is the attractiveness of firefly at the beginning i.e. at $r = 0$.

The distance among fireflies s_i and s_j is represented as Euclidean space by the base firefly algorithm by way of:

$$r_{ij} = \left\| s_i - s_j \right\| = \sqrt{\sum_{k=1}^{k=n} (s_{ik} - s_{jk})^2} \tag{7}$$

where n means the dimension of the optimization task.

Fireflies move as per Equation (8):

$$s_i = s_i + \beta_0 e^{-\gamma r_{ij}^2} (s_i - s_j) + \alpha \varepsilon_i \tag{8}$$

4. Results and Discussions

4.1 Application of FA Algorithm

The performance of FA greatly depends on three parameters. They are randomization parameter α, the absorption coefficient γ, the attractiveness β which are selected in the range 0 to 1. A number of runs were performed to appropriately select these parameters[18]. The selected algorithm parameters are: number of fireflies = 5; β = 0.2; α = 0.5 and γ = 0.5, maximum generation = 100. The lower and upper bound of search parameters are taken as -2.0 and 2.0. To calculate ITAE value, the load in area 1 is increased by 5 % in stepwise manner. The FA technique is run 50 times and the best parameters attained in 50 independent implementations is selected as controller settings[19]. The optimal settings are provided in Table I. The ITAE value, and settling times (2%) in line power and frequency deviations using optimized control parameters are provided in Table II. To illustrate the advantage of FA, ITAE value, and settling times (2%) in frequency and tie line power deviations with GA tuned Integral controller are also shown in Table II and III. GA is educated with following algorithm parameters: normal geometric selection, non-uniform mutation and arithmetic crossover. No of population = 50, max. no of generation = 100. The details about implementation of GA is available in[20]. For fair comparison, same power system, objective function employed, controller structure (I) are taken for both FA and GA.

Table 2. Comparison of Performance Index

Controller/ Performance		FA PID	FA PI	FA I	GA I
ITAE		1.3459	3.3782	17.4107	17.8181
Settling times (sec)	ΔF_1	3.62	5.20	17.79	19.32
	ΔF_2	3.47	4.83	11.69	14.15
	ΔF_3	3.47	4.52	12.18	14.9
	ΔP_{tie-12}	4.66	5.56	17.12	18.84
	ΔP_{tie-13}	1.93	3.50	8.10	13.64
	ΔP_{tie-23}	2.62	4.73	11.58	14.81

In integral controller is initially chosen for comparison between GA and FA because integral controllers are less effective than PI/PID controllers and so that improvement with FA technique compared to GA technique can be illustrated in a better way. It can be seen from Table II that an ITAE value of 17.4107 is obtained with FA compared to ITAE value of 17.8181 with GA so it may be said that FA gives better results than GA. The best system performance is realized with FA tuned PID controller which gives the lowest ITAE value. It is obvious from the results of Table II that lowest ITAE value of 1.3459 is attained with FA tuned PID controller compared to ITAE values of 3.3782 obtained with FA tuned PI controller. As a result, improved dynamics characteristics are realized with FA based PID controller as related to other alternative controllers considered in the study.

Table 1. Optimized Controller Parameters

Controller	Controller gains
GA Based I controller	K_{I1}= -0.1393; K_{I2}= -0.1249; K_{I2}= -0.1815
FA Based I controller	K_{I1}= -0.1665; K_{I2}= -0.2137; K_{I2}= -0.0209
FA Based PI controller	K_{P1}= 0.5071, K_{P2}= 0.2844, K_{P3}= -0.4559 K_{I1}= -0.5067, K_{I2}= -0.5973, K_{I3}= -0.024
FA Based PID controller	K_{P1}= 0.2119, K_{P2}= -0.6949, K_{P3}= -1.996 K_{I1}= -0.8674, K_{I2}= -1.9868, K_{I3}= -1.9919 K_{D1}= -0.155, K_{D2}= -0.9824, K_{D3}= -0.8735

For transient performance evaluation, the load in areas 1 and 2 are increased by 5% and 2% respectively and transient response are shown in in Figures. 2-7 from which it is noticeable that, FA based PID performs satisfactorily when the load disturbances are applied to both areas. Therefore, it may be concluded that the suggested control method is robust and gives acceptable perform regardless of location of load disturbance.

4.2 Sentivity Investigation

To investigate the robustness of designed controller under changed generator loading and system time constants, sensitivity analysis is carried out 3,5,7,14,17. Generator loading and system time constants are varied from their normal values by +50% +20%, -20%, -50% and system performance under 5% step increase in load in area 1 are gathered in Table III.

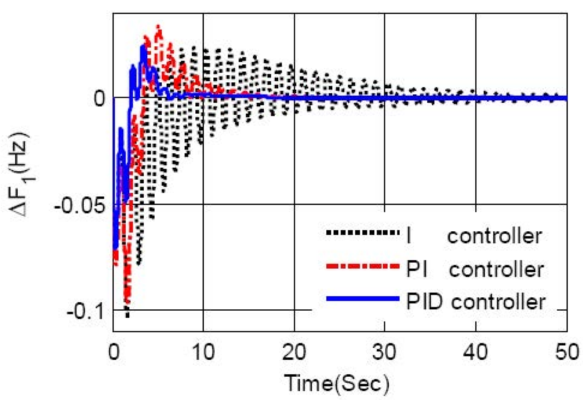

Figure 2. Frequency deviation of area-1.

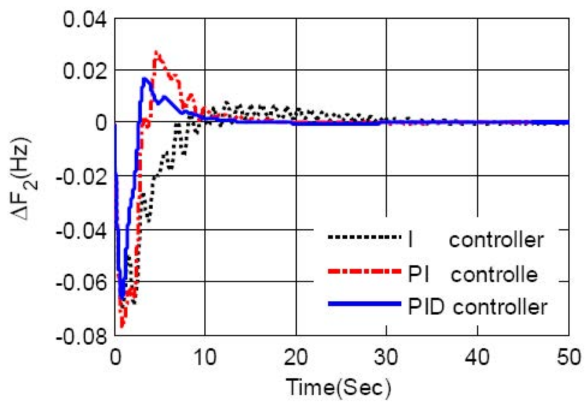

Figure 3. Frequency deviation of area-2.

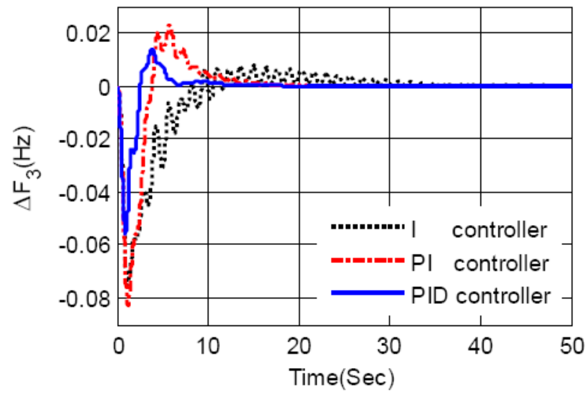

Figure 4. Frequency deviation of area-3.

Careful inspection of Table III shows that the system performance remains almost identical and the influence of the change in generator loading and system parameters on dynamic performance is insignificant.

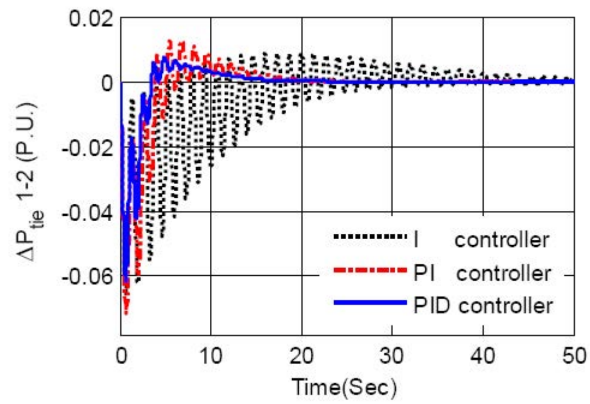

Figure 5. Tie line power deviation between area 1 and area 2.

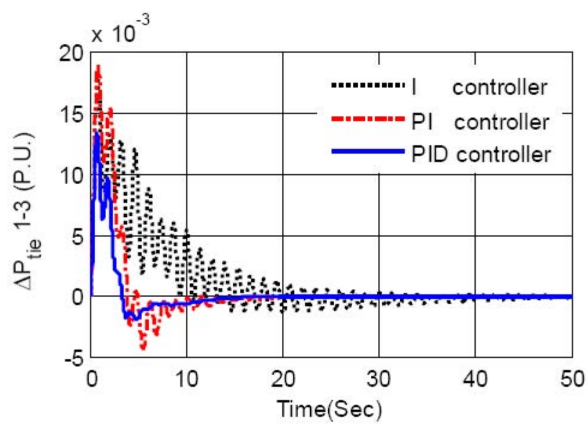

Figure 6. Tie line power deviation between area 1 and area 3.

Table 3. Sensitivity Analysis

Parameter variation	% Change	Settling time T_s(Sec)						ITAE
		ΔF_1	ΔF_2	ΔF_3	ΔP_{tie-12}	ΔP_{tie-13}	ΔP_{tie-23}	
No change	0	3.62	3.47	3.47	4.66	1.93	2.62	1.3459
T_G	+50	5.23	5.13	4.29	5.57	2.99	4.33	1.4156
	+20	4.52	3.69	3.94	5.03	1.96	3.95	1.3673
	-20	3.51	3.37	3.39	4.41	1.92	2.58	1.3229
	-50	3.35	3.24	3.27	4.22	1.92	2.53	1.3006
T_T	+50	5.45	5.33	5.25	5.82	3.77	4.84	1.4887
	+20	4.64	3.77	4.05	5.16	3.44	4.08	1.3848
	-20	3.40	3.28	3.32	4.14	1.95	2.57	1.3001
	-50	2.87	2.82	2.87	3.43	1.86	2.34	1.2568
H	+50	3.13	3.27	3.27	4.25	2.70	2.49	1.4104
	+20	3.56	3.42	3.41	4.45	1.86	2.59	1.3595
	-20	4.22	4.05	4.01	5.07	2.47	3.32	1.3179
	-50	5.27	5.36	4.89	5.95	2.94	3.82	1.3337

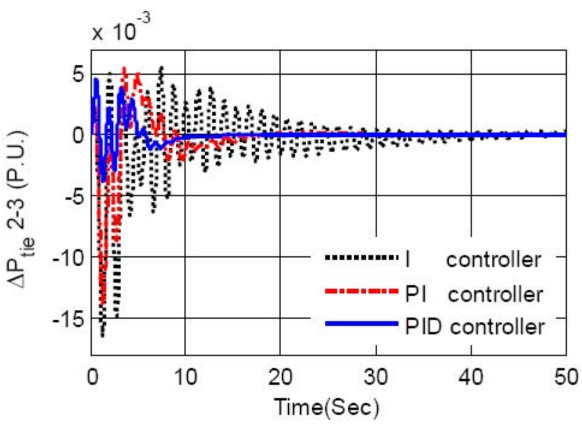

Figure 7. Tie line power deviation between area 2 and area 3.

5. Conclusion

Firefly Algorithm (FA) has been implemented frequency control of power systems. A three unequal thermal area nonlinear power system with GRC nonlinearity is taken and the settings of I/PI/PID are tuned by means of FA. It is observed that FA outperforms GA. Simulation results validate the capability of FA algorithm to deal with nonlinear power system with dissimilar controllers and nonlinearity. Finally, robustness analysis is done by changing the generator loading and time constants of the system from their normal values to show the robustness of the designed control methodology. It is seen that the designed control approach is robust and provides acceptable dynamic performance under varied condition.

Appendix

Normal test system parameters:

P_{R1} =2000 MW, P_{R2} =4000 MW, P_{R3} =8000 MW, f =60 (Hz); D_1 = D_3 =0.015, D_2 =0.016 (pu Hz); B_1 =0.3483, B_2 =0.3827, B_3 = 0.3692 (pu Hz); $2H_1$ =0.1667, R_1 =3.0, R_2 =2.73, R_3 =2.82 (Hz/pu); $2H_2$ =0.2017, $2H_3$ =0.1247, (pu s); T_{t1} =0.4, T_{t2} =0.44, T_{t3} =0.3 (s); $K_{r1} = K_{r2} = K_{r3}$ =0.5; T_{12} =0.2, T_{23} =0.12, T_{31} =0.25 (pu/Hz), $T_{r1} = T_{r2} = T_{r3}$ =10 (s), T_{g1} = 0.08, T_{g2} =0.06, T_{g3} =0.07 (s);

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