GU J Sci 31(1): 139-153 (2018)

Gazi University

Journal of Science

http://dergipark.gov.tr/gujs

Gravitational Search Algorithm (GSA) Based PID Controller Design for Two Area Multi-Source Power System Load Frequency Control (LFC)

Shah Jahan SAFI [1,*], Suleyman Sungur TEZCAN[2], Ibrahim EKE[3], Zakirhussain FARHAD[4]

[1,4] *Kabul Polytechnic University, Faculty of Electro-mechanics, Department of Electrical Power Engineering, 1001, Kabul, Afghanistan.*

[2] *Gazi University, Faculty of Engineering, Department of Electrical and Electronics, 06570, Ankara, Turkey.*

[3] *Kirikkale University, Faculty of Engineering, Department of Electrical and Electronics, 71450, Kirikkale, Turkey.*

Article Info

Received: 19/10/2017
Accepted: 23/12/2017

Keywords

Automatic Generation Control.
Gravitational Search algorithm.
Proportional, Integral and Derivative plus Filter controller.

Abstract

This paper presents the design and performance analysis of a meta-heuristic search technique (Gravitational-Search-algorithm) for optimal tuning of Proportional-Integral-Derivative plus Filter (PIDF) controller for automatic generation control of multi-source two area interconnected power system. Integral of absolute magnitude of square of error (IASE) is used as objective function. Excellency of the proposed approach is shown with comparison of differential evolution and particle swarm optimization algorithm. The dynamic response has been studied under variety of operating-conditions. The simulation results by MATLAB/Simulink program represent that the tuned PIDF-controllers by gravitational search algorithm supply the better damping of oscillations in power system.

1. INTRODUCTION

In large scale interconnected power system operation and control, the subject of load frequency control (LFC) or automatic generation control (AGC) is very important to supply consumers, reliable and high-quality electric energy. Varies the demand load during time interval and that variation caused changing operating point of power system, the frequency deviates from predetermined value and can be moves towards instabilities [1]. The main aim of automatic generation control problem is to minimize zero steady-state errors for the deviation of frequency and better tracking load demands in power system [2]. The traditional proportional, integral (PI) and the derivative (PID) controllers are widely used for minimizing the deviation of the system frequency in modern power systems. Due to the conventional PI and PID controllers have fixed structure and constant gain parameters which are commonly used to tune for one operating condition [3]. However, owing to the complication of the power systems like variable operating points and nonlinear load characteristics, in some operating conditions the PI and PID controllers tuning with conventional methods may not work suitably [4]. Literature reported on load frequency control problem that some of existence control strategies to perform good performance [5]. On the base of these methods are modern control theory, Fuzzy system theory, Self-Tuning control, Neural Network control, Adaptive control and Genetic Algorithm [6-11]. Over the past few years, a lot of stochastic methods have been used for tuning of the parameters of PID to keep the scheduled constant value of the system frequency. These techniques have been applied by many researchers for AGC problem in modern power systems. H. Gozde et al. designed PI and PID controllers for two-area thermal

*Corresponding author, e-mail: safi.2001@kpu.edu.af

interconnected power system using artificial bee colony (ABC) algorithm to tune the parameters. By the transient response analysis method the performance of ABC which tuned PI/PID parameters are compared with PSO algorithm [12]. M. Omar et al. presented a novel artificial intelligence technique known as ant colony optimization (ACO) is used for PID parameters optimization for load frequency control [13]. Sahu Rabindra Kumar et al. for load frequency control of interconnected tow-area power system, have been designed GSA based PI-controllers. To demonstrate the superiority of the designed controllers that is compared with the results of modern heuristic optimization methods like genetic algorithm (GA) and bacteria foraging optimization algorithm (BFOA) based PI- controllers that released in recently [14]. Sathya et al. highlighted dual mode Bat algorithm based scheduling of PI controllers for interconnected power systems [15]. K. P. Singh Parmar, investigated the multi-source single area power system load frequency control problem with redox flow batteries (RFB) using efficient particle swarm optimization technique and obtained PSO based PI controller gains which is robust and performs well under the wide range of load disturbances [16]. Paramasivam Balasundaram et al. to improve the multi-area interconnected multi-unit power system load frequency control, proposed a complicated application of RFB coordinated with unified power flow controller (UPFC) and applied ABC algorithm to obtain optimum parameters of RFB [17]. Adaptive indirect adaptive fuzzy control technique for multi-area power system has been recently proposed by Yousef [18]. Haluk Gozde et al. is suggested a novel gain scheduling PI control strategy for AGC with nonlinearity governor dead-band of power system. This strategy evaluates the control as problem of optimization, and to increase the performance of convergence to the global optima, two different objective functions with tuned weight coefficients are derived. The Particle Swarm Optimization algorithm based on craziness is proposed to optimize the parameters, because of convergence superiority [19]. Sukhwinder Singh Dhillon et al. investigates load frequency control of large interconnected power system consisting of conventional and renewable energy sources, using hybrid heuristic approach to obtain optimum gains for PI controller [20].

This study introduces a novel heuristic search technique known as GSA for optimal tuning of PIDF controllers that some benefits of the proposed algorithm are reported in [21,22] such as low algorithm memory, the ability of defection from local optima, easy implementation, good and fast convergence and adaptive learning rate. The proposed approach superiority is compared by the results of some newly released techniques like DE and PSO algorithms which they have some advantages like stable convergence characteristics, simplicity and high quality solutions within shorter calculation time, easy use, high efficiency and real coding and speediness. The motivation behind this research is to prove and demonstrate the robustness of GSA based PIDF controller, and to enhance the dynamic response of both frequency deviation and tie-line power change under various operating point in presence of system nonlinearities. The rest of this paper is organized as follows: Section II focuses on the modeling of the system under investigation. Structure of the controllers is offered in section III. Section IV is an overview of GSA. Simulation analysis is presented in section V and finally conclusion is discussed in section VI.

2. MODELING OF POWER SYSTEM

The system under investigation consists from interconnected two-area multi-source power system that given in Figure 1, using the GSA based PIDF controllers. The system consists of non-reheat thermal, hydro and gas based units in control area-1 and a non-reheat thermal unit in control area-2. The rating power and nominal load of control area are 2000 MW and 1740 MW respectively, inertia constant (H = 5 MW-s/MVA) and rated frequency (f_r = 60 Hz). The interconnected power system transfer function model is shown in Figure1. Each area of the system as shown in Figure1 consists of generator, turbine and speed governing system. The inputs are the control area (u_1 and u_2), load disturbances (ΔP_{D1} and ΔP_{D2}), and power error (ΔP_{Tie}) of tie-line. The outputs are the area control error (ACE) and frequency deviations of generator (denoted as Δf_1 and Δf_2) given by [19]. In Figure 1, ACE_1 and ACE_2 are area control errors; β_1 and β_2 are the frequency bias parameters; u_1 and u_2 are the outputs of the PIDF-controller; R_{T1} and R_{T2} are the regulation parameters of speed governor in Hz/p.u MW; T_{SG1}, T_{SG2}, T_{T1} and T_{T2} are the speed governor time constants and the non-reheat thermal turbine time constant in second respectively. R_H

speed governor regulation parameter; T_{RS}, T_{RH}, T_{GH} and T_W are the rest time of speed governor in s, transient droop time constant in s, main servo time constant in s and water time constant of hydro turbine in s, respectively. R_G, X_G and Y_G are speed governor regulation parameter in Hz/p.u MW and speed governor lead and lag time constants in s, respectively; B_G and C_G are the valve positional constants; T_F and T_{CD} are fuel and compressor discharge volume time constants of gas turbine in s, respectively and T_{CR} is combustion reaction time delay in sec; K_{PS1} and K_{PS2} are the power system gains; T_{PS1} and T_{PS2} are the time constant in sec power system for control area 1 and 2; Δf_1 and Δf_2 are the system frequency deviations in Hz and T_{12} is the coefficient of synchronizing. In Appendix A given the nominal parameters of under power system investigation [23].

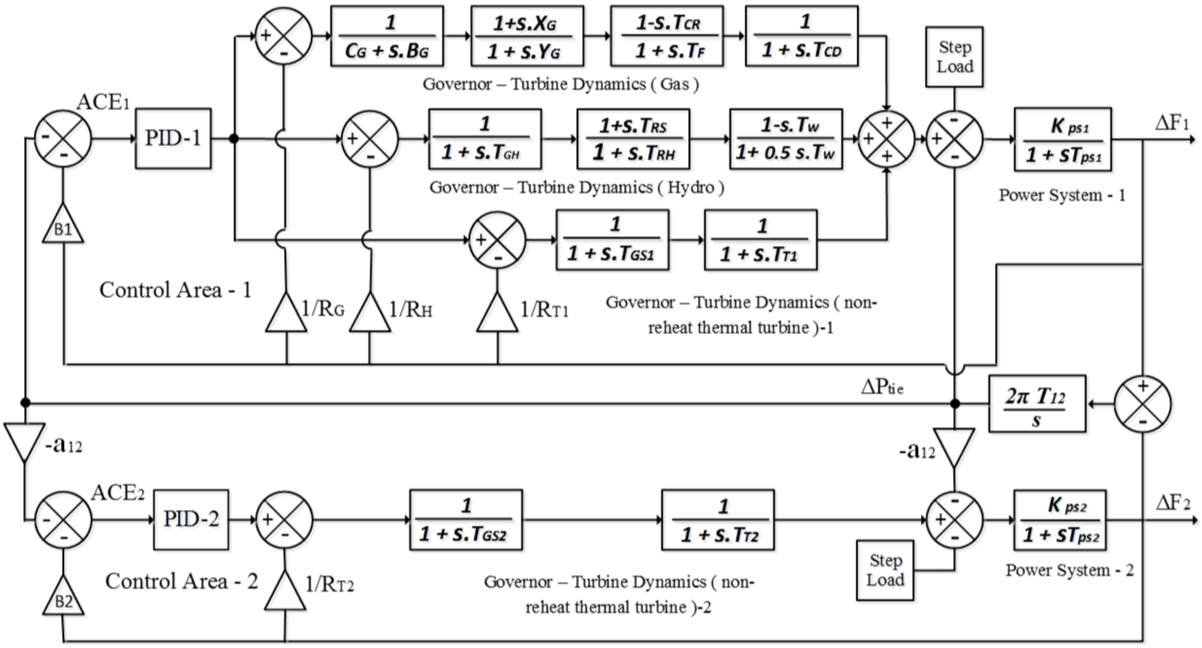

Figure 1. *Under investigation power system transfer function model [18].*

Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (denoted as u_1 and u_2), load disturbances (denoted as ΔP_{D1} and ΔP_{D2}), and tie-line power error ΔP_{Tie}. The outputs are the generator frequency deviations (denoted as Δf_1 and Δf_2) and Area Control Error (ACE) given by:

$$ACE = \beta\Delta f + \Delta P_{tie} \quad (1)$$

where β is the frequency bias parameter. To simplicity the frequency-domain analyses, transfer functions are used to model each component of the area. Turbine is represented by the following transfer function:

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1 + sT_r} \quad (2)$$

The transfer function of a governor is as follows:

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_T(s)} = \frac{1}{1 + sT_G} \quad (3)$$

The speed governing system has two inputs ΔP_{ref} and Δf with one output $\Delta P_G(s)$ given by:

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta f(s) \quad (4)$$

The generator and load is represented by the transfer function:

$$G_P(s) = \frac{K_P(s)}{1 + sT_P} \quad (5)$$

Where $K_P = 1/D$ and $T_P = 2H/fD$.
The generator load system has two inputs $\Delta P_T(s)$ and $\Delta P_D(s)$ with one output $\Delta f(s)$ given by:

$$\Delta f(s) = G_P(s)[\Delta P_T(s) - \Delta P_D(s)] \quad (6)$$

In normal operation, the power flow of tie-line between control areas can be given as follow:

$$P_{tie,1.2} = \frac{|V_1||V_2|}{X_{12}}\sin(\delta_1 - \delta_2) \quad (7)$$

Where X_{12} is tie-line reactance between control areas 1 and 2; V_1, V_2 are the voltages at machine terminals and δ_1, δ_2 the power angles of equivalent machines in control area 1 and 2 respectively. For small deviation of tie-line power flow between controls areas can be written as:

$$\Delta P_{tie,1.2}(s) = \frac{2\pi}{s}T_{12}[\Delta f_1(s) - \Delta f_2(s)] \quad (8)$$

The generalized theory on LFC modeling is contained with more detail in the literature [24-26].

2.1. Structure of Controller

Today among the industrial controllers more than 90% are composed from PID controller that has simplest construction and efficient solution to many real-world control problems. The PID controller consists of the proportional integral plus derivative modes, respectively. A proportional terms is used to reduce the rise time, however cannot zeros the steady-state error. The gain of integral in PID controller has the ability to make zero steady-state error, however it may create the worse transient response. The controller derivative parts are used to increase the system stability, improving the transient response and decreasing the overshoot [27]. Proportional integral controllers are widely used in industry now. When fast response is not need in the system, a controller without derivative (D) mode is used. If high stability or fast responses of system are conceded, proportional, integral plus derivative modes controllers are used [28]. In practical applications, due to the derivative kick pure derivative terms is never used, produced in the control signal for a step input, and to the undesirable noise amplification. For solution to these problems the derivative terms generally can be equipped by a low pass first-order filter. In Figure 2 the structure of PID with first-order low pass filter is given where proportional (K_P) integral (K_I) plus derivative (K_D) gains respectively, and N is the first-order low pass filter coefficient is selected from 1 up to100 [21]. The Eq. 3 represents the PIDF-controller transfer function (Laplace Domain).

$$TF_{PID} = \left[K_p + K_i(\frac{1}{s}) + K_d(\frac{Ns}{s+N})\right] \quad (9)$$

In time domain, the PIDF-controller output as fallow;

$$u_i(t) = K_p * ACE_i(t) + K_i \int_0^t ACE_i(t)dt + \frac{d}{dt} ACE_i(t) \tag{10}$$

Where *ACE* (t) is error signal and *u* (t) is control signal. In the PIDF controllers, control inputs are ACE_1 and ACE_2 whereas u_1 and u_2 are the outputs of control area 1 and 2, respectively. On relating to the inputs and outputs signals of the system u_1 and u_2 are given as:

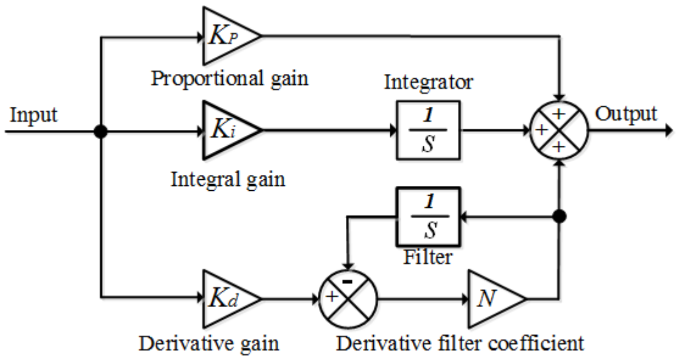

Figure 2. *PIDF controller structure*.

$$u_1 = ACE_1 \left(K_{p1} + \frac{K_{i1}}{s} + K_{d1}s \right) \tag{11}$$

$$u_2 = ACE_2 \left(K_{p2} + \frac{K_{i2}}{s} + K_{d2}s \right) \tag{12}$$

The error signal fed into the proposed PIDF controller consists from ACE. The ACE can be defined in terms of frequency, frequency bias parameters and tie-line error as given by:

$$ACE_1 = \Delta P_{tie,12} + \beta_1 \Delta f_1 \tag{13}$$

$$ACE_2 = \Delta P_{tie,21} + \beta_2 \Delta f_2 \tag{14}$$

$$\mathrm{ACE} = (ACE_1 + ACE_2) \tag{15}$$

In this study, setting of PIDF controller parameters constraint is a major problem. Thus, the PIDF gains should be in limits:

$$Kp_{min,j} \leq Kp_j \leq Kp_{max,j} \qquad Ki_{min,j} \leq Ki_j \leq Ki_{max,j}$$

$$Kd_{min,j} \leq Kd_j \leq Kd_{max,j} \qquad N_{min,j} \leq N \leq N_{max,j}$$

where j is the number of controller gain (here j = 2, due to two controllers). The allowable values (maximum and minimum) of PIDF parameters are Kp_{min}, Ki_{min}, Kd_{min}, N_{min} and Kp_{max}, Ki_{max}, Kd_{max}, N_{max} respectively.

2.2. Gravitational Search Algorithm

Rashedi et al. in 2009 [22], improved one of the recently developed meta-heuristic search algorithm inspired of the gravity and motion based on the law of Newtonian such as gravitational search algorithm (GSA). In GSA, agents are considered as objects and their performance is measured by their masses. In search space each object can be considered as a solution or a part of a solution to the selected problem. All these objects in search space by the force of gravity attract each other, while this force causes a global movement of all objects toward the objects with an enormous mass. The motion of enormous masses that correspond to good solution of the problem is not as quickly as smaller ones. Every mass (agent) is specified by four parameters in GSA, mass position in *d*th dimension, masses of inertia, active and passive gravity masses respectively. The mass positions indicate a solution of the problem and the gravitational and the inertial masses, those control the velocity of an agent are computed by the function of fitness evaluation of the problem. The best fitness and position of corresponding agent in search space will be the global solution and global fitness of the problem at the final recorded iterations [22,29]. For 'n' agent (masses) system, the *i*th position of an agent X_i is given by:

$$X_i = \left(X_i^1 \ , \ldots , X_i^d , \ldots \ X_i^n \right) \quad for \ \ i = 1,2,3, \ldots n \tag{16}$$

where, X_i^d is shows the i^{th} mass position in the d^{th} dimension. At a particular time't' the force acting from mass 'j' to mass 'i' is given by:

$$F_{ij}^d(t) = G(t) \frac{M_{pi}(t) \ \times M_{aj}(t)}{R_{ij}(t) + \varepsilon} \left[X_j^d(t) - \ X_i^d(t) \right] \tag{17}$$

where M_{aj}, G(t), M_{pi} and $R_{ij}(t)$ are active gravitational mass related to agent 'j', gravitational constant at time 't', passive gravitational mass is related to agent 'i', and Euclidian distance between two agents 'i and j' respectively. ε is a small constant, is. In a dimension *d* the total force that acts on agent 'i' can be computed like:

$$F_i^d(t) = \sum_{j=1, j\neq i}^{N} rand_j F_{ij}^d(t) \tag{18}$$

Hence, the acceleration of the agent *i* at time *t* and in d^{th} dimension according to the law of motion, $a_i^d(t)$ is defined by:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{19}$$

where M_{ii} is the i^{th} agent inertial mass. The velocity of an agent is updated depending on the current velocity and acceleration. The velocity and position are given by:

$$V_i^d(t+1) = rand_i * V_i^d(t) + \ a_i^d(t) \tag{20}$$

$$X_i^d(t+1) = X_i^d(t) + \ V_i^d(t+1) \tag{21}$$

For giving a randomized characteristic, the random numbers are used to the search process. At the beginning determine the value of gravitational constant G. For controlling the search accuracy it is decreased by time and expressed as the initial value (G_0) function and time 't' as:

$$\mathrm{G}\ (t) = G_0 \times e^{\left(-\frac{\alpha t}{T}\right)} \tag{22}$$

where α is a constant and T - number of iteration. The inertia masses of gravitational are evaluated with the fitness function. Efficient agents are characterized by heavier mass.

$$m_i\,(t) = \frac{fit_i\,(t) - worst_i\,(t)}{best\,(t) - worst\,(t)} \tag{23}$$

$$M_i\,(t) = \frac{m_i\,(t)}{\sum_{j=1}^{N} m_j\,(t)} \tag{24}$$

where $fit_i\,(t)$ shows ith agent fitness value at time t and $best(t)$ for a minimization problem is defined as follow:

$$Best\,(t) = \min_{j\,\in\,\{1....n\}} fit_j\,(t) \tag{25}$$

$$Worst\,(t) = \max_{j\in\{1....n\}} fit_j\,(t) \tag{26}$$

Between exploitation and exploration to done a good compromise, the agents number is reduced with lapse of Eq. (12) and therefore a collection of agents with enormous mass are used to apply their force to the other. The GSA performance is improved with controlling exploitation and exploration. By GSA, the exploration must be used at beginning for avoiding trapping in a local optimum. By updating after every iteration, exploitation and exploration must fade in and out, respectively.

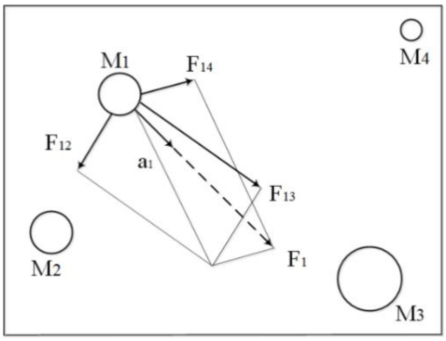

Figure 3. *Total forces acting on an object*

In GSA, only the K_{best} agents attract the others. At the beginning of the proses all agents apply the forces and by passage of time K_{best} is linearly reduced and only one agent to apply force to the others at the end. Therefore, Eq. (12) is rewrite as follows:

$$F_i^d(t) = \sum_{j\in k_{best},j\neq i} rand_j F_{ij}^d(t) \tag{27}$$

The GSA steps:

1. Identifying the search space of parameters to be searched.
2. Initializing the variables.
3. Evaluating the fitness of every agent.
4. *G (t), best (t), worst (t)* and $M_i(t)$ are updated for *i= 1, 2, 3,…………………………., N.*
5. Calculating the total force in various directions.
6. Calculating the acceleration and velocity.
7. Updating the position of the agents
8. Repeating of the steps (3) to (7) up to stop to reach criteria.
9. End.

3. SIMULATION RESULTS

Simulation studies are achieved to examine the performance of the interconnected two-area multi-source non-reheat thermal, hydro and gas turbine power system given in Figure1. 1% step load (ΔP_{D1}) is applied in area 1 as a case -1. The PIDF controller parameters are tuned by GSA and the results are compared with some recently published techniques like PSO and DE algorithm. In this study, integral of absolute magnitude of square of error (IASE) is used to obtained optimum gains of the PIDF-controller as cost function, which given as follows:

$$J = \text{IASE} = \int_0^t (|ACE|)^2 \cdot t \cdot dt \qquad (28)$$

Further, in this work the system and controller parameters held fixed and step load disturbance is varied from 1% to 10% increased linearly and suddenly to examine the performance of the proposed LFC system. The PIDF controller parameters are given in Table 1.

Table 1. *PIDF parameters obtained by proposed techniques*

Controller/ Control Area		Area-1	Area-2
GSA-PIDF	K_P	7.7222	1.6005
	K_i	7.8643	6.4498
	K_D	2.8549	3.4393
	N	77.6759	49.5001

Case 1: 1 % ΔP_{D1} has been applied to area-1 as a step load. The responses of frequency deviation and tie-line power change in control area-1and area -2 are shown in Figs. 4, 5 and 6, respectively. It is clear from figure (4, 5 and 6), that the designed controller using GSA provides better performance than DE and PSO based PIDF controller for frequency response of the power system under investigation. The proposed PID-controller succeeded in damping all oscillations, minimizing settling time and reducing overshoot as shows in Table 2.

Case 2: A step load change linearly increased from 1% to reach 10% in area-1. The responses of frequency deviation and tie line power change are shown in Figure 7. It has been found that first over shoot increases with increase of 1% ΔP_{D1} and then by increasing of ΔP_{D1} up to 10%, it's over shoot and settling time remains almost the same as shows in Table 3. The controller performs well for 1% to 10% variation of ΔP_{D1}.

Case 3: in this case we suppose a step load suddenly change from 1% up to 10% in area-1. The responses of frequency deviation in area-1, 2 and tie-line power change are shown in Figure 8, 9, 10. It can be seen that the over shoot is increased by increasing of ΔP_{D1} from 1% up to 10%, however settling time remains almost the same as shows in Table 4. The results declared that the PIDF controller which is able to guarantee robustness and better performance of power system under investigation in wide load variation of ΔP_{D1}.

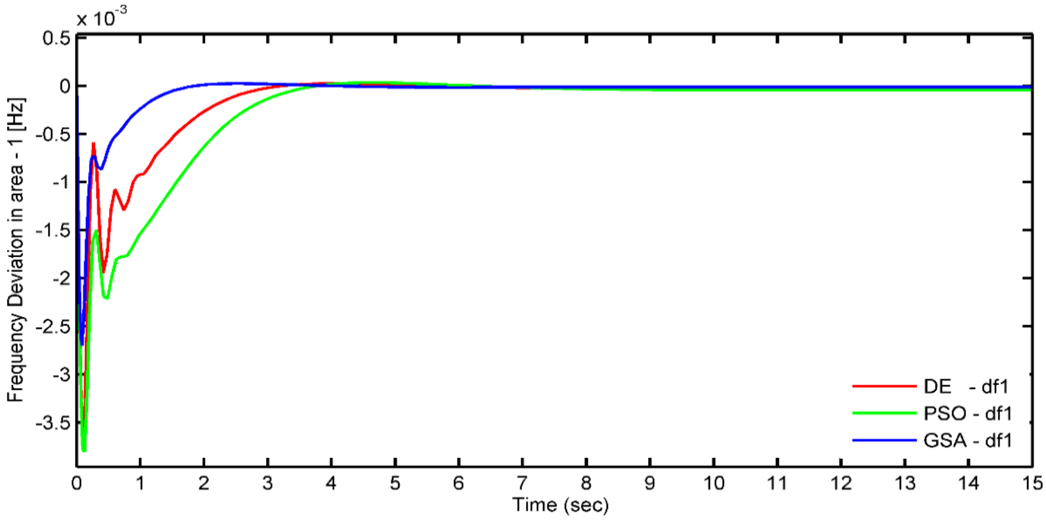

Figure 4. *Deviation of* Δf_1 *for* $\Delta P_{D1} = 0.01$ *p.u.*

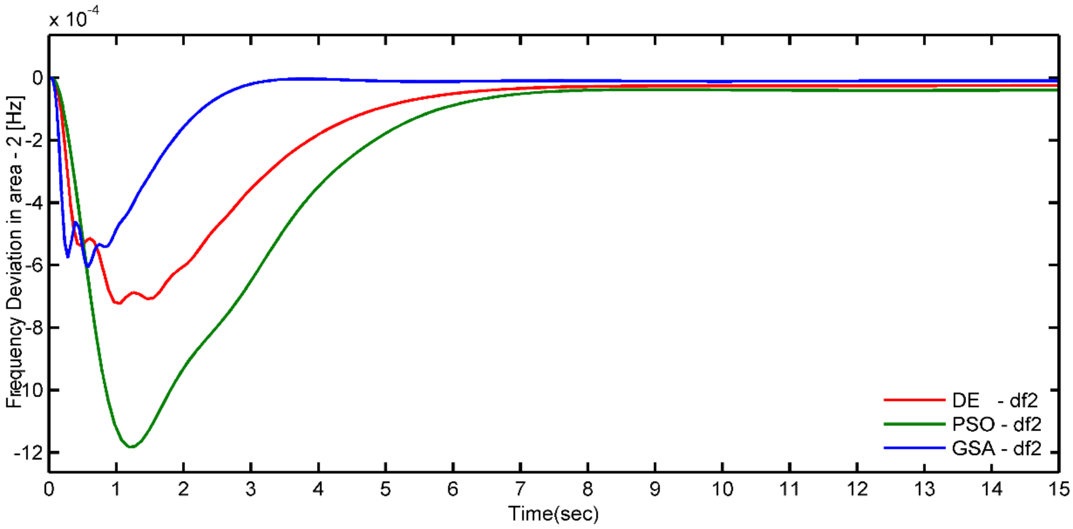

Figure 5. *Deviation of* Δf_2 *for* $\Delta P_{D1} = 0.01$ *p.u.*

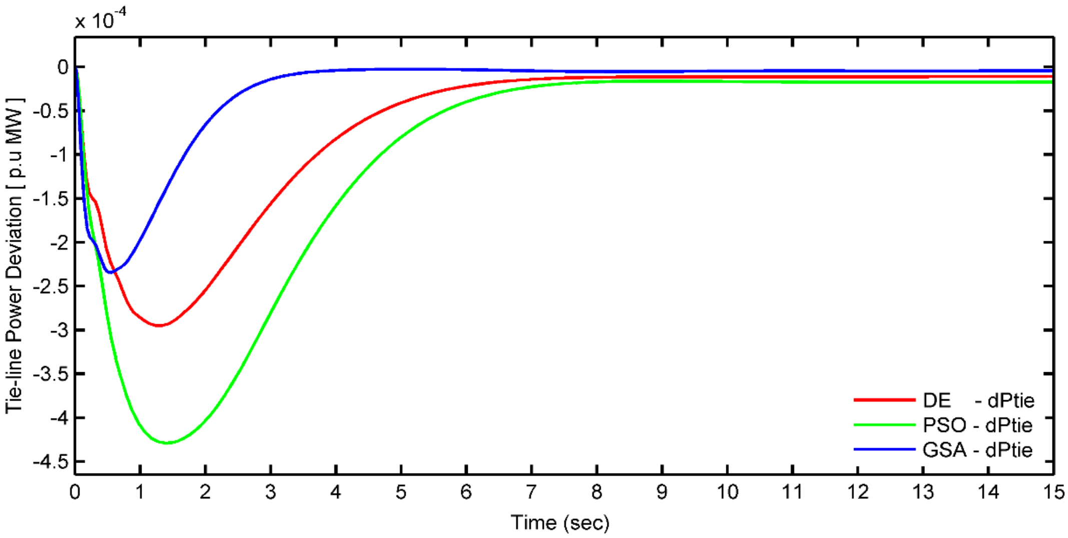

Figure 6. *Deviation of* ΔP_{tie} *for* $\Delta P_{D1} = 0.01$ *p.u.*

Table 2. *Simulation result obtained by different algorithms*

Δf & ΔP_{tie} / Techniques		GSA	DE	PSO
Δf_1 [Hz]	Overshoot	0	0	0
	Undershoot	0.00269	0.0036	0.0038
	Settling time (sec)	1.6	3.2	3.8
Δf_2 [Hz]	Overshoot	0	0	0
	Undershoot	0.0006	0.00072	0.0012
	Settling time (sec)	3.3	7.2	8
ΔP_{tie} [p.u MW]	Overshoot	0	0	0
	Undershoot	0.00023	0.0003	0.00043
Settling time (sec)		3.8	8	8

Case 4: In this operating condition, 15% and 10% of step load demand are simultaneously applied for nominal operating condition in the control area-1, 2. The frequency deviation in area 1, 2 and tie-line power change responses are shown in Figure 11, it can be seen that the over shoot is increased in both area-1 and area-2 according to 15% ΔP_{D1} and 10% ΔP_{D2} but the settling time remains very closed compared with case 1 & 2 as shows in Table 5. From Figure 11, it is obvious that the designed PIDF controller that its parameters are optimize by GSA stochastic method provide better performance for frequency responses of the power system under study.

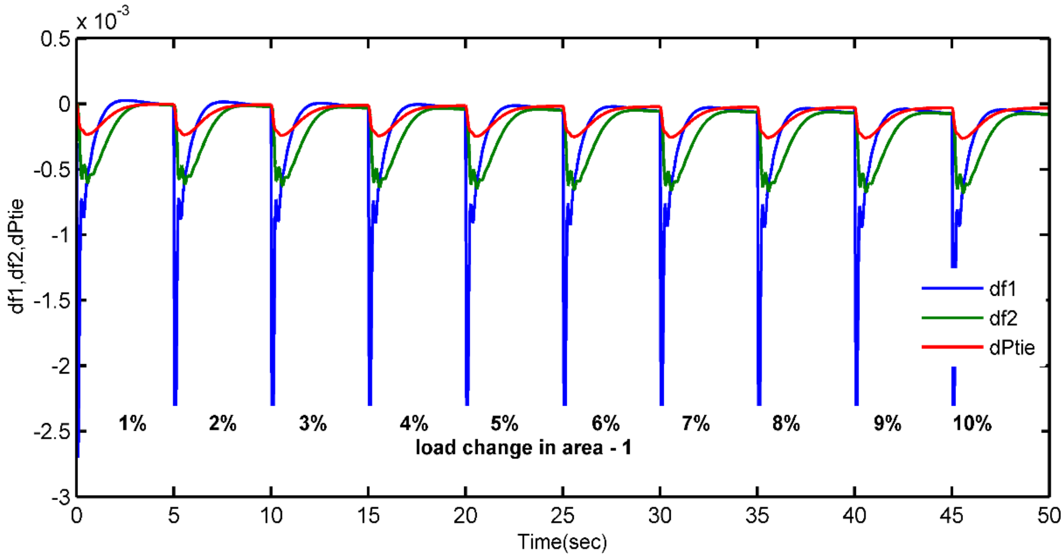

Figure 7. *Deviation of Δf_1, Δf_2 and $\Delta Ptie$ for (1-10) % of ΔP_D*

Table 3. *Simulation result obtained by applied (1-10) % of ΔP_{D1} in area-1*

Δf & ΔP_{tie} / ΔP_{D1}		**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
Δf_1 [Hz]	Overshoot	0	0	0	0	0	0	0	0	0	0
	Undershoot	0.00269	0.00269	0.00269	0.00269	0.00269	0.00269	0.00269	0.00269	0.00269	0.00269
Settling time (sec)		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Δf_2 [Hz]	Overshoot	0	0	0	0	0	0	0	0	0	0
	Undershoot	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Settling time (sec)		3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
ΔP_{tie} [p.u.MW]	Overshoot	0	0	0	0	0	0	0	0	0	0
	Undershoot	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023
Settling time (sec)		3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8

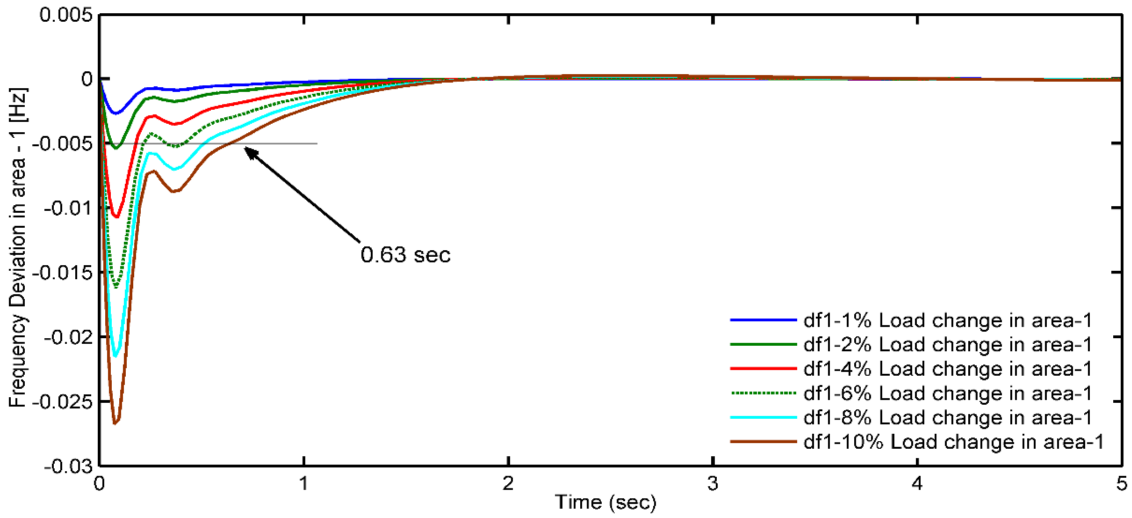

Figure 8. *Deviation of Δf_1 for (1-10) % of ΔP_{D1}.*

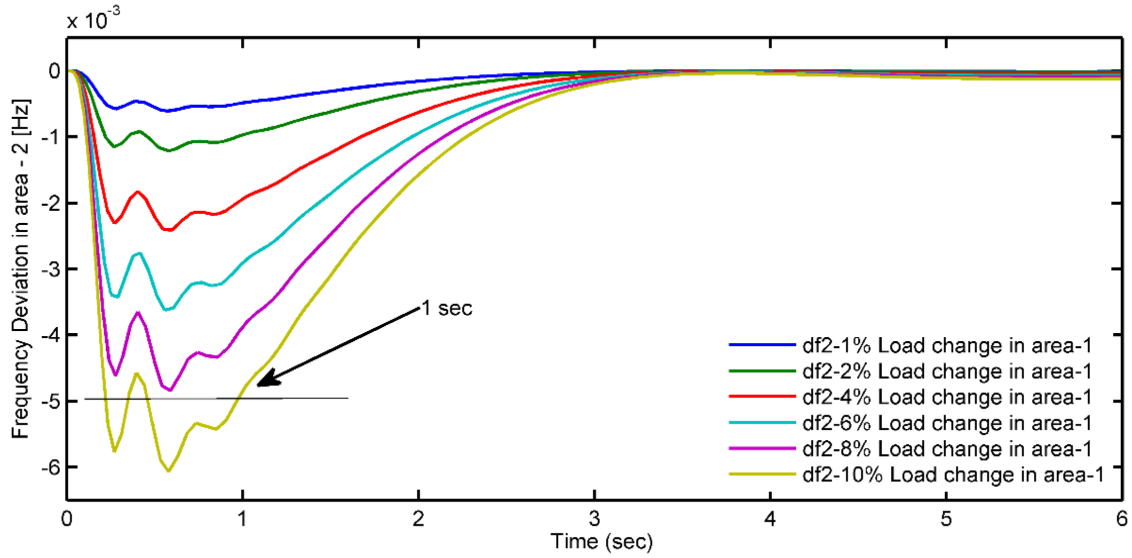

Figure 9. *Deviation of Δf_2 for (1-10) % of ΔP_{D1}.*

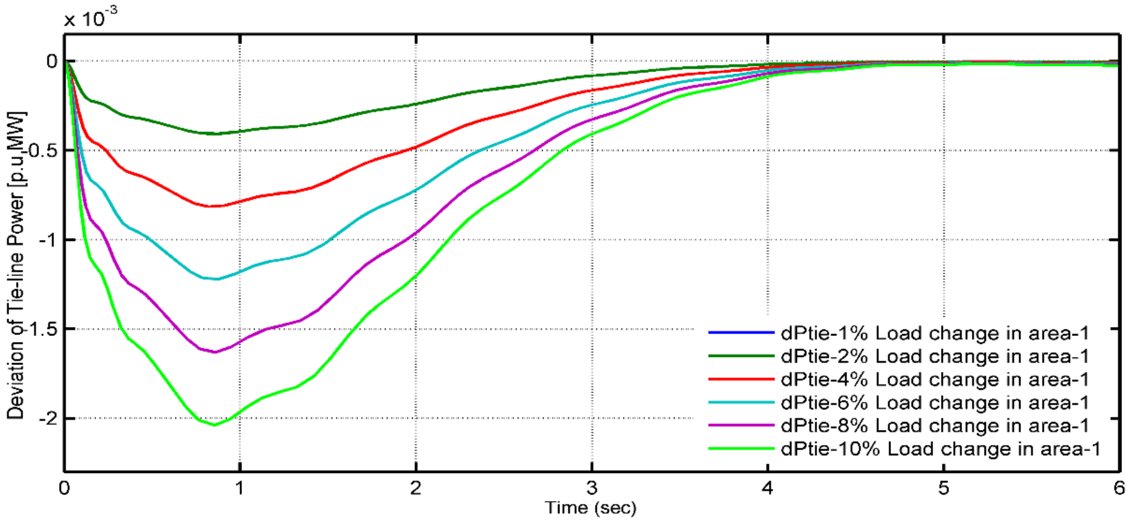

Figure 10. *Deviation $\Delta Ptie$ for (1-10) % of ΔP_{D1}.*

***Table 4.** Simulation result obtained by suddenly applied (1-10) % of ΔP_{D1} in area-1*

ΔP_{D1}/ Δf & ΔP_{tie}		1%	2%	4%	6%	8%	10%
Δf_1 [Hz]	Overshoot	0	0	0	0	0	0
	Undershoot	0.00269	0.0054	0.0107	0.01622	0.02154	0.0267
Settling time (sec)		1.6	1.6	1.6	1.6	1.6	1.6
Δf_2 [Hz]	Overshoot	0	0	0	0	0	0
	Undershoot	0.0006	0.00121	0.0024	0.00362	0.0048	0.0061
Settling time (sec)		3.3	3.3	3.3	3.3	3.3	3.3
ΔP_{tie} [p.u MW]	Overshoot	0	0	0	0	0	0
	Undershoot	0.00023	0.00046	0.00093	0.0014	0.00187	0.00235
Settling time (sec)		3.8	3.8	3.8	3.8	3.8	3.8

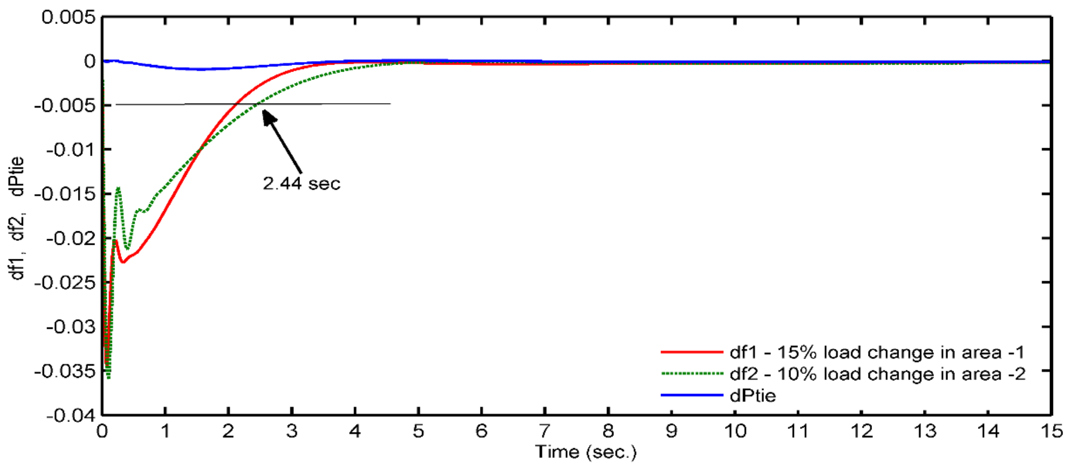

***Figure 11.** Deviation Δf_1, Δf_2, and $\Delta Ptie$ for ΔP_{D1}=15 % and ΔP_{D2}=10 % p.u load change respectively.*

***Table 5.** Simulation result obtained by applied 15 % & 10 % of ΔP_{D1} and ΔP_{D2}.*

ΔP_{D1}& ΔP_{D2}/ Δf & ΔP_{tie}		Δf_1[Hz]	Δf_2[Hz]	ΔP_{tie}[p.u.MW]
(15, 10)%	Overshoot	0	0	0
	Undershoot	0.03439	0.0355	0.001
Settling time (sec)		3.6	4.6	3

4. CONCLUSION

In this paper the gravitational search algorithm is used to obtain optimum gains of the PIDF controller for problem of automatic generation control (AGC). First GSA is illustrated in detail and therefore investigated power system under study. The results of simulation emphasize the effectiveness of the GSA. The GSA based PIDF controller has better performance of the convergence to the best solution than DE-PIDF and PSO-PIDF performance for frequency response of the power system under investigation. Moreover, for the superiority of the designed controller that tuned its gains by proposed algorithms, the system parameters held fixed and dynamic response has been studied under the wide variety of operating conditions. In the case in which 15% and 10% of step loads were applied simultaneously to area-1 & 2 respectively, the undershoot of the frequency deviation are Δf_1 = 0.03439 Hz, Δf_2 = 0.0355 Hz, and $\Delta Ptie$ = 0.001 p.u.MW. It is evident that the proposed PIDF controller shows better dynamic response that satisfies the requirements of AGC. The PIDF controller which is tuned by GSA has been strongly proposed for automatic generation control. The controller design is simple and systematic.

Appendix A

The power system under investigation parameters consist of:
P_{rt} = 2000 Rated capacity of the area [MW]
P_{Lo} = 1740 Nominal load of the area [MW]
$K_{PS1} = K_{PS2}$ = 68.9655 [Hz/p.u MW]
$R_{T1} = R_{T2} = R_H = R_G$ =2.40 [Hz/p.u MW]
$T_{SG1} = T_{SG2}$ = 0.06 [sec], $T_{T1} = T_{T2}$ = 0.30 [sec]
T_{RS} = 5 [sec], T_{RH} =28.75 [sec], T_{GH} = 0.20 [sec]
T_W = 1.1 [sec], X_G = 0.6 [sec], Y_G = 1 [sec], B_G = 0.050
C_G= 1, T_F = 0.230 [sec], T_{CR} = 0.010 [sec], T_{CD} = 0.020 [sec]
T_{12} = 0.0433 [sec], $\beta_1 = \beta_2$= 0.4312, α_{12} = -1
$T_{PS1} = T_{PS2}$ = 11.49 [sec],

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Duman, S., Yorukeren, N., Altas, I. H., "Load Frequency Control of a Single Area Power System using Gravitational Search Algorithm", International Symposium on Innovations in Intelligent Systems and Applications (INISTA), Trabzon, 1-5, (2012).

[2] Shayeghi, H., Shayanfar, H. A., Jalili, A., "Load Frequency Control Strategies: A State-of-the-Art Survey for the Researcher", Energy Conversion and Management, 50(2): 344-353, (2009).

[3] Duman, S., Yorukeren, N., "Automatic Generation Control of the Two Area Non-reheat Thermal Power System using Gravitational Search Algorithm" Przegląd Elektrotechniczny (Electrical Review), 88(10a): 254-259. (2012).

[4] Gözde, H., Taplamacıoğlu, M. C. and Kocaarslan, İ., "A swarm optimization based load frequency control application in a two area thermal power system", International Conference on Electrical and Electronics Engineering (ELECO 2009), Bursa, 124-128, (2009).

[5] Singh, O., Tiwari, P., Ibraheem., Singh, A., "A Survey of Recent Automatic Generation Control Strategies in Power Systems", International Journal of Emerging Trends in Electrical and Electronics (IJETEE), 7(2): 1-14, (2013).

[6] Kothari, D. P., Nagrath, I. J., Modern power system analysis, 4th edition, Tata McGraw Hill, New Delhi, (2011).

[7] Ramesh S., Krishnan, A., "Fuzzy Rule Based Load Frequency Control in a Parallel AC–DC Interconnected Power Systems through HVDC Link", International Journal of Computer Applications, 1(4): 62-69, (2010).

[8] Sheikh, M. R. I., Muyeen S. M., Takahashi, R., "Application of Self-Tuning FPIC to AGC for Load Frequency Control in Multi-Area Power System" IEEE Power Tech Conference, Bucharest, 2-7, (2009).

[9] Ogbonna, B., Ndubisi, S. N., "Neural Network Based Load Frequency Control for Restructuring Power Industry", Nigerian Journal of Technology (NIJOTECH), 31(1): 40-47, (2012).

[10] Rao C. S., “Adaptive Neuro Fuzzy Based Load frequency Control of Multi Area System under Open Market Scenario” IEEE- International Conference on Advances in Engineering, Science and Management (ICAESM -2012), Gumushane, 5-10, (2012).

[11] Shankar, R., Chatterjee, K., Chatterjee, T. K., “Genetic Algorithm Based Controller for Load-Frequency Control of Interconnected Systems” 1st International Conference on Recent Advances in Information Technology (RAIT-2012), Dhanbad, 1-6, (2012).

[12] Gözde, H., Taplamacıoğlu, M. C., Kocaarslan, I., “Comparative Performance Analysis of Artificial Bee Colony Algorithm in Automatic Generation Control for Interconnected Reheat Thermal Power System”, International Journal of Electrical Power and Energy Systems, 42(1): 167-178, (2012).

[13] Omar, M., Soliman, M., Ghany, A. A. M., Bendary, F., “Ant Colony Optimization based PID for single Area Load Frequency Control”, Intemational Conference on Modelling, Identification & Control (ICMIC), 119-123, Cairo, (2013).

[14] Kumar, S. R., Sidhartha, P., Kumar, R. U., Prabina, R.., “Application of Gravitational Search Algorithm for Load Frequency Control of Multi Area Power System”, Journal of Bioinformatics and Intelligent Control, 2(3): 200-210, (2013).

[15] Sathya MR., Mohamed Thameem Ansari M., “ Load frequency control using Bat inspired algorithm based dual mode gain scheduling of PI controllers for interconnected power system”, Electr Power Energy Syst, 64: 365–374, (2015).

[16] Parmar, K. P. S., “Load Frequency Control of Multi-Source Power System with Redox Flow Batteries and Analysis”, International Journal of Computer Applications, 88(8): 46-52, (2014).

[17] Balasundaram, P., Akilandam C. I., “ABC Algorithm based Load- Frequency Controller for an interconnected Power System Considering nonlinearities and Coordinated with UPFC and RFB”, International Journal of Engineering and Innovative Technology (IJEIT), 1(3): 1-11, (2012).

[18] Yousef, H., “Adaptive fuzzy logic load frequency control of multi-area power system”, Electr Power Energy Syst, 68: 384–95, (2015).

[19] Gözde, H., Taplamacıoğlu, M. C., “Automatic Generation Control Application With Craziness Based Particle Swarm Optimization In A Thermal Power System”, International Journal of Electrical Power and Energy Systems, 33(1): 8-16, (2011).

[20] Dhillon, S. S., Lather J.S., Marwaha S., “ Multi objective load frequency control using hybrid bacterial foraging and particle swarm optimized PI controller”, Electrical Power and Energy Systems, 79: 196–209, (2016).

[21] Sahu, R. K., Panda S., Padhan, S., “Optimal gravitational search algorithm for automatic generation control of interconnected power systems”, Ain Shams Engineering Journal (ASEJ), 5(3): 1-13, (2014).

[22] Rashedi, E., Nezamabadi-pour H., Saryazdi, S., “GSA: A Gravitational Search Algorithm”, Information Sciences, 179(13): 2232-2248, (2009).

[23] Parmar, K. P. S., “PSO based PI Controller for the LFC System of an Interconnected Power System”, International Journal of Computer Applications, 88(7): 20-25, (2014).

[24] Elgerd, O. I., Electric energy system theory, 2nd edition, McGraw Hill, New York, (1983).

[25] Kundur, P., Power system stability and control, 5th reprint, McGraw Hill, New Delhi, (2008).

[26] Bevrani, H., Robust power system frequency control. 1st edition, Springer, New York, (2009).

[27] Patel, A. K., Dharmendra, K. S., Sahoo, B. K.,"Automatic generation control of a two unequal area thermal power system with PID controller using Differential Evolution Algorithm", Journal of Engineering Research and Applications (IJERA), 3(4): 2628-2645, (2013).

[28] Sahu, R. K., Panda, S., Rout, U. K., "DE optimized parallel 2-DOF PID controller for load frequency control of power system with governor dead-band nonlinearity" Electrical Power and Energy Systems, 49: 19–33, (2013).

[29] Rashedi, E., Nezamabadi-pour, H., Saryazdi, S., "Filter modeling using gravitational search algorithm", Engineering Applications of Artificial Intelligence, 24(1): 117-122, (2011).