Ain Shams Engineering Journal (2016) **xxx**, xxx–xxx

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

ELECTRICAL ENGINEERING

A flower pollination algorithm based automatic generation control of interconnected power system

Satya Dinesh Madasu *, M.L.S. Sai Kumar, Arun Kumar Singh

National Institute of Technology Jamshedpur, India

Received 13 November 2015; revised 24 May 2016; accepted 8 June 2016

KEYWORDS

Flower pollination;
Weights;
Dynamic loading;
Automatic generation control;
Two area thermal system;
Governor dead-band nonlinearity

Abstract This paper presents the design and performance analysis of Flower Pollination Algorithm (FPA) based Proportional Integral Derivative (PID) controllers for Automatic Generation Control (AGC) of an interconnected power system. A two area thermal system with governor dead-band nonlinearity is considered for the design and analysis purpose. A different kind of approach is made to design a multi-objective function which contains weighted performance functions such as ISE, IAE, ISTE, ITAE. These weights are the functions of system response. It is noticed that the dynamic performance of new objective optimized PID controller is better than the others mentioned in the literature. The objective function also includes performance response for various percentage of loads, so that obtained gain parameters are optimal for dynamic load conditions.

1. Introduction

The power system is a large-scale network which contains a large number of generators interconnected through the transmission network. In this system, the amount of power generated is consumed at the same instant. Any deviation of power causes frequency imbalance in the system network, where frequency is one of the parameter indexes of an AC network which is sensitive to load imbalance. So the frequency of power system is important performance signal to the system operator for stability and security point of view. The primary response of a power system after a disturbance is mainly accomplished by power plants through their speed governor characteristics and load-frequency response. On the other hand, the secondary control in a power system is performed by some units that are equipped with automatic controller which changes the speed governor set points [1]. The primary objective of the AGC is to regulate frequency at specified nominal value and maintain the power exchange between the control areas at the scheduled values by adjusting the generated power of specific generators. The combined effects of both the tie line power and the system frequency deviation are generally treated as controlled output of AGC known as Area Control Error(ACE). As the ACE is adjusted to zero by the AGC, both frequency and tie-line power errors will become zero [2,3].

* Corresponding author at: Department of Electrical & Electronics Engineering, NIT Jamshedpur, Jharkhand 831014, India.
E-mail address: msdinesh.nitjsr@gmail.com (S.D. Madasu).

Peer review under responsibility of Ain Shams University.

ELSEVIER | **Production and hosting by Elsevier**

http://dx.doi.org/10.1016/j.asej.2016.06.003
2090-4479 © 2016 Ain Shams University. Production and hosting by Elsevier B.V.

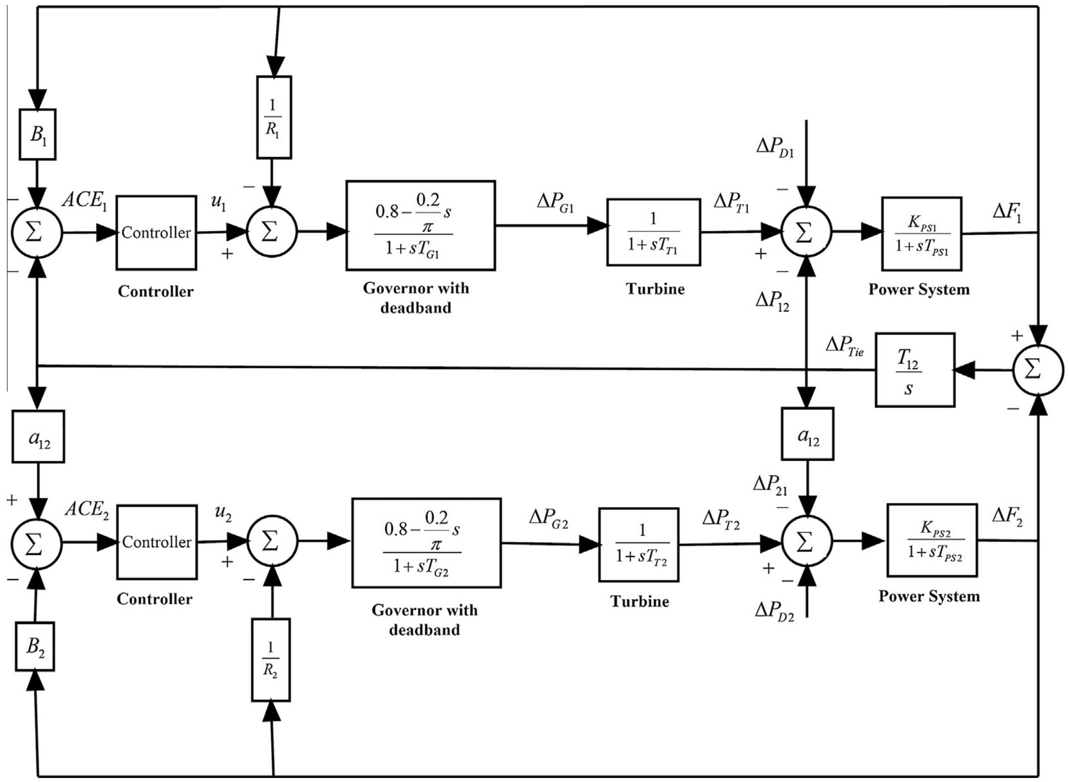

Figure 1 Transfer function model of the two-area interconnected thermal power system.

Optimal control techniques such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy Logic Controller (FLC), and Artificial Neural Network (ANN), have been proposed for Load Frequency Control [4–9]. Controller for AGC is developed in two ways. One of them is self-tuning technique which uses the neural network and fuzzy logic controllers and is adopted by group researchers while others follow suitable optimization algorithms. Fuzzy logic based PID controller can be implemented for all non-linear systems but there is no specific mathematical formulation to decide the proper choice of fuzzy parameters (such as inputs, scaling factors, membership functions, and rule base) [10]. From literature survey the enhancement of power system performance not only depends on control structure but also on well-tuned controllers. For this purpose, a number of artificial optimization techniques are utilized. So a new high-performance heuristic optimization algorithm is always welcome to solve real world problems. Flower Pollination Search Algorithm (FPA) is a newly developed heuristic optimization method based on Pollination of flowers. [11–14] illustrate that FPA has the better quality solution, and robustness than other published methods and also has shown considerable domination over GA. It has only one key parameter p (switch probability) which makes the algorithm easier to implement and faster to reach optimum solution [15]. FPA has special capabilities such as extensive domain search with quality and consistency solution. So it is utilized along with DE for multi-objective optimal dispatch problem [16]. FPA is compared with numerous algorithms [17] and its performance encourages to implement for present problem.

The rest of this paper is organized as follows. Section 2 details the type of power system and their parameters considered for investigation. The FPA is described briefly in section 3, while Section 4 deals proposed approach and Section 5 is presented with results and discussions. Finally, Section 6 shows the conclusions of work.

2. System understudy

The primary objective of the Automatic generation control (AGC) is controlling the power system frequency to the specified nominal value for small perturbation in load. Consider system of Fig. 1 which consists of interconnected power system with two thermal plants. Each one equipped with the non-reheat turbine and a governor modeled along dead band non linearity. These areas are connected through a tie line and whole system is under investigation. From Fig. 1, B_1 and B_2 are frequency bias parameters; ACE_1 and ACE_2 are area control errors; u_1 and u_2 are the control outputs from the controller; R_1 and R_2 are the governors speed regulation parameters in p.u. Hz; T_{G1} and T_{G2} are the speed governor time constants in seconds; ΔP_{G1} and ΔP_{G2} are the changes in governor valve positions (p.u.); T_{T1} and T_{T2} are the turbine time constants in seconds; ΔP_{T1} and ΔP_{T2} are the changes in turbine output powers; ΔP_{D1} and ΔP_{D2} are the load demand changes; ΔP_{Tie} is the incremental change in tie line power (p.u.); K_{PS1} and K_{PS2} are the power system gains; T_{PS1} and T_{PS2} are the power system time constants in seconds; T_{12} is the synchronizing coefficient and Δf_1 and Δf_2 are the system frequency deviations in Hz. The relevant parameters are given in Appendix. The transfer function of governor with nonlinearity is given by [18]

$$G_g = \frac{0.8 - \frac{0.2}{\pi}s}{1 + sT_g} \quad (1)$$

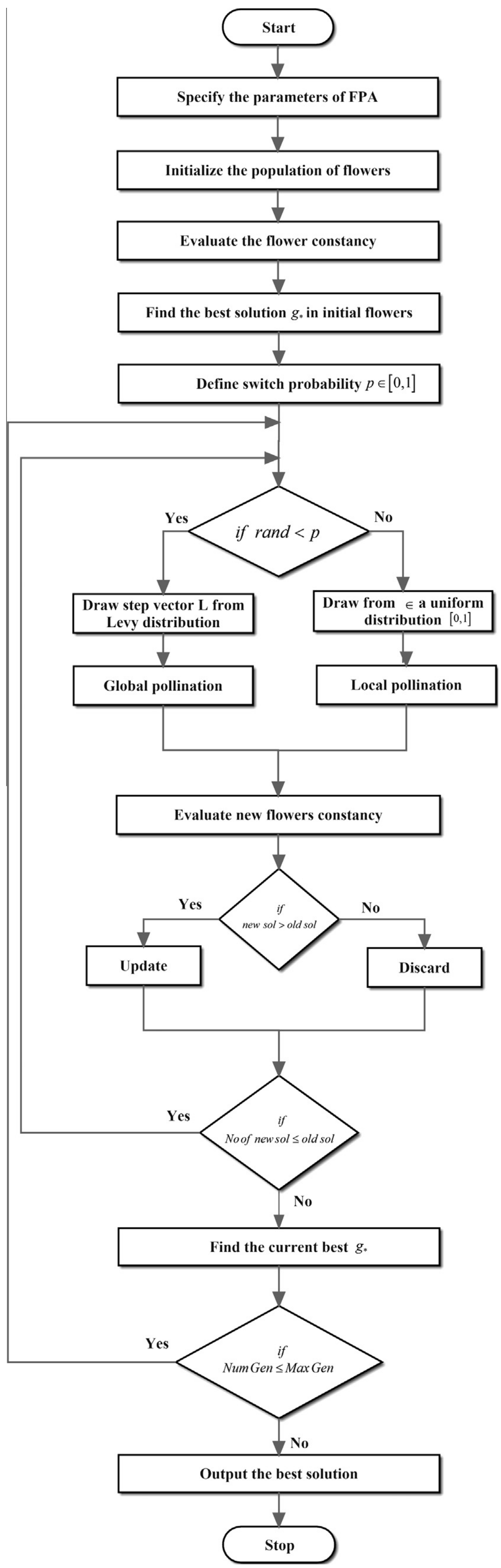

Figure 2 FPA chart.

3. Overview of flower pollination search algorithm

Flower Pollination Algorithm (FPA) was developed by Xin-She Yang in 2012 [19], inspired by pollination of flowering plants. FPA with multi-objective optimization function is utilized for controller design [20,21]. Flower pollination is an activity involving the transfer of pollen among the flowers. This takes place typically in two ways. First One through self-pollination (or) local pollination is a biotic form, which contributes 10% of pollination where no pollinators are required. The second one through cross pollination (or) global pollination is an abiotic form which involves pollinators such as insects, birds, bats and other animals, and contributes 90% of pollination. This phenomenon involves agents such as pollinators that move from one flower to other flowers exhibiting a foraging behavior with a pollinator moving more

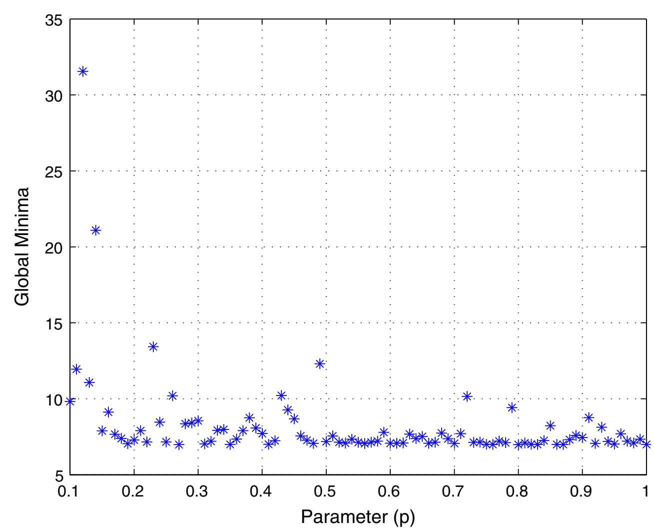

Figure 3 Change in global minima with respect to parameter p of FPA.

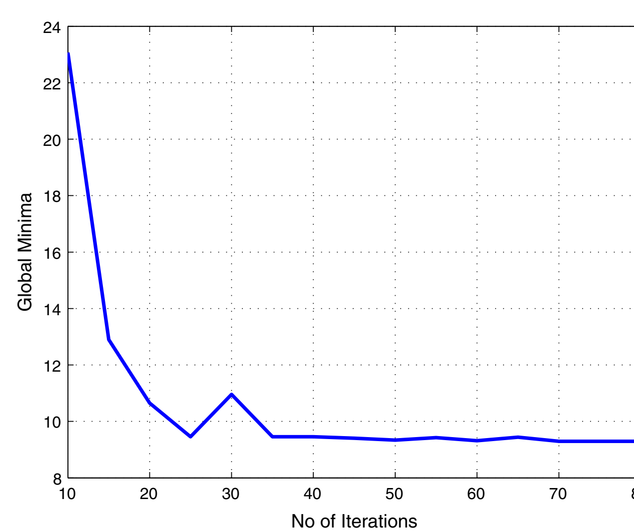

Figure 4 Change in global minima with respect to number of iteration of FPA.

Please cite this article in press as: Madasu SD et al., A flower pollination algorithm based automatic generation control of interconnected power system, Ain Shams Eng J (2016), http://dx.doi.org/10.1016/j.asej.2016.06.003

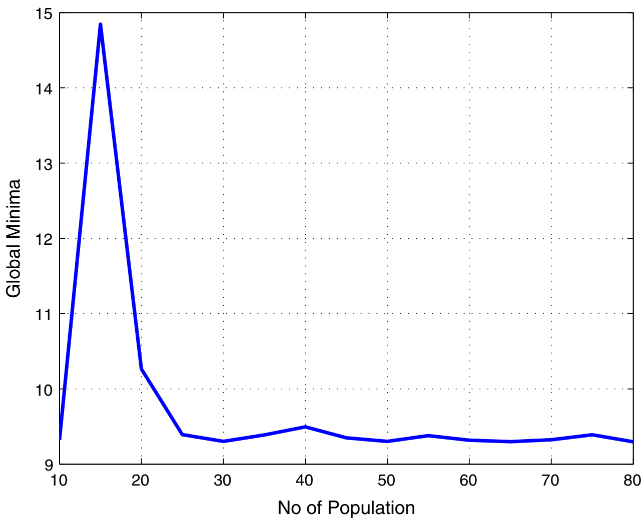

Figure 5 Change in global minima with respect to population of FPA.

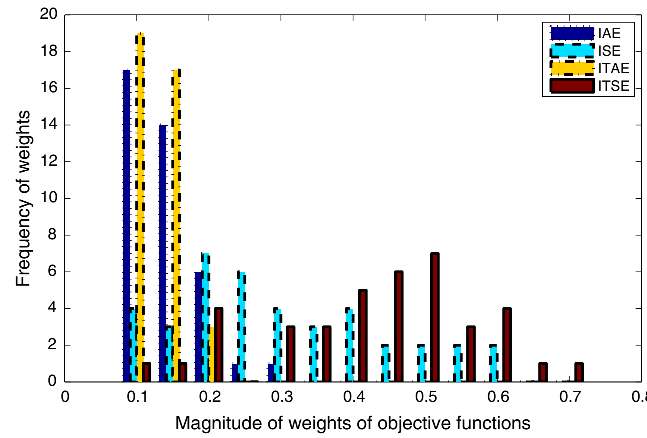

Figure 6 Magnitude of weights of objective functions V_s frequency of weights.

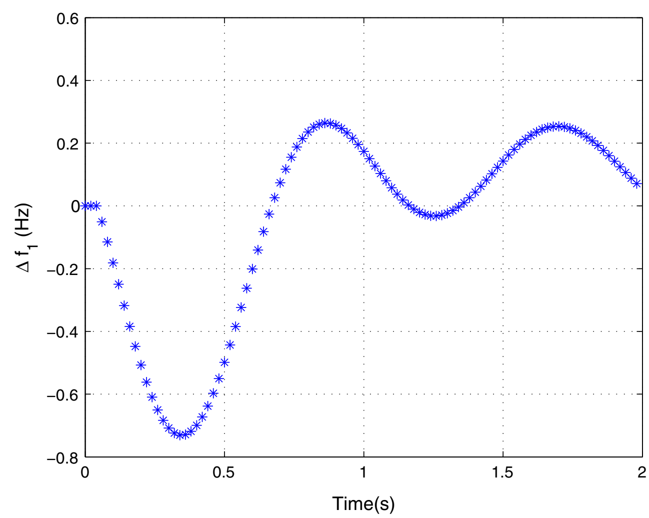

Figure 7 Discrete response from proposed model for Δf_1 V_s time.

frequently to certain flowers than others. The frequency of visit to a flower is indicated by term flower constancy. The proposed flower pollination algorithm is depicted through flowchart as shown in Fig. 2.

From the flowchart, it is evident that initial step of this algorithm deals with the selection of population size (N) and a parameter (p) which help to decide the amount of self-pollination and cross pollination to take place. The algorithm continues by initializing specified number of population (N), with each one containing a group of variables which are optimized using the objective function. This algorithm contains an indexing term called flower constancy for each population which determines how well their variables minimize the objective function. Based on the flower constancy, population are queued and best among them is found.

FPA proceeds through generation of new population based on the parameter p, which decides whether this population is generated through self-pollination (or) cross pollination. This is carried out by generating a random variable between 0 and 1 and comparing with p i.e., if the random variable is less than $p$global pollination takes place (or) else local pollination occurs. For global pollination, agents would move with a different step size of length from one flower to another, which is mimicked by levy distribution of flight [22,23] and mathematically represented as (2)

$$L \sim \frac{\lambda\Gamma(\lambda)sin(\frac{\pi\lambda}{2})}{\lambda}\cdot\frac{1}{s^{1+\lambda}}, \quad (s \gg s_0 > 0). \tag{2}$$

The new population generated through global pollination is given by Eq. (3).

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(g_* - x_i^t) \tag{3}$$

where x_i^t is the pollen i or solution vector x_i at iteration t and g_* is the current best solution found among all population at the current iteration. Here γ is a scaling factor to control the step size and $L(\lambda)$ is a step-size parameter that corresponds to the strength of the pollination and a standard gamma function. The local pollination occurs within a small neighborhood of the current population. So its step size 'ϵ' is taken from a uniform distribution. The mathematical expression for such an operation is expressed as (4)

$$x_i^{t+1} = x_i^t + \epsilon\left(x_j^t - x_k^t\right) \tag{4}$$

where x_j^t and x_k^t are pollen from different flowers of the same plant species.

Flower constancy for the new population is found in a similar manner as stated before. If new population flower constancy is better than the previous population, they are updated in the position of the previous one (or) else discarded. This process of generation and comparison will continue until the count reaches N. The best among the current population is found and declared as current global best. This process repeats for a maximum number of iterations as specified. The current global best is declared as best solution.

4. The proposed approach

Over the past decades, many control strategies have been proposed for AGC, viz. Proportional and integral (PI), and Pro-

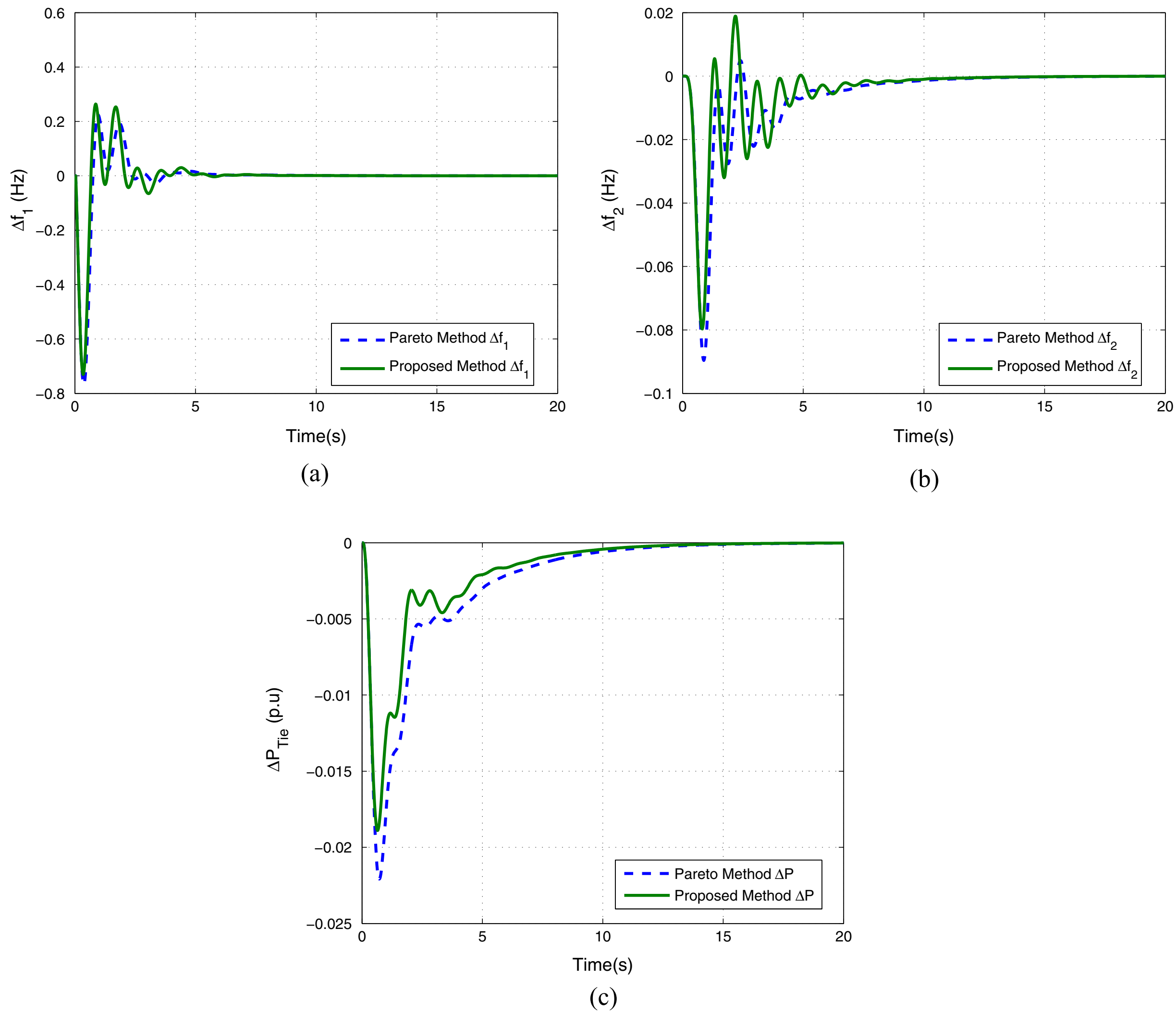

Figure 8 Comparison of Pareto and proposed methods: (a) Δf_1, (b) Δf_2, (c) ΔP_{Tie}.

portional, Integral and Derivative (PID). [24]. In this paper, PID controllers are used to improve the dynamic performance of AGC for a two area thermal power system. The PI, PID control action depends on K_P, K_I, K_D gains which vary for different applications. The tuning of these variables depends on the desired responses of the system. The main function of AGC is to control load frequency and tie line power during load disturbance. So the error signals of frequency and tie line power are used as design criteria to tune the PID controller. The error inputs to the controllers are the respective area control errors (ACE) given by Eqs. (5) and (6):

$$e_1(t) = ACE_1 = B_1\Delta f_1 + \Delta P_{Tie} \tag{5}$$

$$e_2(t) = ACE_2 = B_2\Delta f_2 + \Delta P_{Tie} \tag{6}$$

The control inputs of the power system u_1 and u_2 with PID structure are given by Eqs. (7) and (8):

$$u_1 = K_{P1}ACE_1 + K_{I1}\int ACE_1 + K_{D1}\frac{dACE_1}{dt} \tag{7}$$

$$u_2 = K_{P2}ACE_2 + K_{I2}\int ACE_2 + K_{D2}\frac{dACE_2}{dt} \tag{8}$$

The controllers in both the areas are considered to be identical i.e., $K_{P1} = K_{P2}, K_{I1} = K_{I2}, K_{D1} = K_{D2}$. In this work, flower pollination algorithm (FPA) which is described in Section 3 is used to tune the PID controller for a two area Interconnected system. Proportional gain constant (K_{P1}), Integral gain constant (K_I), and Derivative gain constant (K_D) are considered as variables describing a population defined in an FPA. FPA requires an objective function which uses the design criteria to calculate the flower constancy of the defined population.

An objective function is created which uses the variables of the population from FPA, passes through a model containing two area thermal system and obtains the error signals frequency and tie line power. The performance of these responses is measured using performance functions such as Integral of Absolute Error (IAE), Integral of Squared Error (ISE), Integral of Time multiplied Absolute Error (ITAE), Integral of Time multiplied Squared Error (ITSE) given by Eqs. (9)–(12) respectively.

$$J_1 = IAE = \int_0^{t_{sim}} [|\Delta f_1| + |\Delta f_2| + |\Delta P_{Tie}|] \cdot dt \tag{9}$$

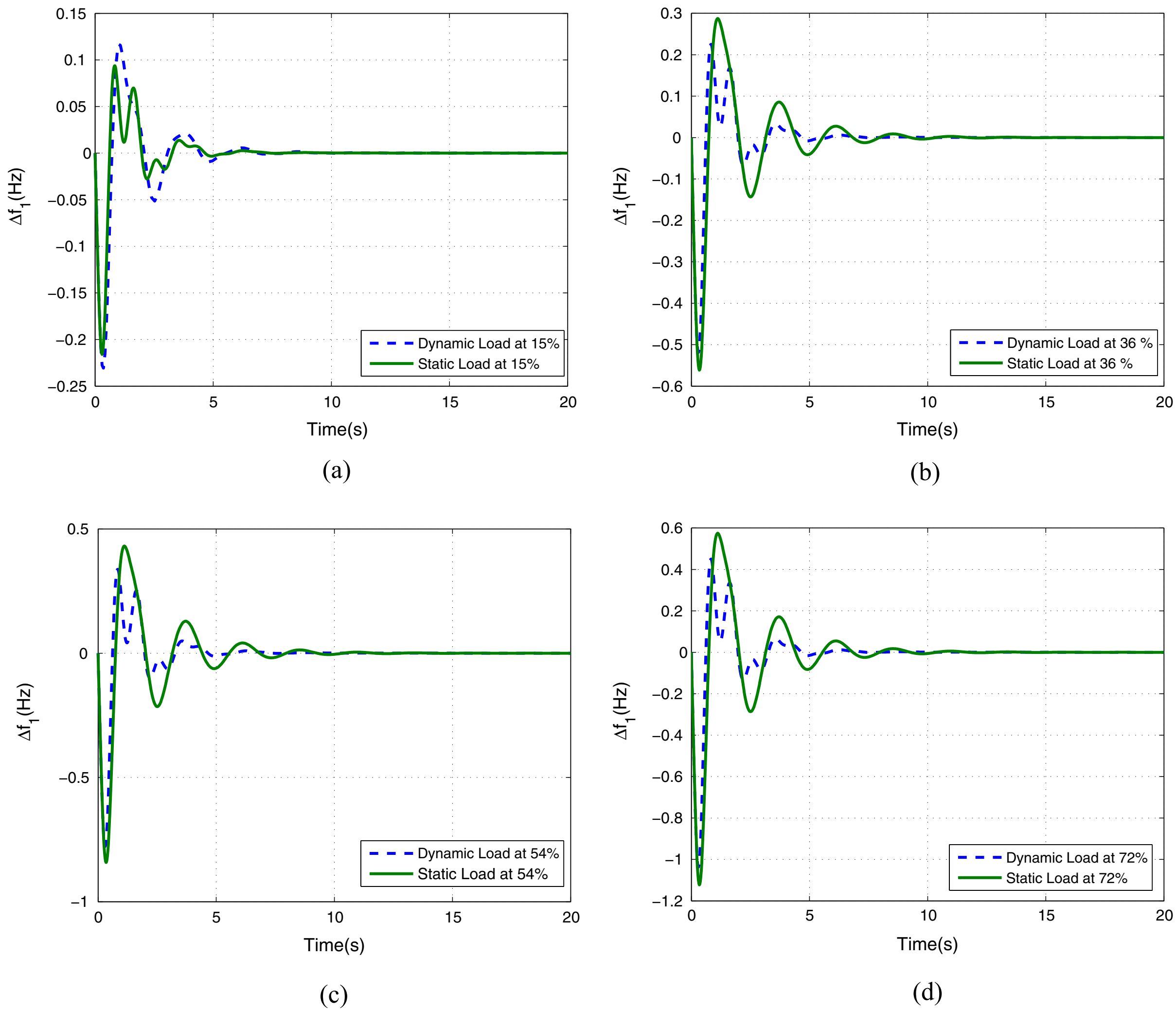

Figure 9 Change in frequency of area-1: (a) At 15% load, (b) at 36% load, (c) at 54% load and (d) at 72% load.

$$J_2 = ISE = \int_0^{t_{sim}} (\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{Tie})^2 \cdot dt \tag{10}$$

$$J_3 = ITAE = \int_0^{t_{sim}} (|\Delta f_1| + |\Delta f_2| + |\Delta P_{Tie}|) \cdot t \cdot dt \tag{11}$$

$$J_4 = ITSE = \int_0^{t_{sim}} [(\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{Tie})^2] \cdot t \cdot dt \tag{12}$$

The objective function is designed to consider all the criteria through a weighted sum approach and is given by Eq. (13):

$$J_5 = \omega_1 \cdot IAE + \omega_2 \cdot ISE + \omega_3 \cdot ITAE + \omega_4 \cdot ITSE \tag{13}$$

$\omega_1, \omega_2, \omega_3, \omega_4$ are multiplied with IAE, ISE, ITAE, ITSE respectively to form Eq. (13). All these weights should satisfy the following equations as (14) [19]:

$$\sum_{i=1}^{N} \Delta\omega_i = 1, \qquad \omega_i > 0 \tag{14}$$

Pareto optimality is generally used for choosing these weights. In this work, following approach is proposed to assign weights to the objective function. For this purpose, the performance function behavior is studied from [25]. It presents the following conclusions:

(1) The ISE and ITSE functions are appropriate to use for measuring the performance when error value is greater than one and vice versa with IAE and ITAE.
(2) The ITAE and ITSE are good measures when error signal persists for a long time and helps to improve steady state error.
(3) While IAE and ISE are useful to mitigate the initial transients, they are used when the transient time is less than one second.

The desired responses that are observed represent all situations, mentioned above, highlighting the fact, that which one of the above performance criteria is best suited for specific time intervals, from a control point of view.

Objective function receives a response from proposed model for a population in FPA. This response is divided for a small interval of step time. A condition is created to implement the conclusions of performance criteria. This condition helps to assign the highest value to $\Delta\omega_{ji}$ when jth performance

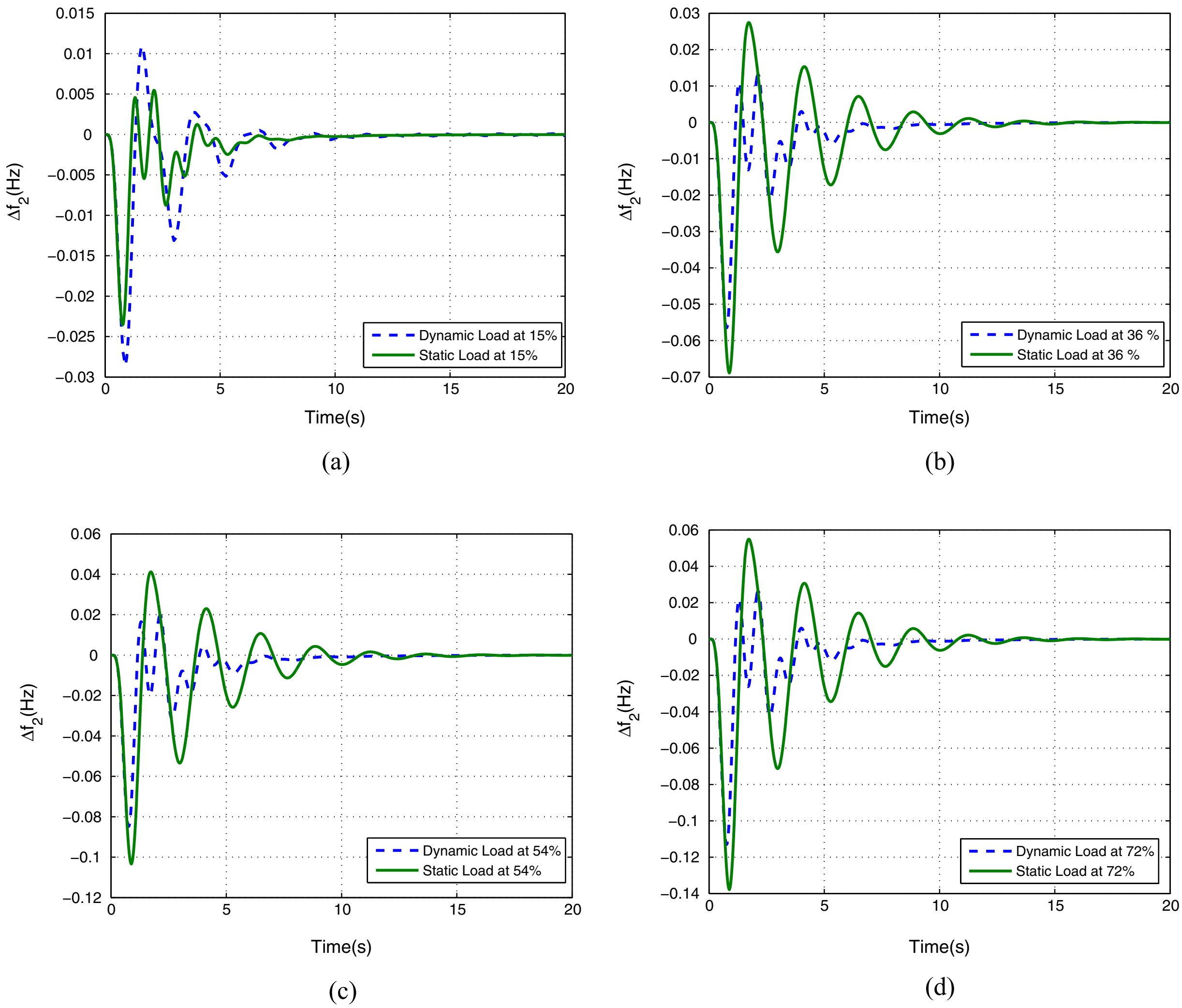

Figure 10 Change in frequency of area-2: (a) at 15% load, (b) at 36% load, (c) at 54% load and (d) at 72% load.

criteria are best suited for step time, while the others are assigned with minimum values. Later the ω_j are found from Eqs. (15) and (16):

$$N = \frac{Total\ simulation\ time}{Definite\ time\ interval\ step} \tag{15}$$

$$\omega_j = \frac{1}{N}\left[\sum_{i=1}^{N} \Delta\omega_{ji}\right] \qquad j = 1, 2, 3, 4\ldots \tag{16}$$

using these weights and Eq. (13) flower constancy for FPA is found. This procedure is carried out for a fixed number of iteration in FPA, then weights obtained for total best are chosen as fixed weights (or) optimal weights. The FPA restarts its procedure for finding the solution for PID controller parameters K_P, K_I, K_D using objective for which now has known weights. Thus, solution for desired PID controller is found.

In [26–29], the proposed objective function was based on fixed step load perturbation and the obtained controller parameters were optimal at fixed step load. But the system load is dynamic, so there is a requirement to design a controller that gives optimal response for various load conditions. In this paper, the objective function includes responses of various percentage step load changes, so the designed controller parameters give optimal response for most load disturbance.

5. Results and discussions

In this paper a two area thermal system with governor dead band is used to test the proposed theory along with FPA. The simulation is performed by using Matlab 2009A on a *i7* processor base with 4 GB ram. From Section 3 it is evident that FPA has parameters p, N (size of population) and *itermax* (maximum number of iterations). The parameter p defines the amount of local search and global search for FPA. To choose this parameter, the proposed method is simulated for various values and that simulated for p varies from 0.1 to 1 with step change of p with step size 0.01 in the range of 0.1 to 1. A graph is plotted between parameter p and respective global minima as shown in Fig. 3.

This Fig. 3 shows that objective function is constantly minimized between 0.5 and 0.6. This is carried out for a number of times and in each case above condition is true, so p is chosen as

Please cite this article in press as: Madasu SD et al., A flower pollination algorithm based automatic generation control of interconnected power system, Ain Shams Eng J (2016), http://dx.doi.org/10.1016/j.asej.2016.06.003

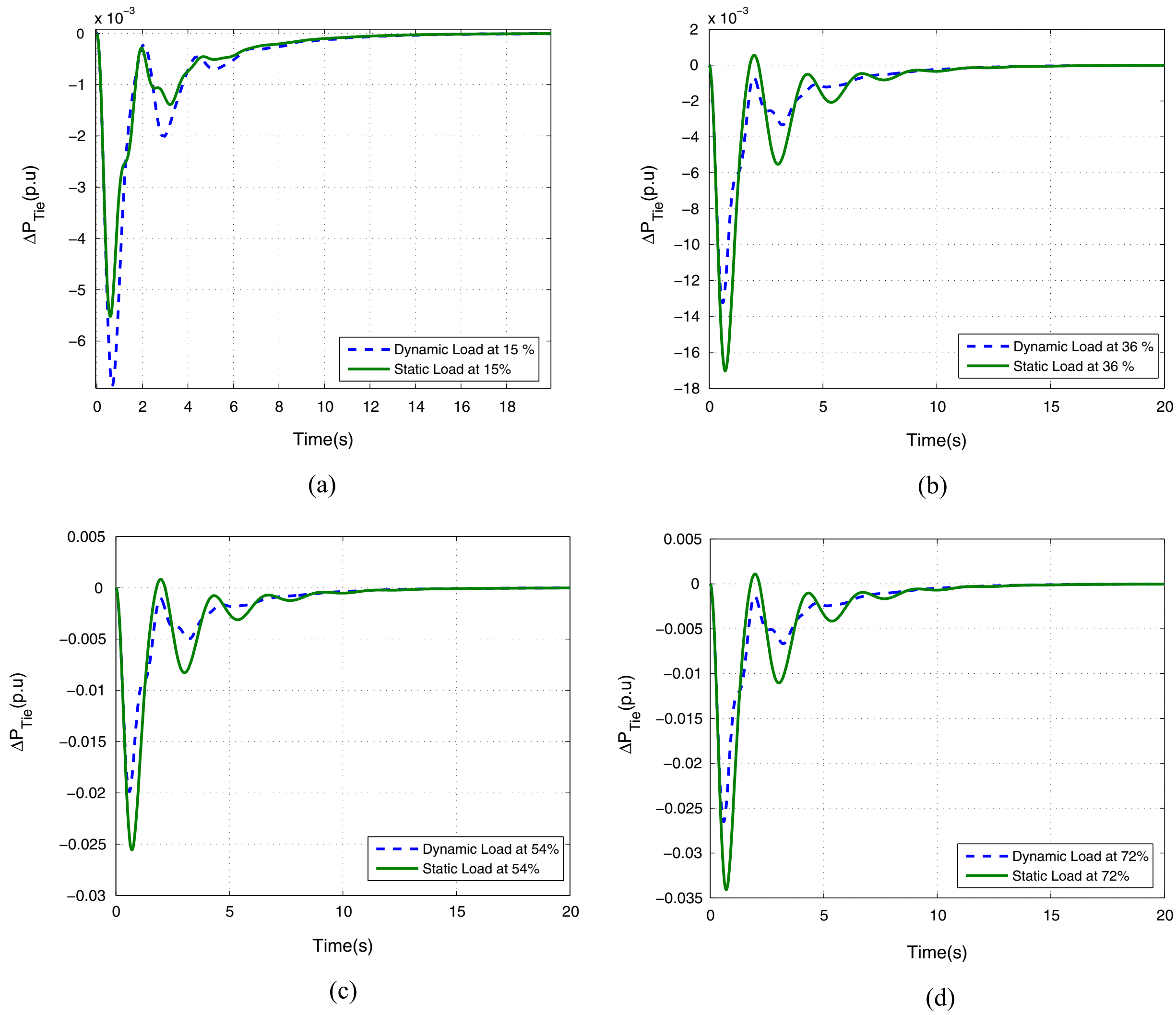

Figure 11 Change in Tie line power (a) at 15% load, (b) at 36% load, (c) at 54% load and (d) at 72% load.

5.5. A Similar case study is done for a maximum number of iteration, and it shows that after 40 iterations count value of global minima remains constant as in Fig. 4.

Similarly from the Fig. 5 we have obtained the parameter population size as $N = 30$.

The objective function contains multiple performance criteria as mentioned in Section 3, with (16) a set of combinations created. For each combination weight, the proposed method is evaluated and respective global minima are stored. When this data is fed into Pareto efficiency algorithm it has produced following weights. This weight combined together will result in 65,536 permutations. By using constraint Eq. (16), these are reduced to 367. Each combination of these weights is passed through FPA and respective global minima are found and stored. These combinations along with the stored vector of global minima are passed through Pareto efficiency algorithm and Pareto optimal weights are found [0.14230.30260.12950.4256]. These combinations of weights are sorted according to ascending order of global minima. The first 10% of weight combinations that yields best global minima are analyzed by plotting their histogram as shown in Fig. 6.

Our proposed techniques as described in Section 4 would divide the response like Δf_1 into definite time interval (0.01 s) as shown in Fig. 7. Suppose at 1.02s the error value is 0.1507 which is less than one and time greater than one. At this point ITAE is best suited for minimizing error, so $\Delta\omega_{ji}$, ITAE is assigned with a higher value.

Weights related to ITSE, IAE, ISE are assigned with the lowest value. This is done for the $\Delta f_2, \Delta P_{Tie}$ signals. The mean of step weights $\Delta\omega_{ji}$, ITAE for three signals is found. It is followed by step weights of other performance function. This procedure is carried out for total simulation time (20 s). Now Eq. (16) is used to find the weights $\omega_1, \omega_2, \omega_3, \omega_4$ from this step weight vectors. As mentioned in Section 4 all this procedure is carried out for single population and using Eq. (13) flower constancy of the population is found. This is carried out for 20 iterations in FPA then weights obtained for total global minima are fixed and are given [0.1255 0.100 0.5796 0.1949]. Fig. 8. shows the response for both methods and it can observed that proposed method has slightly good response when compared to Pareto method. By this proposed method is easy to implement compared to Pareto method.

Table 1 Appendix.

Variables	Typical value
B_1, B_2	0.425 p.u. MW/Hz
R_1, R_2	2.4 Hz/p.u.
$T_{G1}, -T_{G2}$	0.2 s
T_{T1}, T_{T2}	0.3 s
K_{PS1}, K_{PS2}	120 Hz/p.u. MW
T_{PS1}, T_{PS2}	20 s
T_{12}	0.0707 p.u.
a_{12}	−1

The second aspect of proposed theory is to construct an objective function which includes a performance for various load percentages (1%, 10%, 30%, 55%, 65%, 80%, 90%) to obtain tuned parameters for a controller of considered system. This yielded gain parameters were optimal for any load change between 1 and 100%. We have tested these gains for 15%, 36%, 54%, 72% load performance. We have also obtained gain parameters tuned for 15% fixed load and test for 36%, 54%, 72% load changes. The comparison of above two performance is shown in Figs. 9–11 for $\Delta f_1, \Delta f_2, \Delta P_{Tie}$ respectively. This shows parameters chosen from proposed method are optimal for most load changes, so these could give optimal performance for dynamic loads also.

6. Conclusion

This study was carried out to design PID controller through Flower Pollination Algorithm (FPA) for Automatic Generation Control (AGC) of an interconnected power system. A two area thermal system with governor dead-band non linearity is considered for the design and analysis purpose. A new kind of approach is made to design a multi-objective function which contains weighted performance functions. This method takes less effort to obtain the weights for multi objective function. A single run of the proposed algorithm yields both optimal weights and global minimum. The performance of the results is comparable with Pareto optimal solution as shown in Section 5. The objective function also includes performance response for various percentage of loads so that obtained gain parameters are optimal for different load conditions and this change could be observed in $\Delta f_1, \Delta f_2, \Delta P_{Tie}$ responses.

Appendix A.

See Table 1.

References

[1] Kundur P. Power system stability and control. TMH 8th reprint, New Delhi; 2009.
[2] Elgerd OI. Electric energy systems theory: an introduction. New Delhi: TMH; 1983.
[3] Kothari DP, Nagrath IJ. Modern power system analysis. 4th ed. New Delhi: TMH; 2011.
[4] Saikia LC, Nanda J, Mishra S. Performance comparison of several classical controllers in AGC for multi-area interconnected thermal system. Int J Electr Power Energy Syst 2011;33 (3):394–401.
[5] Parmar KPS, Majhi S, Kothari DP. Load frequency control of a realistic power system with multi-source power generation. Int J Electr Power Energy Syst 2012;42(1):426–33.
[6] Saikia LC, Mishra S, Sinha N, Nanda J. Automatic generation control of a multi area hydrothermal system using reinforced learning neural network controller. Int J Electr Power Energy Syst 2011;33(4):1101–8.
[7] Ibraheem I, Kumar P, Kothari D. Recent philosophies of automatic generation control strategies in power systems. IEEE Trans Power Syst 2005;20(1):346–57.
[8] Ghoshal SP. Optimizations of PID gains by particle swarm optimizations in fuzzy based automatic generation control. Electric Power Syst Res 2004;72(3):203–12.
[9] Golpira H, Bevrani H. Application of GA optimization for automatic generation control design in an interconnected power system. Energy Convers Manage 2011;52(5):2247–55.
[10] Yesil E, Guzelkaya M, Eksin I. Self tuning fuzzy PID type load and frequency controller. Energy Convers Manage 2004;45 (3):377–90.
[11] Huang S-J, Gu P-H, Su W-F, Liu X-Z, Tai T-Y. Application of flower pollination algorithm for placement of distribution transformers in a low-voltage grid. In: 2015, IEEE international conference on industrial technology (ICIT). p. 1280–5.
[12] Oda ES, Abdelsalam AA, Abdel-Wahab MN, El-Saadawi MM. Distributed generations planning using flower pollination algorithm for enhancing distribution system voltage stability. Ain Shams Eng J 2015.
[13] Chakravarthy V, Rao PM. On the convergence characteristics of flower pollination algorithm for circular array synthesis. In: 2nd International conference on electronics and communication systems (ICECS). IEEE; 2015. p. 485–9.
[14] Draa A. On the performances of the flower pollination algorithm qualitative and quantitative analyses. Appl Soft Comput 2015;34:349–71.
[15] Abdelaziz A, Ali E, Abd Elazim S. Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index. Int J Eng Sci Technol 2016;19(1):610–8.
[16] Dubey HM, Pandit M, Panigrahi B. Hybrid flower pollination algorithm with time-varying fuzzy selection mechanism for wind integrated multi-objective dynamic economic dispatch. Renew Energy 2015;83:188–202.
[17] Dubey HM, Pandit M, Panigrahi BK. A biologically inspired modified flower pollination algorithm for solving economic dispatch problems in modern power systems. Cognit Comput 2015;7(5):594–608.
[18] Gozde H, Taplamacioglu MC. Automatic generation control application with craziness based particle swarm optimization in a thermal power system. Int J Electr Power Energy Syst 2011;33 (1):8–16.
[19] Yang X-S. Flower pollination algorithm for global optimization. Berlin Heidelberg: Springer; 2012.
[20] Yang X-S, Karamanoglu M, He X. Flower pollination algorithm: a novel approach for multiobjective optimization. Eng Optim 2014;46(9):1222–37.
[21] Yang X-S, Karamanoglu M, He X. Multi-objective flower algorithm for optimization. Proc Comput Sci 2013;18:861–8.
[22] Vedula VSSSC, Paladuga SRC, Prithvi MR. Synthesis of circular array antenna for sidelobe level and aperture size control using flower pollination algorithm. Int J Antennas Propagat 2015;2015:1–9.
[23] Lukasik S, Kowalski PA. Study of flower pollination algorithm for continuous optimization. Adv Intell Syst Comput 2015;322:451–9.
[24] Kumar J, Ng K-H, Sheble G. AGC simulator for price-based operation. I. A model. IEEE Trans Power Syst 1997;12(2):527–32.
[25] Wade M, Johnson M. Towards automatic real-time controller tuning and robustness. 38th IAS annual meeting. Conference

Please cite this article in press as: Madasu SD et al., A flower pollination algorithm based automatic generation control of interconnected power system, Ain Shams Eng J (2016), http://dx.doi.org/10.1016/j.asej.2016.06.003

record of the industry applications conference 2003, vol. 1. p. 352–9.
[26] Mohanty B, Panda S, Hota PK. Differential evolution algorithm based automatic generation control for interconnected power systems with non-linearity. Alexandria Eng J 2014;53(3):537–52.
[27] Sahu RK, Panda S, Padhan S. A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems. Int J Electr Power Energy Syst 2015;64:9–23.
[28] Sahu RK, Panda S, Padhan S. Optimal gravitational search algorithm for automatic generation control of interconnected power systems. Ain Shams Eng J 2014;5(3):721–33.
[29] Padhan S, Sahu RK, Panda S. Automatic generation control with thyristor controlled series compensator including superconducting magnetic energy storage units. Ain Shams Eng J 2014;5(3):759–74.

Satya Dinesh Madasu received the M.Tech. degree from National Institute of Technology, Jamshedpur, Jharkhand, India, in 2010. He is currently working towards the Ph.D. degree at the Department of Electrical & Electronics Engineering, NIT Jamshedpur, Jharkhand, India. His research interests are Application of Control System in Power and Energy Systems and Non Conventional Energy.

M.L.S. Sai Kumar received the B.Tech. degree from Anil Neerukonda Institute of Technology & Science, Vizag, India, in 2013. He received the M.Tech. degree from National Institute of Technology, Jamshedpur, Jharkhand, India, in 2015. He is currently working towards the Ph.D. degree in the Department of Electrical & Electronics Engineering, NIT Jamshedpur, Jharkhand, India. His research interests are Automatic Generation Control and Power System Protection.

Arun Kumar Singh received the B.Sc. Engineering degree from NIT Kurukshetra (formerly REC Kurukshetra), Haryana, India, M.Tech. degree from the IIT BHU (formerly IT BHU), Varanasi, UP, India, and Ph.D. degree from the Indian Institute of Technology, Kharagpur, India. He has been a faculty in the Department of Electrical & Electronics Engineering at National Institute of Technology, Jamshedpur, since 1985. His areas of research interest are in Control System, Control System Application in Power and Energy Systems and Non Conventional Energy.