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Automatic Generation Control of the Two Area Non-reheat Thermal Power System using Gravitational Search Algorithm

***Abstract**. In this study, determination of the optimal proportional-integral-derivate (PID) parameters with Gravitational search algorithm (GSA) for automatic generation control (AGC) of the two area non-reheat thermal power system is proposed. GSA is applied to search for the optimal PID controller parameters to minimize various performance indexes. The designed PID controller with the proposed approach is simulated under variety of operating conditions. Simulation results are shown that dynamic performance of the two area non-reheat thermal power system is improved by the designed PID controller with the proposed approach.*

***Streszczenie.** W artykule zaproponowano określenie optymalnej wartości PID w cieplnym systemie wytwarzania energii. Do tego celu użyto algorytmu grawitacyjnego GSA. Opracowany sterownik został zbadany metodami symulacyjnymi. (**Automatyczne sterowanie cieplnym system wytwarzania energii z wykorzystaniem algorytmu grawitacyjnego GSA**)*

Keywords: automatic generation control, gravitational search algorithm, power systems, optimization.
Słowa kluczowe: GSA – grawitacyjny system badania, optymalizacja, system cieplny wytwarzania energii.

Introduction

An interconnected modern power system is normally consist of control areas or regions each one of which stands for a coherent group of generating units operating under nominal system frequency. A nominal system frequency is subject to the balance between generation and load demand plus losses [1]. A sudden load demand variation or generation losses in operating point any of the interconnected large scale power system areas causes the deviation of frequencies of all the areas and also of the tie line power flow between control areas. Hence, Load Frequency Control (LFC) or Automatic Generation Control (AGC) is a very important issue in modern power system operation and control, which to provide users with reliable, high-quality electric power. The main goal of the AGC is to maintain the system frequency which has zero steady state error at scheduled value by keeping the balance between generation and load demand plus losses. The traditional PI and PID controllers are widely used to minimize the steady state error of the system frequency in modern large-scale power systems. Due to conventional the PI and PID controllers have fixed structure and constant gain parameters which are commonly used to tune for one operating condition. Interconnected power systems have nonlinear load characteristics and variable operating points. Owing to the complexity of the power system, the PI and PID controllers tuning with traditional techniques such as Ziegler Nichols, Karl-Astrom etc., may not be efficient under different operating conditions in interconnected power systems. Lately, this AGC has received much attention by many researchers who have proposed different AGC schemes based on parameters such as linear and nonlinear power system models and different control approaches based on adaptive control, self-tuning control, digital control, classical and optimal control, multilevel control, fuzzy logic control and the applications of neural network regarding the AGC control of single and multi-area power systems [2-6].

Recently, many stochastic methods have been used to keep the scheduled constant value of the system frequency. These techniques have been handled by many researchers for AGC problem in modern power systems. Multiple tabu search algorithm (MTS) has been used to simultaneously tune PID gains, membership functions and control rules of fuzzy logic-based-proportional-integral-derivative (FLPID) by Pothiya and Ngamroo in two area interconnected power system including superconducting magnetic energy storage units. The proposed controller has better damping of the oscillations than the other controller [7]. Bhatt proposed craziness-based particle swarm optimization for optimization parameters of the integral controller, thyristor controlled phase shifter and superconducting magnetic energy storage in interconnected two area multi-unit power system [8]. Golpîra et al. investigated the determination of the parameter of the integral controller using genetic algorithm for under operating conditions in three area interconnected power system [9]. Khodabakhshian and Hooshmand presented maximum peak resonance specification for design a PID controller in multimachine power system [10]. Shayeghi used particle swarm optimization algorithm in order to optimize parameters of the PID controller in three area restructured power system with thyristor controlled phase shifter [11]. Abraham et al. have investigated effect of capacitive energy storage on automatic generation control in two area power system [12]. Khamsum et al. used improved genetic algorithm for AGC including SMES units. The proposed meta-heuristic approach is simulated to tune the PID controller parameters [13]. Yeşil et al. used self-tuning fuzzy PID type controller for solving the load frequency control of two area power systems [14].

In this study, newest stochastic method is presented as an alternative to other optimization techniques. One of the recently developed newest meta-heuristic algorithms is the gravitational search algorithm (GSA), which was proposed by Rashedi et al. as a new stochastic population based optimization search algorithm inspired from Newton's law of gravity and mass interactions [15]. Masses are regarded as individuals of the population in this proposed approach. GSA can be regarded as a simple concept that is both easy to execute and calculate influential. It has been reported in [15] that the GSA has a lot of advantages such as adaptive learning rate, memory-less algorithm, capability to escape from local optima, good and fast convergence and being easily implemented. GSA has exploration and exploitation abilities which can be developed for its flexible and well-balanced structure [15,16]. The most characteristic feature of GSA is that gravitational constant adjusts the accuracy of the search so that it speeds up the solution process [16]. These characteristic features make the GSA more powerful. Nowadays, many researchers has been used this algorithm to verify high quality performance in solving different optimization problems in literature [17-27]. In this paper, meta-heuristic gravitational search algorithm is applied to design optimal parameters of the PID controller in automatic generation control of two area non-reheat thermal power system. The designed PID controller with proposed approach is simulated within various scenarios and its performance is compared with those reported in ref [28].

Power System Model

A two area interconnected non-reheat thermal power system is considered to determine optimal parameters of the PID controller in automatic generation control problem. The transfer function model of a two area non-reheat thermal power system is shown in Fig.1. At the simulation process, it is assumed that there is a step load changing in the control area-1, area-2 and under parameter variation conditions. From Fig. 1, it is clear that u_1 and u_2 are the control inputs from optimized parameters of the PID controllers. R_1 and R_2 are regulation constants, T_{G1} and T_{G2} are speed governor speed time constants, T_{T1} and T_{T2} are turbine time constants, T_{P1} and T_{P2} are power system time constants, K_{P1} and K_{P2} are power system gains, ΔP_{tie} is the changing of tie-line power between control areas, Δf_1 and Δf_2 are frequency deviations of each control area, ΔP_{D1} and ΔP_{D2} are the load demand change in the control areas and ACE_1 and ACE_2 are the area control error. The state space equation of the power system can be modelled as follow:

(1) $$\dot{x} = Ax + Bu + Ld$$

(2) $$y = Cx$$

(3) $$u = [u_1 \quad u_2] \quad y = [y_1 \quad y_2]^T = [ACE_1 \quad ACE_2]^T$$
$$x = [\Delta f_1 \quad \Delta P_{t1} \quad \Delta P_{g1} \quad \Delta P_{c1} \quad \Delta P_{tie} \quad \Delta f_2 \quad \Delta P_{t2} \quad \Delta P_{g2} \quad \Delta P_{c2}]$$
$$d = [d_1 \quad d_2]^T = [\Delta P_{D1} \quad \Delta P_{D2}]^T$$

(4) $$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie1}$$

(5) $$ACE_2 = B_2 \Delta f_2 - \Delta P_{tie2}$$

The transfer function of the PID controller is presented as follow.

(6) $$K(s) = K_p + \frac{K_i}{s} + K_d s$$

The obtained control inputs from optimized parameters of the PID controllers are defined as follow.

(7) $$u_i(s) = -K(s) \times ACE_i(s)$$

(8) $$u_1 = -\left(K_{p1} ACE_1 + K_{i1} \int ACE_1 dt + K_{d1} \frac{dACE_1}{dt} \right)$$

(9) $$u_2 = -\left(K_{p2} ACE_2 + K_{i2} \int ACE_2 dt + K_{d2} \frac{dACE_2}{dt} \right)$$

The system parameters of the two area power system are given in Table 1 [28].

Table 1. The system parameters

Parameter	Value
$T_{G1,2}$	0.08 s
$T_{T1,2}$	0.3 s
$T_{P1,2}$	20 s
$K_{P1,2}$	120 Hz/puMW
T_{12}	0.545 pu
$R_{1,2}$	2.4 Hz/puMW
$B_{1,2}$	0.425 puMW/Hz

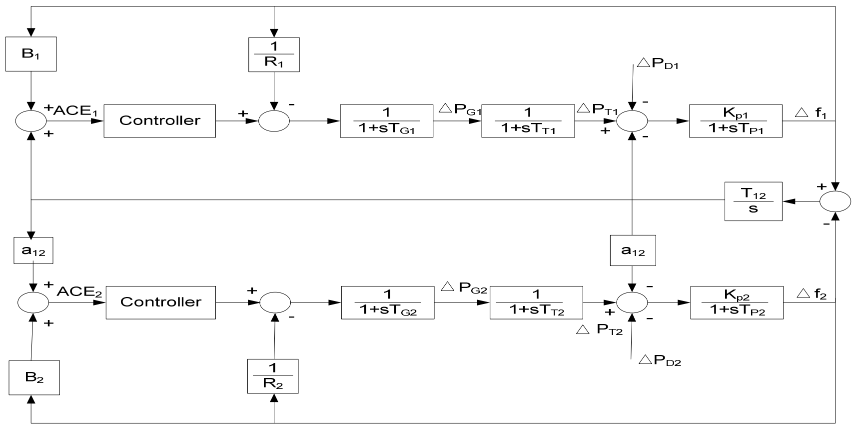


Fig.1. Transfer function model of a two area non-reheat thermal power system [28].

Gravitational Search Algorithm

The Gravitational search algorithm (GSA) is one of the newest meta-heuristic searching algorithms, which is motivated by the Newton's laws of gravity and law of motion, improved by Rashedi et al. in 2009 [15]. GSA has a great potential to be a break-through optimization method. In this proposed algorithm, agents are assumed to be objects that their performances are measured by their masses. Every object represents a solution or a part of a solution to the problem. All these objects attract each other by the gravity force, and this force causes a global movement of all objects towards the objects with heavier masses. The heavier masses have higher fitness values; they depict good optimal solution to the problem and they move slowly than lighter ones representing worse solutions. The position of the mass equaled to a solution of the problem and its gravitational and inertial masses are specified using a fitness function [15]. GSA algorithm can be explained as follow:

At the beginning of the algorithm the positions of a system are described with N (dimension of the search space) masses.

(10) $$X_i = (x_i^1, \ldots x_i^d \ldots, x_i^n) \qquad \textit{for } i=1,2,\ldots,N$$

where n is the space dimension of the problem and x_i^d defines the position of the i^{th} agent in the d^{th} dimension.

All agents are evaluated at each step and the *best* and the *worst* fitness are calculated for every iteration as defined below:

(11) $$best(t) = \min_{j \in \{1,..,N\}} fit_j(t)$$

(12) $$worst(t) = \max_{j \in \{1,..,N\}} fit_j(t)$$

where $fit_j(t)$ is the fitness of the j^{th} agent of iteration t, *best(t)* and *worst(t)* are best (minimum) and worst (maximum) fitness of all agents.

The gravitational constant at iteration t *(G(t))* is computed as follows.

(13) $$G(t) = G(G_0, t)$$

(14) $$G(t) = G_0 e^{-\alpha \frac{t}{T}}$$

G is a function of the initial value (G0) and time (t). The gravitational constant, G, which is initialized randomly at the starting, gravitational constant adjusts the accuracy of the search, so it is reduced with time. α is a user specified constant, t is the current iteration and T is the total number of iterations.

The gravitational and inertial masses are updated for each agent at iteration as follows.

(15) $$M_{ai} = M_{pi} = M_{ii} = M_i, \qquad i = 1,2,\ldots,N$$

(16) $$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)}$$

where fiti(t) is the fitness of the ith agent at iteration t.

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

where M_{ai} is the active gravitational mass of the i^{th} agent, M_{pi} is the passive gravitational mass of the i^{th} agent, M_{ii} is the inertia mass of the i^{th} agent, $M_{i(t)}$ is the mass of the i^{th} agent at iteration t.

The total force acting on the i^{th} agent $(F_i^d(t))$ is computed as follows.

(18) $$F_i^d(t) = \sum_{j \in kbestj \neq i} rand_j F_{ij}^d(t)$$

where $rand_j$ is a random number between interval [0,1] and *kbest* is the set of first K agents with the best fitness value and biggest mass.

The force acting on the i^{th} mass $(M_i(t))$ from the j^{th} mass $(M_j(t))$ at the specific iteration t is defined according to the gravitational theory as follows. Sum of the forces acting on an object and its acceleration are shown in Fig. 2.

(19) $$F_{ij}^d(t) = G(t)\frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right)$$

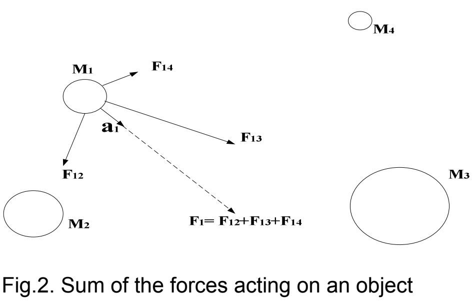


Fig.2. Sum of the forces acting on an object

G(t) is the gravitational constant at time t, ε is a small constant and $R_{ij}(t)$ is the Euclidian distance between i^{th} and j^{th} objects defined as follows:

(20) $$R_{ij}(t) = \left\| X_i(t), X_j(t) \right\|_2$$

In order to find the acceleration of the i^{th} agent, at t time in the d^{th} dimension law of motion is used directly to calculate. In accordance with this law, it is proportional to the force acting on that agent, and inversely proportional to the mass of the agent. $a_i^d(t)$ is given as follows

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

(22) $$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} = \sum_{j \in kbestj \neq i} rand_j G(t) \frac{M_j(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right)$$

Next velocity of an agent is defined as a function of its current velocity added to its current acceleration. Hence, the next position and next velocity of an agent can be computed as follows:

(23) $$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t)$$

where $rand_i$ is a uniform random variable in the interval [0,1]. The next position of the i^{th} agents in d^{th} $(x_i^d(t+1))$ dimension are updated as follows:

(24) $$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$$

The operational flowchart of the GSA is illustrated in Fig. 3.

Simulation Results

The proposed stochastic algorithm has been applied to determine optimal parameters of the PID controllers. In order to show the effectiveness and verify the performance of the proposed GSA approach based on Newtonian physical law of gravity and law of motion which is tested under operating conditions for automatic generation control of a two area non-reheat thermal power system.

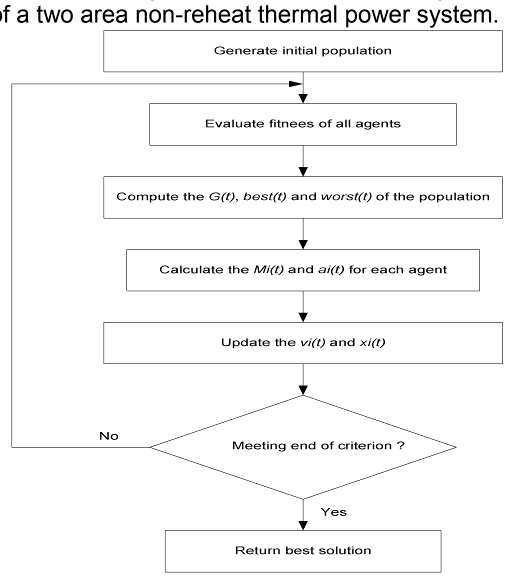


Fig.3. The principle diagram of the GSA [15].

First of all, integral square error (ISE) is used to determine optimal values of the gains of the PID controller as objective function, which is explained as the sum of squares of cumulative errors in area control error. After that, secondly, integral time absolute error (ITAE) is defined as the sum of absolute of cumulative the frequency deviations of the control areas, area control errors and tie-line power changes. The objective functions are described as follows:

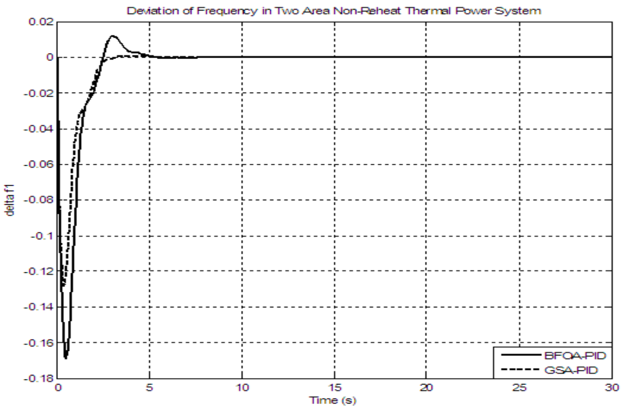
(25) $$J_1 = ISE = \int_0^t \left(ACE_i\right)^2 dt$$

(26) $$J_2 = ITAE = \int_0^t t\left(\left|ACE_1\right| + \left|ACE_2\right| + \left|\Delta f_1\right| + \left|\Delta f_2\right| + \left|\Delta P_{tie}\right|\right)$$

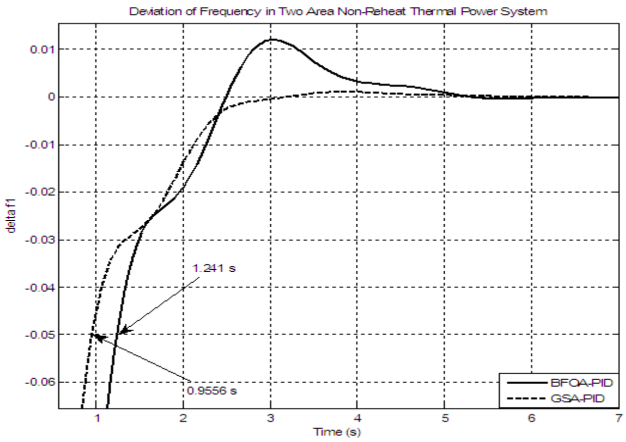
The optimized PID controller parameters with proposed approach are simulated under different operating scenario conditions.

Scenario 1: In this operating condition, 10% of step load demand is applied for nominal operating condition in the control area-1. The PID controller parameters are optimized using performance index (J2) for proposed heuristic approach. The results obtained from the designed PID controller using proposed approach are compared with the results obtained from optimized the PID controller parameters using bacterial foraging optimization algorithm (BFOA) in ref. [28].

The frequency deviations of the control areas and tie-line power changes are shown in Fig. 4. Settling times are shown within 5 % bandwidth in Fig. 4 (b). From Fig. 4, it is clear that the designed PID controller by GSA stochastic method provide better performance than the optimized gains of the PID controller using BFOA [28] for frequency responses of the system in two area non-reheat thermal power system.



(a)



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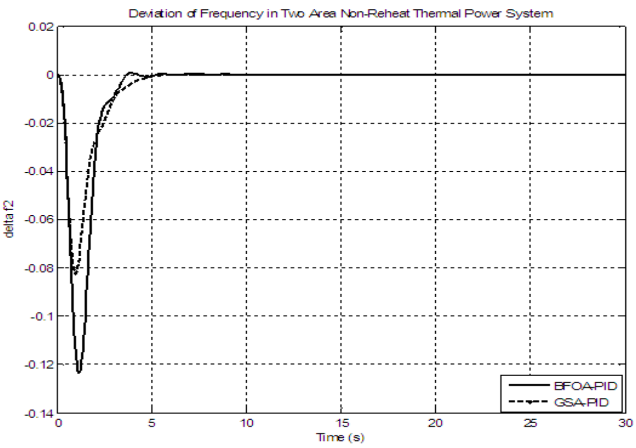

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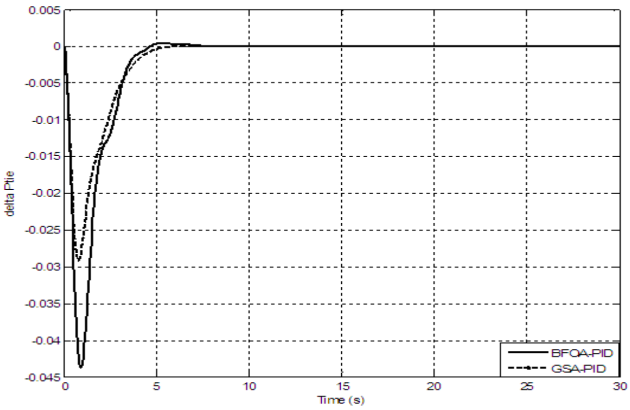
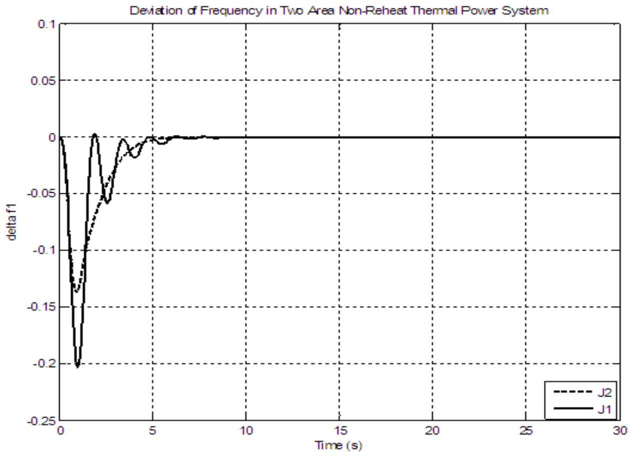
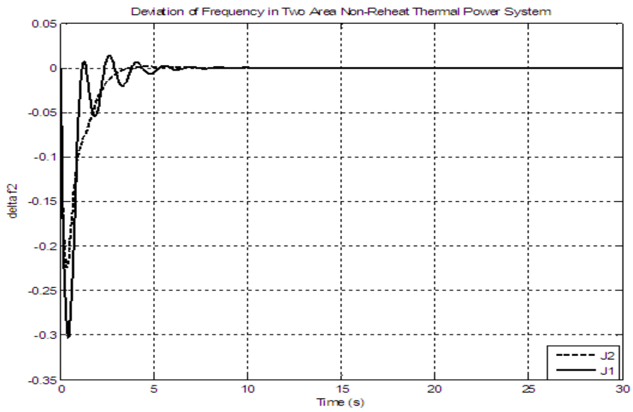


(d)

Fig.4. For ΔP_{D1}=0.1 change of in control area-1 (a) the deviations of Δf_1 (b) the zoom of deviations of Δf_1 (c) the deviations of Δf_2 (d) the deviations of ΔP_{tie}



(a)



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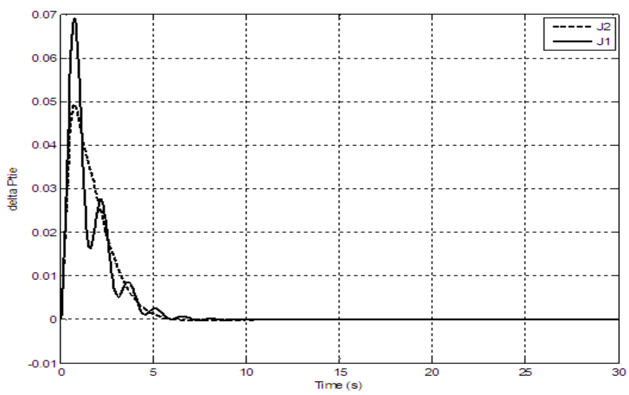


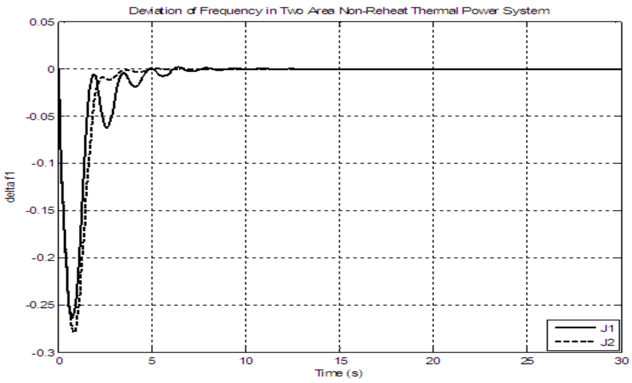
(c)

Fig.5. For ΔP_{D2}=0.2 change of in control area-2 (a) the deviations of Δf_1 (b) the deviations of Δf_2 (c) the deviations of ΔP_{tie}

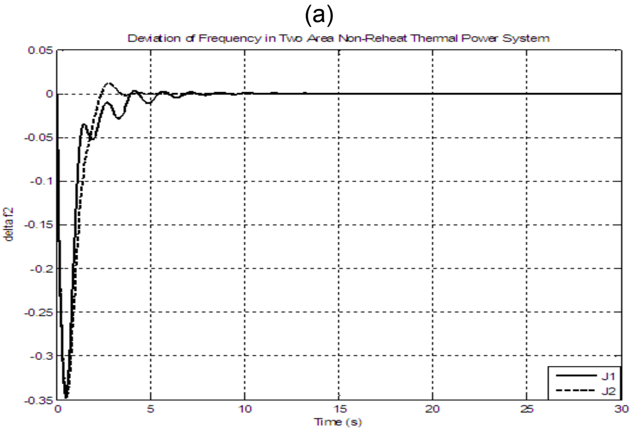
Scenario 2: In this operating condition, 20% of step load demand is applied for nominal operating condition in the control area-2. The PID controller parameters are optimized using performance indexes for proposed heuristic approach.

Scenario 3: In this operating condition, 10% and 20% of step load demand are simultaneously applied for nominal operating condition in the control area-1 and area-2, respectively.

From the results in Fig. 5 and Fig. 6, it can be seen that the obtained results according to performance index-2 (J2) provide a good better damping of oscillations such as the frequency deviations of the control areas and tie-line power changes than performance index-1 (J1) in the proposed approach.



(a)



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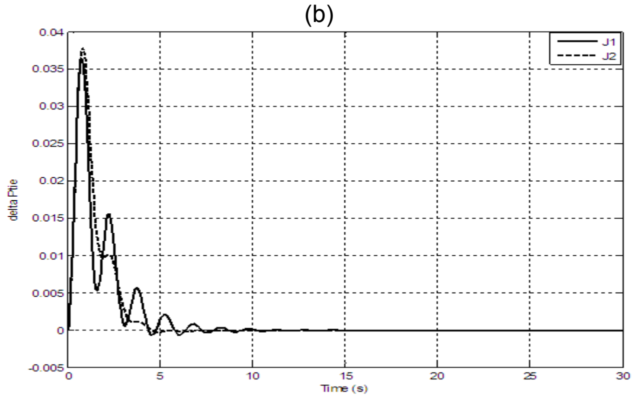
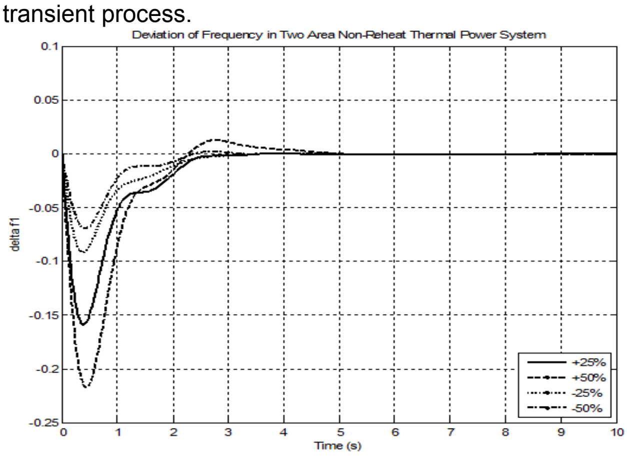


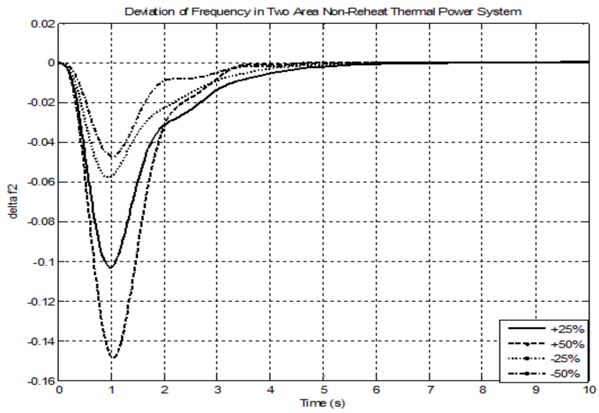
(c)

Fig.6. For ΔP_{D1}=0.1 and ΔP_{D2}=0.2 change of in control area-1 and area-2 (a) the deviations of Δf_1 (b) the deviations of Δf_2 (c) the deviations of ΔP_{tie}

Scenario 4: In this operating condition, step load demand change of the control area-1 in nominal operating condition (ΔP_{D1}=0.1) is increased the step of 25% and 50%, and decreased the step of 25% and 50%, respectively. The performance index-2 (J2) is used as objective function under different operating conditions to show the effectiveness of the designed PID controller by GSA approach. Fig.7.(a), (b) and (c) show the damping of frequency deviations and tie-line power change in shorter transient process.



(a)



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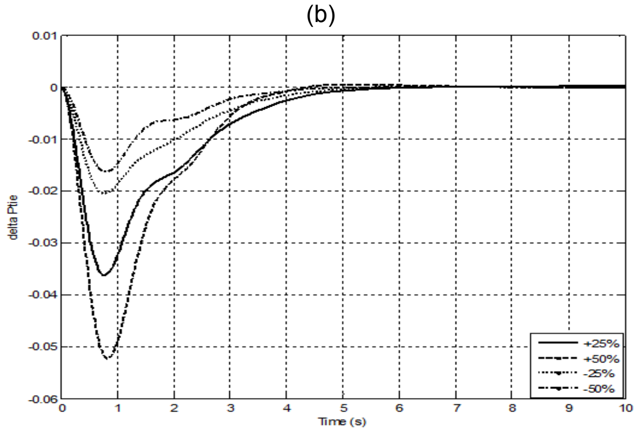

(c)

Fig.7. For different operating conditions of ΔP_{D1} (a) the deviations of Δf_1 (b) the deviations of Δf_2 (c) the deviations of ΔP_{tie}

On the other hand, the designed PID controller by GSA technique provides high quality performance a robust control in the range of ±50% of the step load demand change.

The obtained gains of the PID controller from the proposed GSA method and the setting parameters of GSA approach are given in Table 2 and Table 3 for different operating scenario conditions, respectively.

Conclusion

In this paper, one of the recently improved heuristic algorithms is the gravitational search algorithm which is proposed to tune the gains of PID controller for automatic generation control.

Table 2. Optimized the PID controller parameters for different operating conditions

Gains	Scenario 1	Scenario 2		Scenario 3	
		J1	J2	J1	J2
K_p	0.4892	0.5801	0.6244	0.5674	0.253
K_i	1	1	1	1	1
K_d	0.3529	0.1735	0.4848	0.1311	0.1965

Gains	Scenario 4			
	+25%	+50%	-25%	-50%
K_p	0.5458	0.2523	0.553	0.3998
K_i	1	1	1	1
K_d	0.3510	0.2661	0.3975	0.2838

Table 3. Setting parameters of GSA approach for different operating conditions

Setting Parameters			
N	G_0	α	T
10	100	10	25

A two area non-reheat thermal power systems is considered to indicate effectiveness and robustness of the proposed approach under different operating conditions and different objective functions. For scenario 1, the obtained results are compared with BFOA reported in ref [28] which performance index-2 (J2) used as objective function. From the simulation results, it is clear that the designed PID controller by the proposed technique yields damping of frequency deviations and tie-line power change. Moreover, performance index-2 (J2) has better performance of the convergence to the best solution than performance index-1 (J1) for frequency response of the system in two area non-reheat thermal power system.

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