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Dual Proportional Integral Controller of Two-Area Load Frequency Control Based Gravitational Search Algorithm

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Abstract

Gravitational Search Algorithm (GSA) has recently been explored to develop a novel algorithm for distributed optimization and control. This paper proposes a dual Proportional Integral (PI) controller of Load Frequency Control (LFC) based GSA to enhance the damping of oscillations in a two-area power system. A two-area non-reheat thermal system is considered to be equipped with dual PI controller. GSA is utilized to search for optimal controller parameters by minimizing a time-domain based objective function. The performance of the proposed controller has been evaluated with the performance of the conventional PI controller, and PI controller tuned by GSA in order to demonstrate the superior efficiency of the proposed dual PI controller tuned by GSA. Simulation results emphasis on the better performance of the optimized dual PI controller based on GSA in compare to optimized PI controller based on GSA and conventional one over wide range of operating conditions, and system parameters variations.

Keyword: *gravitational search algorithm, load frequency control, dual PI controller*

1. Introduction

Frequency control, during the load and generation imbalance, represents a very imperative issue for large-scale power systems. Automatic generation control (AGC) plays a significant role in the power system by maintaining the scheduled system frequency and tie-line power flow during normal operating conditions and during small perturbations [1-3]. This function of an AGC is always referred to as “load frequency control (LFC)” as mentioned by Kundur [2]. LFC is often considered as one of the first and foremost large-scale, decentralized, robust controllers in engineering practice. LFC is accomplished by two different control actions of the primary speed control and supplementary speed control in an interconnected power system.

In the literature, some control strategies have been suggested based on the conventional linear control theory. The conventional PI controller is considered the most widely controller between various types of load frequency controllers. The PI controller is very simple for application and gives better dynamic response, but their performance deteriorates when the complexity in the system increases [4]. The PI control strategy has slightly smaller overshoot than integral control strategy but settling time for only integral control is less. The response with the PI controller has more oscillatory than the integral controller [5]. Control system performance can be improved by allowing the controller to switch from one mode to another. For instance, for certain linear systems switching from a proportional controller to integral controller in a feedback loop may provide a fast response and small overshoot [6]. Based upon the above-mentioned facts, it is desirable to adopt a dual–mode controller conclude both proportional and integral controller. In [5] the rate of change of the error is used as switching criteria between proportional and integral controller. The proportional controller acts when rate of change of the error is sufficiently large, whereas the integral controller would be better one when the rate of change of the error is small. In [7-9] the error is used as switching criteria between proportional and integral controller. The proportional controller is used when the error is large, the integral

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controller acts when the error is small. The main problem which faces dual–mode controller in [5-9], it is the switching condition. This paper proposes to solve this problem by make relation between the switching condition and the summation of disturbance on the system. If summation of disturbance on the system increase the switching condition increase.

In order to get better performance from any controller, its parameters need good optimization. The conventional methods face some difficulties to achieve this purpose, such as complex mathematical equations for large systems. Several approaches such as optimal, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Bacterial Foraging Optimization (BFO), etc., for the design and optimization of the LFC system, have been reported in the literature [10-21]. Modern optimal control concept for AGC designs of interconnected power system was firstly presented by Elgerd and Fosha [10-11]. Genetic algorithms (GAs) have been extensively considered for the design of AGC. Optimal integral gains and optimal PID control parameters have been computed by GAs technique for an interconnected, equal non-reheat and reheat type two generating areas [12-13]. In [14] the Parameters of PID sliding-mode used in LFC of multi area power systems with nonlinear elements are optimized by GA. In [15], GA is used to compute the decentralized control parameters to achieve an optimum operating point for a realistic system comprising generation rate constraint (GRC), dead band, and time delays. The use of particle swarm optimization (PSO) for optimizing the parameters of AGC, where an integral controller and a proportional-plus-integral controller, is reported in [16]. In [17] the parameters of PI controller are designed by PSO with the new cost function and compared their results with [16]. In [18], a robust PID controller based ICA used for LFC application. The authors of [19-20] have proposed bacterial foraging optimization algorithm (BFOA) for designing PI and PID-based load frequency controller for two-area power system with and without GRC. Application of BFOA to optimize several important parameters in AGC of an interconnected three unequal area thermal systems such as the integral controller gains, governor speed regulation, and the frequency bias parameters, has been reported in [21]. In [22] a new optimization algorithm based on the law of gravity and mass interactions is introduced. In the algorithm, the searcher agents are a collection of masses which work with each other based on the Newtonian gravity and the laws of motion.

This paper proposes the GSA for optimal tuning of dual PI controller in two area interconnected power system to damp power system oscillations. The dual PI control design is formulated as an optimization problem and GSA is employed to search for optimal controller parameters by minimizing a candidate time-domain based objective function. The considered objective function involves the integral time multiply the absolute error (ITAE) in the frequency and tie line power. The performance of the proposed dual PI control-based GSA is evaluated by comparison with PI-based GSA. Simulations results on a two-area test system are presented to assure the superiority of the proposed method compared with PI-based GSA and conventional one.

2. Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) is a novel heuristic algorithm inspired by the Newtonian laws of gravity and motion [22]. In GSA, agents are considered as objects and their performance is evaluated by their masses. All these objects attract each other by the force of gravity and moves toward the objects with a heavier mass. The heavy masses correspond to good solution, and this guarantees the exploitation step of the algorithm. In GSA, each mass (agent) has four representations: position, inertial mass, active gravitational mass and passive gravitational mass. The position of the mass represent a solution of the problem and it's gravitational and inertia masses are determined using a fitness function. In other words each mass presents a solution and the algorithm is run by properly adjusting the gravitational and inertia masses. By lapse of time it is predictable that masses be attracted by the heavier mass. This mass will represent an optimum solution in the search space. GSA is representing a small artificial world of masses obeying the Newtonian laws of gravitation and motion. Masses obey the following laws [22-24].

2.1. Law of Gravity

Each agent attracts every other agent and the gravitational force between the two agent is directly proportional to the product of their masses and inversely proportional to the distance between them *R*. It has been concluded in the literature that R provides better results than $R^{\wedge 2}$ in all experiment cases [22].

2.1.1. Law of Motion

The current velocity of any agent is equal the sum of the fraction of its previous velocity and the variation in the velocity. Variation in the velocity or acceleration of any agent is equal to the force acted on the system divided by mass of inertia. For a system with ‘n’ agent (masses), the ith position of an agent X_i is defined by:

$$X_i = (x_i^1, \ldots., x_i^d, \ldots\ldots, x_i^n) \text{ for } i=1,2,\ldots,n \tag{1}$$

Where *n* is the space dimension of the problem and, x_i^d is the represents the position of ith agent in the dth dimension.

At a specific time ‘t’, the force acting on mass ‘i’ from mass ‘j’ is defined as following:

$$\mathrm{F}_{ij}^d = G(t) \frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) + £} (x_j^d(t) - x_i^d(t)) \tag{2}$$

Where M_{aj} is the active gravitational mass related to agent j, M_{pi} is the passive gravitational mass related to agent i, *G(t)* is gravitational constant at time t, ε is a small constant, and $R_{ij}(t)$ is the Euclidian distance between two agents i and j:

$$R_{ij}(t) = \left\| x_i(t), x_j(t) \right\|_2 . \tag{3}$$

To give a stochastic characteristic to algorithm, it is suppose that the total force that acts on mass i in a dimension d be a randomly weighted sum of dth components of the forces exerted from other agents:

$$F_i^d(t) = \sum_{j=1, j \neq i}^{N} rand_j F_{ij}^d(t) , \tag{4}$$

Where $rand_j$ is a random number in the interval [0,1].

Hence, by the law of motion, the acceleration of the mass i at time t, and in direction dth, $a_i^d(t)$, is given as follows:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} , \tag{5}$$

Where M_{ii} is the inertial mass of ith agent.

Furthermore, the next velocity of an mass is considered as a fraction of its current velocity added to its acceleration.Therefore, its position and its velocity could be calculated as follows:

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) , \tag{6}$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) , \tag{7}$$

Where $rand_i$ is a uniform random variable in the interval [0,1].

The gravitational constant, *G*, is initialized at the beginning and will be reduced with time to control the search update. In other words, *G* is a function of the initial value (G_0) and time (t) as:

$$G(t) = G_0 e^{(-\sim t/T)} . \tag{8}$$

Where α is a constant and T is the number of iteration.

Gravitational and inertia masses are calculated by the fitness evaluation. A heavier mass means a more efficient object. This means that better objects have higher attractions and walk more slowly. The gravitational and inertial masses of agents are updated by the following equations:

$$M_{ai} = M_{pi} = M_{ii} = M_i \text{, } i=1,2,\ldots,N, \tag{9}$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)}, \tag{10}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)}, \tag{11}$$

Where $fit_i(t)$ present the fitness value of the agent i at time t, and, worst(t) and best(t) are defined as follows (for a minimization problem):

$$best(t) = \min_{j\in\{1,\ldots,N\}} fit_j(t), \tag{12}$$

$$worst(t) = \max_{j\in\{1,\ldots,N\}} fit_j(t) \cdot \tag{13}$$

It is to be noted that for a maximization problem, (12) and (13) are changed to (14) and (15), respectively:

$$best(t) = \max_{j\in\{1,\ldots,N\}} fit_j(t), \tag{14}$$

$$worst(t) = \min_{j\in\{1,\ldots,N\}} fit_j(t) \tag{15}$$

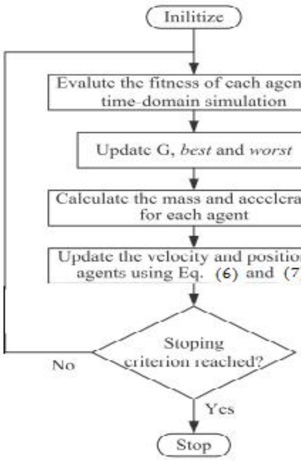

Figure 1. Flow chart of GSA optimization approach

To achieve a good compromise between exploration and exploitation, the number of objects is reduced with lapse of (4) and therefore a set of objects with bigger mass are used for applying their force to the other.

The different steps of the proposed algorithm are the followings:

a) Search space identification.

b) Random initialization.
c) Fitness evaluation of objects.
d) Update G(t), best(t), worst(t) and $M_i(t)$ for i = 1,2,. . .,N.
e) Calculation of the total force.
f) Calculation of acceleration and velocity.
g) Update the position of the objects.
h) Repeat steps c to g until the stop criteria is achieved.

The flow chart of proposed optimization is shown in Figure 1.

3. Dual PI Controller

The control law employed depending upon the magnitude of the rate of change of the error signal.

For $\left|\frac{d(ACE(t))}{dt}\right| > \pounds$

$$U_i = -K_p ACE(t) \qquad (16)$$

Where, *ACE(t)* is an error signal at a particular instant, ε is a small positive constant indicating the specified limit of rate of change of the error signal, U_i the control signal to ith area and K_P is the proportional gain.

$$\pounds = K_c \sum_{i=1}^{N} \Delta P_{Li} \qquad (17)$$

Where K_c is scaling factor, ΔP_{Li} is the disturbance in ith area and *N* the total number of area.

For $\left|\frac{d(ACE(t))}{dt}\right| \le \pounds$

$$U_i = -K_i \int ACE(t)dt \qquad (18)$$

Where K_i is the integral gain.

Then if the parameters K_p, K_i and K_c are suitably selected, one can ensure a high quality transient response. By choosing a suitable value of K_p, one makes sure that speed of the system is high. Whenever the rate of change of error falls within the specified error bound $\left|\frac{d(ACE(t))}{dt}\right| \le \pounds$, the integrator starts accumulating the error. But if the error exceeds the bound the integrator resets to zero. The GSA is proposed in this paper to get the best value of K_p, K_i *and* K_c.The proposed control scheme is shown in Figure 2.

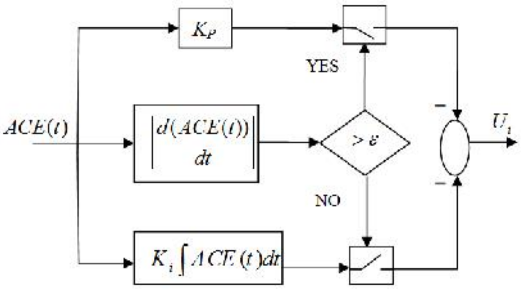

Figure 2. Block diagram for the proposed dual

4. Two Area Power System

A model of controlled non-reheat thermal plants in two-area interconnected power system is shown in Figure 3 where f_i is the system frequency (Hz), R_i is the regulation constant (Hz/unit), T_{Gi} is the speed governor time constant (s), T_{Ti} is the turbine time constant (s) and T_{Pi} is the power system time constant (s), ACE_i is the area control error, ΔP_{Di} is the load demand change, ΔP_{ci} is the change in speed changer position, ΔP_{Gi} is the change in governor valve position, K_{Pi} is the power system gain, and ΔP_{tie} is the change in tie line power. The overall system can be modeled as a multivariable system in the following form:

$$\dot{x} = Ax + Bu + \Gamma d , \tag{19}$$

$$y = cx \tag{20}$$

$$x = [\Delta f_1 \quad \Delta P_{T1} \quad \Delta P_{G1} \quad \Delta P_{C1} \quad \Delta P_{tie} \quad \Delta f_2 \quad \Delta P_{T2} \quad \Delta P_{G2} \quad \Delta P_{C2}]^T$$

$$u = [u_1 \quad u_2]^T, \; y = [ACE_1 \quad ACE_2]^T, \; d = [\Delta P_{D1} \quad \Delta P_{D2}]^T$$

5. Objective Function

The performance index which selected in this paper can be defined by the Integral of Time multiply Absolute Error (ITAE) of the frequency deviation of both areas and tie line power. Accordingly, the objective function J is set to be:

$$J = \int_0^{T_s} t\left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|\right)dt \tag{21}$$

Where T_s is the simulation time.

This study focuses on optimal tuning of controllers for LFC using GSA. The aim of the optimization is to search for the optimum dual PI controller parameters setting that improve the damping characteristics of the system under all operating conditions and various loads and finally designing a low order controller for easy implementation.

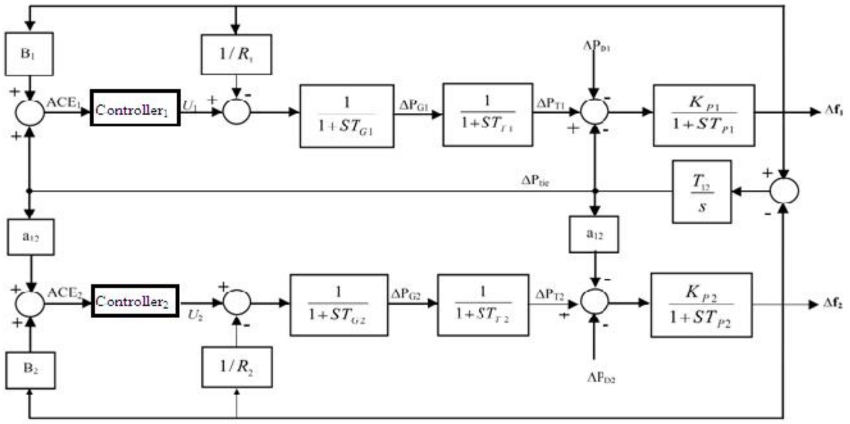

Figure 3. Two-area interconnected power system

6. Simulation Results

In this section different comparative cases are examined to show the effectiveness of the proposed ICA method for optimizing controller parameters of dual PI controller. Table 1 gives the optimum values of controller parameters for different methods. The PI controller parameters of conventional controller due to [19].

Table 1. Controller Parameters and Objective Function (J)

	Conventional PI	GSA-PI	Dual PI
Controller Parameters	K_p= 0.7005, K_I = 0.3802	K_p=-0.3140, K_I =0.4578	K_p = 4.3495 , K_I = 0.7560, K_c=1.0013
J	3.5795	1.1764	0.6774

6.1. Step Increase in Demand of the Frist Area (ΔP_{D1})

In this case, a 0.1 step increase in demand of the first area (ΔP_{D1}) is applied (nominal test case). The change in frequency of the first area Δf_1, the change in frequency of the second area Δf_2, and change in tie-line power of the closed loop system are shown in Figure 4-6. Remarkably, the response with conventional PI controller has high settling time and undesirable oscillations. Also compared with PI-based GSA the proposed method is indeed more efficient in improving the damping characteristic of power system.

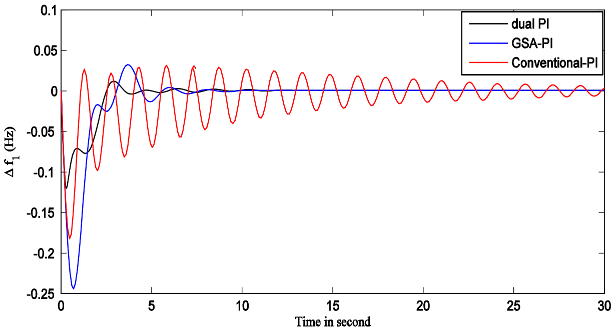

Figure 4. Change in f_1 for 0.1p.u step increment in P_{D1}

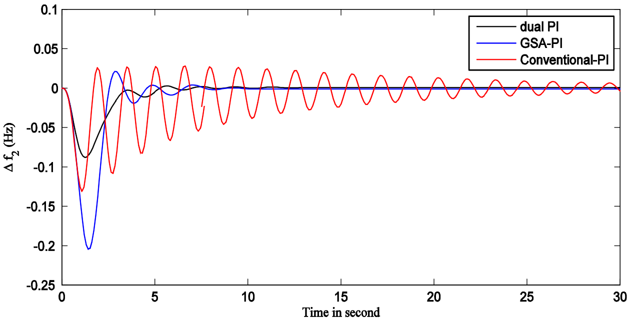

Figure 5. Change in f_2 for 0.1p.u step increment in P_{D1}

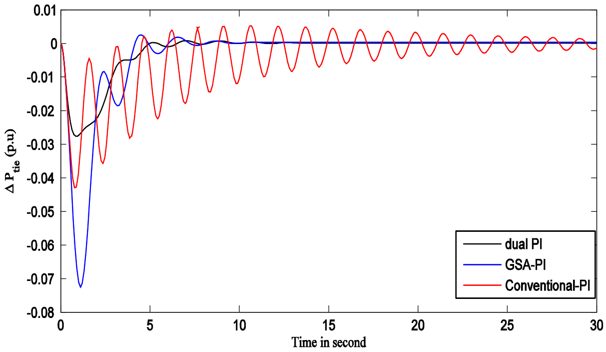

Figure 6. Change in P_{tie} for 0.1p.u step increment in P_{D1}

6.2. Step Increase in Demand of the Second Area (ΔP_{D2})

In this case, a 0.1 step increase is applied as a change of demand in the second area (ΔP_{D2}). The change in frequency of the first area Δf_1, the change in frequency of the second area Δf_2 and change in tie-line power of the closed loop system are shown in Figure 7-9. From these Figures it can be seen that oscillations are disappear in the presence of the proposed controller. Moreover, the proposed method outperforms and outlasts PI-based GSA in damping oscillations effectively and reducing settling time. Hence compared to the conventional controller, and PI-based GSA, dual PI based GSA greatly enhances the system stability and improves the damping characteristics of power system.

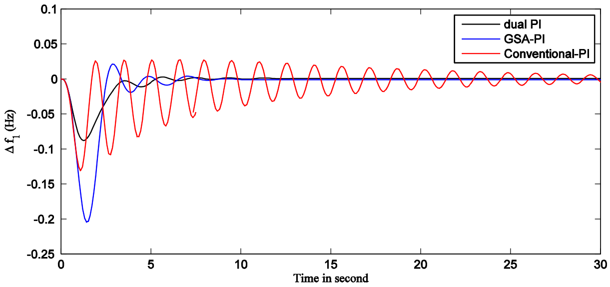

Figure 7. Change in f_1 for 0.1p.u step increment in P_{D2}

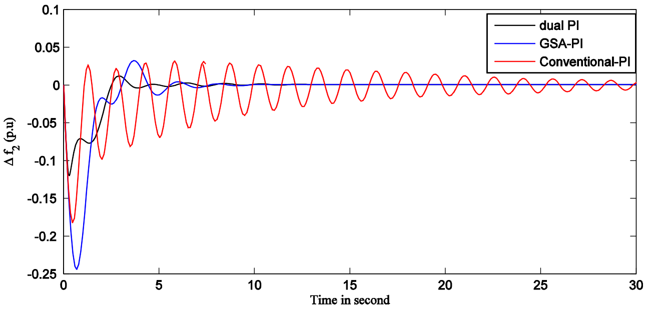

Figure 8. Change in f_2 for 0.1p.u step increment in P_{D2}

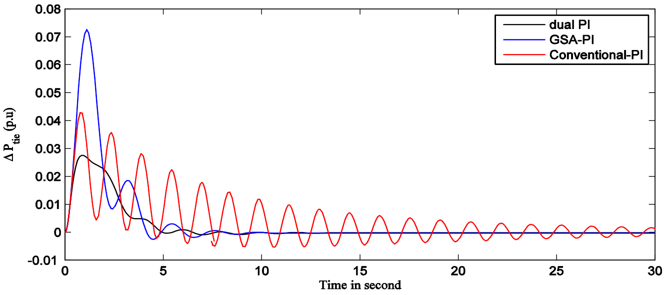

Figure 9. Change in P_{tie} for 0.1p.u step increment in P_{D2}

6.3. Step Increase in Demand of the First and Second Area Simultaneously

In this case, a 10% step increase in demand of the first area (ΔP_{D1}) and second area (ΔP_{D2}) simultaneously are applied. It is clear from Figure 10 that the proposed method has a smaller settling time and system response is quickly driven back to zero compared with conventional controller and PI-based GSA In addition, the potential and superiority of the proposed method over the conventional, and PI-based GSA is demonstrated.

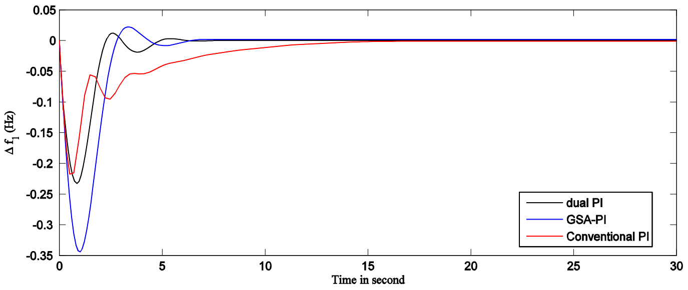

Figure 10. Change in f_1 for 0.1p.u step increment in P_{D1} and P_{D2}

6.4. Parameter Variation

A parameter variation test is also applied to validate the robustness of the proposed controller. Figsure 11-12 show the response of frequency of first area with variation in T_{12}. It is clear that the system stable with the proposed controller.

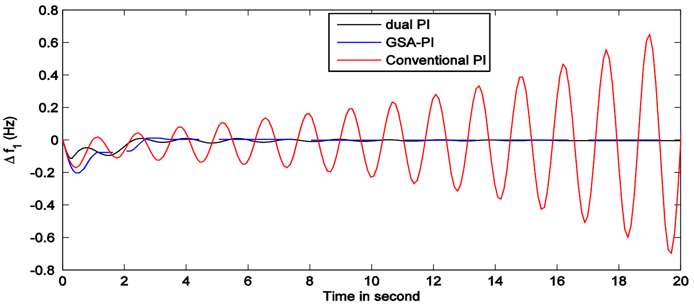

Figure 11. Change in f_1 due to +50% increase in T_{12}

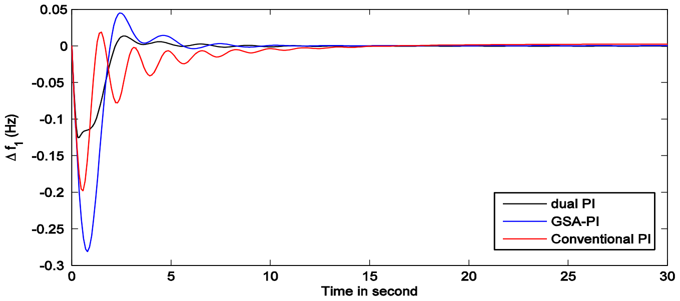

Figure 12. Change in f_1 due to -50% decrease in T_{12}

7. Conclusion

This paper presents the application of the GSA algorithm as a new artificial intelligence technique in order to optimize the AGC in a two-area interconnected power system. GSA algorithm is proposed to tune the parameters of dual PI controller. A two-area power system is considered to demonstrate the proposed method. Simulation results emphasis that the designed dual PI-based GSA is robust in its operation and gives a superb damping performance for frequency and tie line power deviation compared to conventional PI controller, and PI-based GSA. Besides the simple architecture of the proposed controller it has the potentiality of implementation in real time environment.

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