

An Intelligent Method for Automatic Generation Control of Two Area Interconnected Power System Using GSA Based PID Controller

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Abstract: Numbers of optimization techniques has been developed by several researchers to control the load frequency of two area system. In this paper a population based Gravitational Search Algorithm (GSA) is implemented for the same purpose. Here the two area non reheat thermal system is equipped with Proportional-Integral-Derivative (PID) controller whose gains are tuned by using GSA optimization technique and the behavior of the proposed system is investigated by taking Integral Time multiple Absolute Error (ITAE) objective function. The dynamic responses with PID controller are compared with PI controller under different loading condition of the same system. Different system parameters ($\pm 25\%$ to $\pm 50\%$) are considered for the purpose of analysis to obtain the effectiveness and robustness of the system.

Keywords: Automatic Generation Control (AGC), Gravitational Search Algorithm (GSA), Load frequency control, PID controller.

I. INTRODUCTION

The purpose of interconnected large power system is to generate, transmit and to distribute electrical energy at the nominal system frequency, terminal voltage and tolerances of those as per the power quality standards. In this situation we need Automatic Generation Control (AGC) to calculate Area Control Error (ACE), monitor the system frequency and tie line power flows for computing the net change in the generation by which the time average of ACE will be at a low value [1-5]. The Area Control Error (ACE) is a linear combination of the tie line flow and frequency and is calculated by AGC [6]. It represents a mismatch between the area and the load. It maintains the power balance of the system by monitoring both generator and tie line limit.

Various conventional load frequency controllers [9, 10, 11] are discussed in this work, but due to their time consuming and highly oscillatory in nature Proportional Integral (PI) controller is implemented for analysis. The Tabu Search based algorithm for optimal design of a Fuzzy Logic based proportional integral load frequency control in a two area interconnected power system is presented [11]. In order to obtain the dynamic performance, a number of control techniques has been employed to control the load frequency in different interconnected power systems where step load perturbation is considered for both single area system and two area interconnected systems. In the literature various optimization techniques can be proposed and tested for comparative performance study. The research has been attempt AGC system based on modern control theory [12], and several soft computing approaches such as, neural network [13], Fuzzy logic [14, 15], ANFIS approach [16]. The Gravitational Search Algorithm (GSA) is one of the newest heuristic optimization techniques which have been inspired by Newton's law of gravity [17]. The design is formulated as optimization problem and GSA is applied for tuning the controller parameters. The objective function is minimized to improve the system performance in terms of settling time and overshoot of frequency deviation and tie line power of the interconnected power system. The simulation result of the proposed analysis shows the robustness of GSA based PID controller under wide ranges of system parameters. The approach is compared with the simulation result of recently published paper Genetic Algorithm based optimization techniques for load frequency control of interconnected power system [19] and with the GSA based PI controller of the same interconnected two area reheat thermal power system [20].

II. TWO AREA POWER SYSTEM MODEL

The system model considers a two area (equal size) interconnected non-reheat thermal power system. Here the

objective is to find optimal values of the proposed controller in the AGC problem. Fig. 1 shows the simulation model where, Δf_1 and Δf_2 are system frequency deviation in Hz, ΔP_{tie} change in tie line power, ACE_1 and ACE_2 are area control errors, ΔP_{G1} and ΔP_{G2} are changes in governor valve positions, ΔPc_1 and ΔPc_2 are changes in governor speed changer positions, ΔP_{T1} and ΔP_{T2} are changes in turbine output powers, ΔP_{D1} and ΔP_{D2} are load demand changes, T_{ps1} and T_{ps2} are power system time constants, T_{12} is the synchronizing coefficient, u_1 and u_2 are the control outputs from the controllers, R_1 and R_2 are the governor speed regulation parameters, K_{PS1} and K_{PS2} are power system gains, B_1 and B_2 are the frequency bias parameters. T_{G1} and T_{G2} are speed governor time constants in sec. T_{T1} and T_{T2} are the turbine time constants in sec. The applicable parameters are given in Table I.

TABLE I:

Parameters	Value
$T_{PS1}=T_{PS2}$	20s
$B_1=B_2$	0.045pu MW/HZ
$R_1=R_2$	2.4HZ/pu MW
$T_{G1}=T_{G2}$	0.08S
$T_{T1}=T_{T2}$	0.3S
$K_{PS1}=K_{PS2}$	120HZ/pu MW
T_{12}, a_{12}	0.545pu, -1

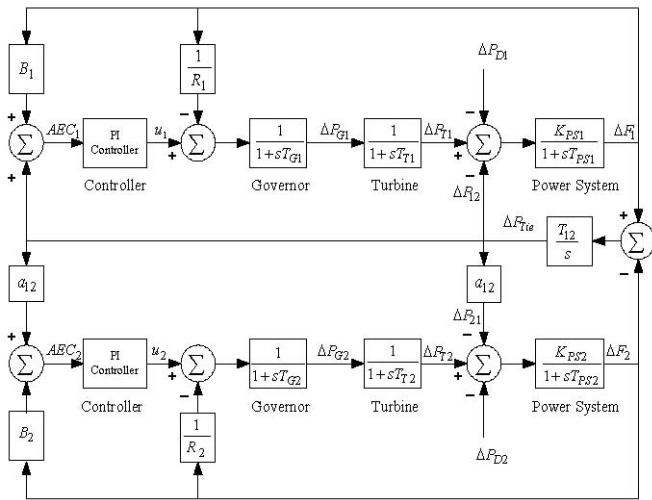


Fig. 1: System Under Study

The structures of the PI controllers is considered as:

$$K(S) = K_p + \frac{K_I}{S} \quad (1)$$

$$K(S) = K_p + \frac{K_I}{S} + SK_D \quad (2)$$

Where K_p , K_I and K_D are proportional gain, integral gain and derivative gain respectively. The input and output of the

controllers for area-1 and area-2 are ACE_1 , ACE_2 and u_1 , u_2 respectively.

III. OBJECTIVE FUNCTION

In this work Integral of Time Multiplied Absolute Error (ITAE) objective function is considered in terms of frequency deviation of the two areas and tie line power.

$$J = \int_0^{t_{sim}} (|\Delta f_1| + |\Delta f_2| + |\Delta P_{Tie}|) \cdot t \cdot dt \quad (3)$$

Here Δf_1 and Δf_2 represent frequency deviation of the system and ΔP_{tie} represents the incremental change in the tie line power. The aim of the objective function (J) is to minimize the value subjected to:

$$K_p^{min} \leq K_p \leq K_p^{max}$$

$$K_I^{min} \leq K_I \leq K_I^{max}$$

$$K_D^{min} \leq K_D \leq K_D^{max}$$

where K_I^{min} , K_p^{min} , K_D^{min} , K_I^{max} , K_p^{max} , K_D^{max} are minimum and maximum value of controller parameters and $K_{P1}=K_{P2}=K_p$, $K_{I1}=K_{I2}=K_I$ and $K_{D1}=K_{D2}=K_D$.

IV. GRAVITATIONAL SEARCH ALGORITHM (GSA)

Step 1: Initialization of the Agents:

Positions in randomly search of the N number of agents within the search interval are initialized in this step.

$$X_i = (x_i^1, \dots, x_i^d, \dots, x_i^n), \text{ for } i=1,2,\dots,n \quad (4)$$

Where x_i^d is the position of i -th agent in the d -th dimension and n represents the space dimension of the problem. Fitness of all agents is evaluated at each step and the best and worst fitness are calculated for every iteration as discussed in step 2.

Step 2: Fitness Evolution and Best Fitness Computation for Each Agents:

Perform the fitness evolution for all agents at each iteration and also compute the best and worst fitness at each iteration defined as below (for minimization problems):

$$Best(t) = \min_{j \in \{1..n\}} fit_j(t) \quad (5)$$

$$Worst(t) = \max_{j \in \{1..n\}} fit_j(t) \quad (6)$$

In the above two equation $fit_i(t)$ represents the fitness values of the agent i at time t and best(t) are defined as follows (for a minimization problem):

Step 3: Computation of the Gravitational Constant G:

G is the gravitational constant which is a function of the initial value G_0 and time t expressed as:

$$G(t)=G(G_0,t)=G_0 e^{-\acute{\alpha}t/T} \quad (7)$$

In this problem, G_0 is the initial value set to 100, $\acute{\alpha}$ is the user specified constant set to 20, and T is the total number of iterations [21].

Step 4: Calculation of Mass of the Agents:

Gravitational mass and inertia mass are calculated by the fitness evaluation represented by equations (8) and (9). Here gravitational and inertia masses are taken equal and are updated by above two equations as given below:

$$M_{ai} = M_{pi} = M_{ii} = M_i, i = 1, 2, \dots, n.$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (8)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^N m_j(t)} \quad (9)$$

Step 5: Calculate Accelerations of the Agents:

The output performance of this algorithm can be enhanced by controlling the exploration and exploitation only when $Kbest$ will attract the others where $Kbest$ is a function of time with initial value K_0 at the beginning. In this way, at the beginning, all agents apply the force, and as time passes, $Kbest$ decreases linearly and at the end there exists just one agent applying force to the others the value of $Kbest$ becomes 2% of the initial number of agents. Thus Eq. (9) can be modified as:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (10)$$

$M_i(t)$ is the inertia mass of i -th agent.

$$F_i^d(t) = \sum_{j=1, j \neq i}^N rand_j F_{ij}^d(t) \quad (11)$$

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

$F_{ij}^d(t)$ is the force acting on agent 'i' from agent 'j' at d -th dimension and t -th iteration is computed as below:

$$F_{ij}^d(t) = G(t) \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij}(t) + \epsilon} (x_j^d(t) - x_i^d(t)) \quad (12)$$

M_{pi} is the passive gravitational mass related to agent i

And M_{pj} is the active gravitational mass related to agent j , $R_j(t)$ is the Euclidian distance between two agents 'i' and 'j' given by $R_{ij}(t) = \|X_i(t), X_j(t)\|_2$

$G(t)$ is the gravitational constant computed at the same iteration and ϵ is a small constant.

Step 6: Updating the Velocity and Positions of the Agents:

The velocity and the position of the agents are computed at the next iteration ($t + 1$) using the following equations:

$$v_i^d(t+1) = rand_i * v_i^d(t) + a_i^d(t) \quad (13)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (14)$$

Where $rand_i$ is a uniform random variable in the interval [0, 1], used to give a randomized characteristic to the search.

Step 7: Steps 2-6 are repeated until iterations reaches their maximum limit. The best fitness computed at the final iteration provides a global fitness of the problem. The positions of the corresponding agent at specified dimensions give the global solution of that problem.

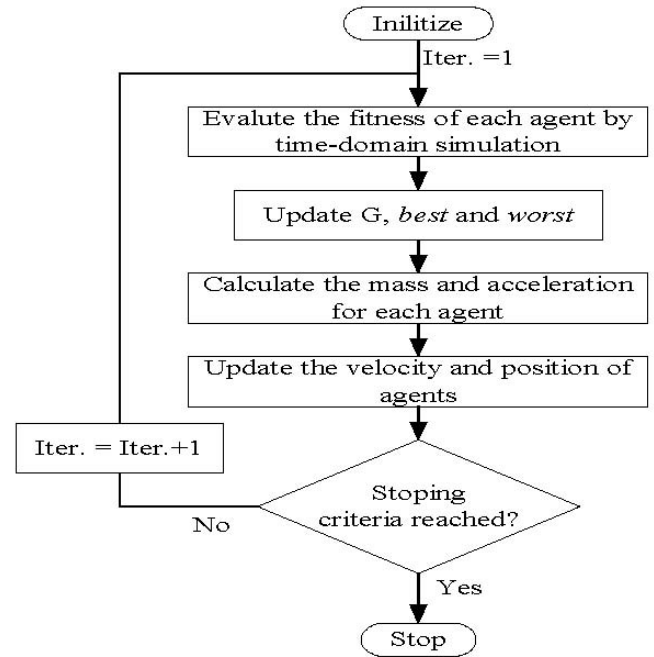


Fig. 2: Flow Chart of Proposed GSA Optimization Approach

Different Steps of the GSA are as follows:

- Search space identification.
- Randomized initialization.
- Fitness evaluation of agents.
- Updating $G(t)$, $best(t)$, $worst(t)$ and $M_i(t)$ for $i = 1, 2, \dots, n$.
- Calculation of the total force in different directions.
- Calculation of acceleration and velocity.
- Updating agent's position.
- Repetition of steps (iii) to (vii) until the stop criteria reached.

V. RESULTS AND DISCUSSIONS

The algorithm has been applied to the automatic generation control of interconnected of two non reheat power system to determine optimal parameters of PI and PID controllers. The results are obtained by ATLAB/SIMULINK environment to run on the computer. From the simulation result the performances has been compared in different cases of perturbation in the two area system. In the analysis the perturbation considered in area-1 and area-2 individually and then in both area simultaneously. The optimization process has been repeated 20 times and the best final solution among the 20 runs is chosen as the controller parameters which are shown in Table II. In Table III different values of settling times of frequency deviations and tie line power of the system are shown.

TABLE II: TUNED CONTROLLER PARAMETERS

	Parameters	J1(ITAE)
GSA with PID controller	K_P	0.8932
	K_I	0.9211
	K_D	0.9376
GSA with PI controller [20]	K_P	-0.3100
	K_I	0.2670
GA with PI controller [19]	K_P	-0.2346
	K_I	0.2662
Conventional PI controller	K_P	0.7005
	K_I	0.3802

TABLE III: DIFFERENT VALUE OF SETTLING TIME OF THE SYSTEM

Parameters		Con.	GA optimized PI Controller	GSA optimized PI controller	GSA Optimized PID controller
T_S Sec	Δf_1	45	10.2	8.7	7.67
	Δf_2	45	10.6	8.45	6.13
	ΔP_{tie}	29.8	9.2	8.87	7.54

Case 1: Step Increase in Demand of the First Area

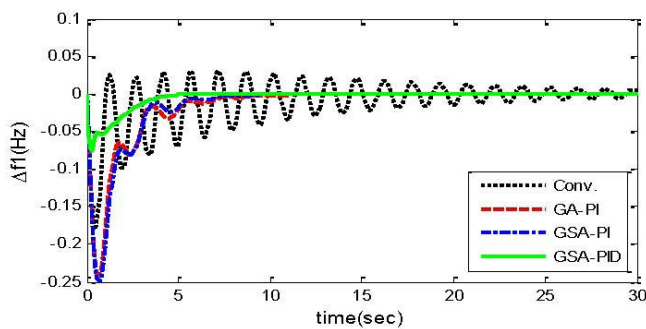


Fig. 3: Frequency Deviation of the Area-1 due to Disturbance in Area-1 as per Case-1

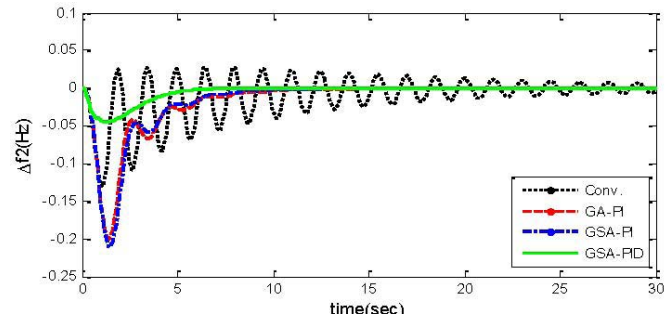


Fig. 4: Frequency Deviation of the Area-2 due to Disturbance in Area-2 as per Case-1

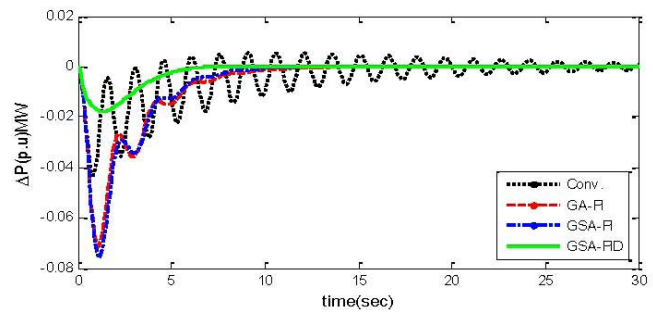


Fig. 5: Tie Line Power Deviation of the Area-1 due to Disturbance in Area-1 as per Case-1

Case 2: Step Increase in Demand of the Second Area

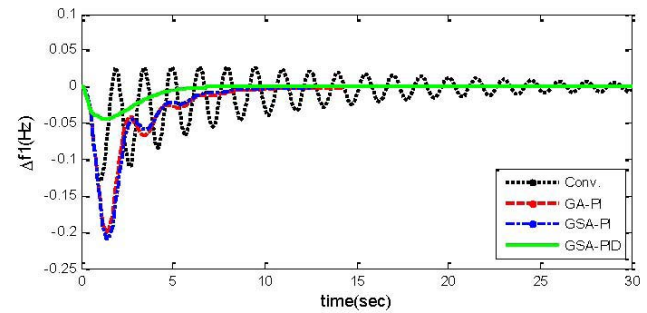


Fig. 6: Frequency Deviation of the Area-1 due to Disturbance in Area-2 as per Case-2

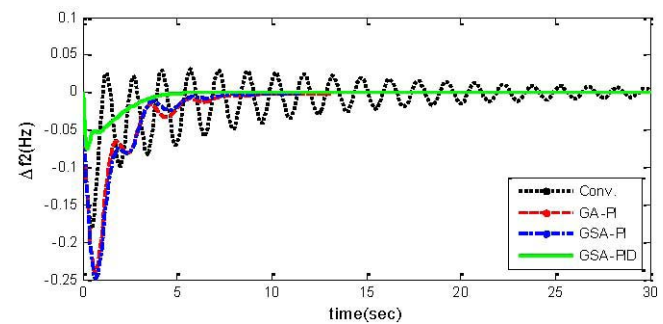


Fig. 7: Frequency Deviation of the Area-2 due to Disturbance in Area-2 as per Case-2

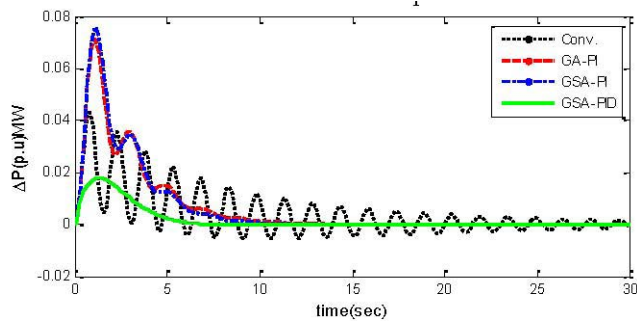


Fig. 8: Tie Line Power Deviation of the Area-2 due to Disturbance in Area-2 as per Case-2

Case 3: Step Increase in Demand of the First and Second Area Simultaneously

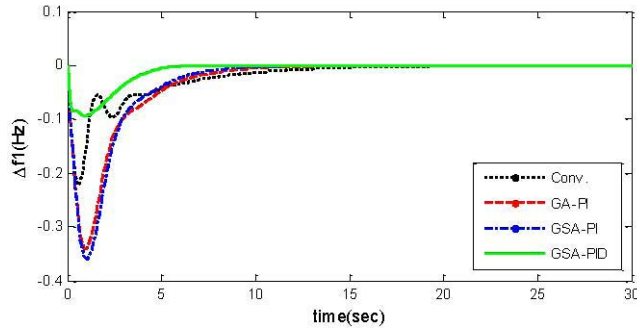


Fig. 9: Frequency Deviation of Area-1 due to Disturbance in Area-1 and Area-2

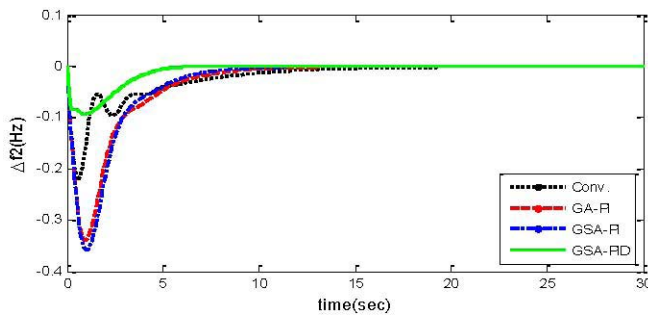


Fig. 10: Frequency Deviation of the Area-2 due to Disturbance in Area-1 and Area-2

In the above two cases and 10% step increase in demand in the area-1 and area-2 are taken at time $t=0$ at the same operating condition.

However, the same system yields better response in term of settling time and overshoots with PID controller.

Similarly the step increase in demand is considered both the area-1 and area-2 simultaneously for the effectiveness of the proposed system. The frequency deviations (Δf_1) in area-1, (Δf_2) in area-2 in the closed loop system are shown in Figs.

11-14. Figs. 9-12 shows that the oscillation of the system is very poor with conventional controller but in GA and GSA based PI controller damping characteristics of the system is improved. However, PID controller gives much better response in comparison to PI controller of the same system as system response quickly reaches steady state.

TABLE IV: TUNED CONTROLLER PARAMETERS FOR DIFFERENT LOADINGS

Controller	Controller Parameters	+25%	+50%	-25%	-50%
P-I	K_p	-0.4989	-0.5342	-0.5034	-0.5183
	K_I	0.2395	0.2082	0.2345	0.2486
P-I-D	K_p	0.1165	0.5578	0.1789	0.3411
	K_I	0.8001	0.9569	0.8879	0.9345
	K_D	0.4456	0.6772	0.5122	0.6342

The tuned PI and PID controller parameters for different loadings ($\pm 25\%$ to $\pm 50\%$) for the interconnected two area system are shown in Table IV. For the tuning of all load of PI/PID controller take range from $[-1, 1]$ for the purpose analysis. Different value of settling times of frequency deviations and tie line power of the proposed system are listed in Table V. The changes in frequency of area-1 and area-2 for increase in load demand from +25% to +50% in area-1 respectively are shown in Fig. 11 and Fig. 12. It is found that the performance of PID controller is better than PI controller in term of settling times under this condition.

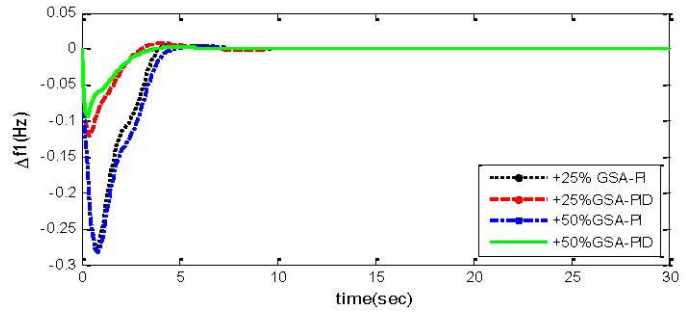


Fig. 11: Change in Frequency of Area-1 for Increase in Load Demands (+25% to +50%) in Area-1

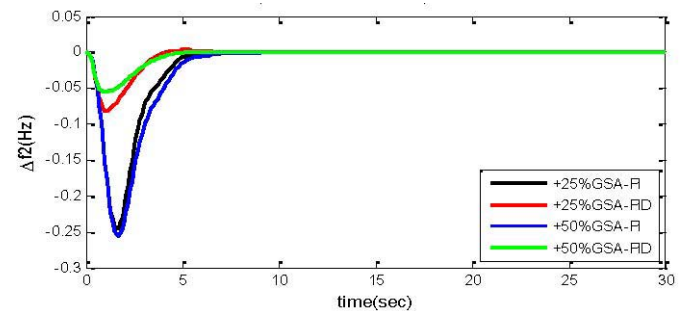


Fig. 12: Change in Frequency of Area-2 for Increase in Load Demands (+25% to +50%) in Area-1

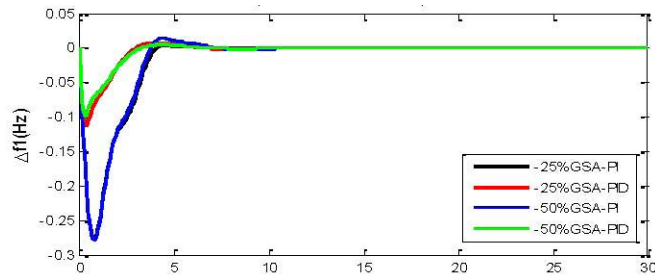


Fig. 13: Change in Frequency of Area-1 due to Decrease in Load Demands (-25% to -50%) in Area-1

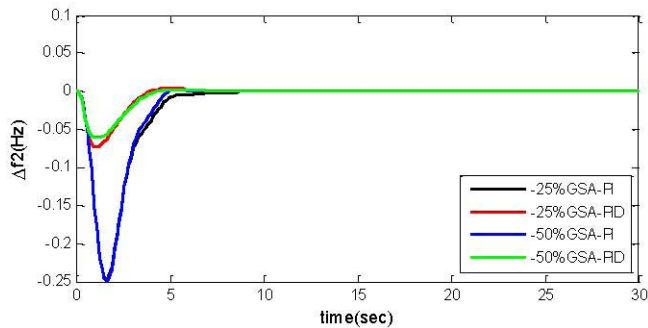


Fig. 14: Change in Frequency of Area-1 for Decrease in Load Demands (-25% to -50%) in Area-2

TABLE V: SETTLING TIME AT DIFFERENT LOADINGS

Ts	GSA optimized PI controller		GSA optimized PID controller	
	Parameters	value	Parameters	value
+25%	$\Delta f1$	7.63	$\Delta f1$	6.45
	$\Delta f2$	6.93	$\Delta f2$	5.15
+50%	$\Delta f1$	8.24	$\Delta f1$	4.95
	$\Delta f2$	7.45	$\Delta f2$	6.38
-25%	$\Delta f1$	7.23	$\Delta f1$	6.76
	$\Delta f2$	8.21	$\Delta f2$	5.36
-50%	$\Delta f1$	7.86	$\Delta f1$	4.89
	$\Delta f2$	8.75	$\Delta f2$	6.49

VI. CONCLUSION

GSA based PID controller using the Automatic Generation Control (AGC) in interconnected two reheat thermal power system is implemented in this work. The controller parameters are obtained by using the objective function ITAE of frequency deviation and tie line power in the both the area. The result shows that the tuning of PID controller gives better performance in terms of overshoot and settling time as compared with PI controller. The robustness of the controller in the given power system analyzed under different loading conditions and gives better performances.

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