Application of Search Group Algorithm for Automatic Generation Control of Multi-area Multi-source Power Systems

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Abstract. This paper proposes a new Search Group Algorithm based PID controller, to deal with Automatic Generation Control of two-area with six unit power system. The supremacy of SGA tuned PID controller is being shown using the comparative study with Firefly Algorithm (FA) optimization method for the same test system using ITAE as an objective function. It has been demonstrated that SGA tuned PID controller improves the performance in a large compared with FA tuned PID controller. Furthermore variation in nominal values of operating load condition and system parameters with the position of step load perturbation is being carried out to achieve sensitivity analysis. From the result of sensitivity analysis it clearly depicts the robustness of the suggested method (SGA with PID controller) for two-area with six unit power system in AGC. Finally for better investigation, the proposed method is also examined by applying randomization in step load.

1 Introduction

Power systems arena is thriving day by day which leads to consider a major factor as Automatic Generation Control (AGC) for stable and secure power system operation. AGC plays a vital role to maintain the consistency in frequency with tie-line power. There is a great gap between electrical load demand and power generation which leads to deviation in outcomes. AGC nullifies the Area Control Error (ACE) using calculation with respect to corresponding load change in each area by adjusting automatically the generator set points. ACE is defined as the linear combination of frequency variation to the corresponding distortion in net tie-line power interchange [1-5]. Researchers are proposed number of control schemes in AGC of power systems to achieve optimized result.

The authors were investigated the different AGC based generic controllers in multi-area multi-source power system [6-9]. Sharma et al. have presented optimal design of AGC regulator controller in frequency regulation of multi-area power system with diverse power generating units [10]. Guha et al. have proposed Grey Wolf Optimization (GWO) based classical controller with PI/PID structure for AGC in multi-area power systems [11]. Saroj et al. have presented the supremacy of Firefly Algorithm tuned PID controller of two-area interconnected power system for AGC [12]. The effectiveness of AGC is not limited to artificial intelligence techniques simultaneously it depends on objective function as well the controller structure chosen which is clearly signifies from past literature.

Recently, metaheuristic based algorithm known as the Search Group Algorithm (SGA) is being proposed by Matheus Silva Goncalves et al. for the application to truss structure [13]. SGA is a population oriented search algorithm which maintains the balance in the design domain between the exploration & exploitation.

The novel contributions in this paper are:

(i) The demonstration of the superiority of new powerful computational intelligence technique like SGA over FA tuned PID controller for AGC

(ii) To show robustness of SGA based PID controller. Here, two area six unit like hydro, gas and thermal units are taken for investigation [14]. The empirical analysis result reflects the supremacy of the suggested method. Lastly, to show the effectiveness of the tuned controller parameters, variation in nominal values of system parameters, operating load condition with the position of SLP is carried out to achieve sensitivity analysis.

2 Proposed Method

2.1 Power System modelling:

Firstly,2-area with 6-unit power system is demonstrated in Fig.1. The nominal loading is being contributed based on the decision of the participation factor assigned by each unit. After summing each control participation factor the outcome should be equivalent to unity. Participation factor for hydro, gas and thermal units are evaluated as 32%, 13% and 55% respectively. The system parameters values are represented in Appendix. Regulation parameters R_1, R_2 and R_3 shown in Fig.1 denotes thermal, hydro and gas unit respectively.

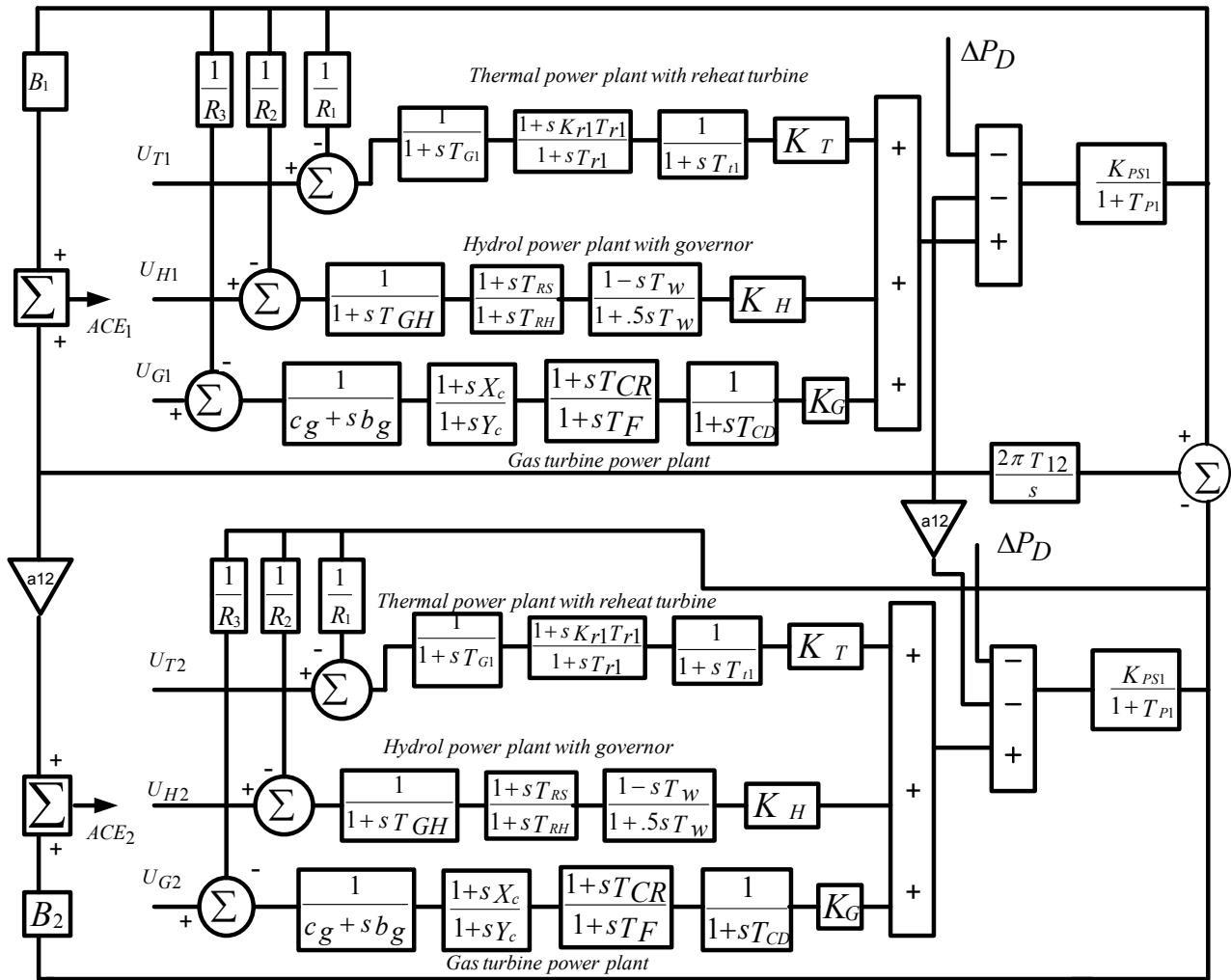[*] Corresponding author: rksahu_ee@vssut.ac.in

Fig. 1. Transfer function model of test system

The control outputs are represented as U_T for thermal, U_H for hydro and U_G for gas units. The participation factors are represented as K_T for thermal, K_H for hydro and K_G gas units. T_{SG}, T_T represents time constant of speed governor for thermal units and reheat steam turbine in second respectively. T_W represents penstock base starting time of water in sec. T_{RS} represents reset time for speed governor, T_{RH} represents time constant for governor droop, T_{GH} represents time constant for main servo of speed governor of hydro turbine in sec respectively. X_C represents lead-time constants and Y_C represents lag-time constants of speed governor for gas turbine in sec respectively. c_g represents gas turbine and b_g represents valve positioned based gas turbine constant. T_F represents time constant of fuel and T_{CR} represents time delay of combustion reaction in sec of gas turbine. T_{CD} represents time constant of discharge volume for compressor based gas turbine in sec. K_{PS} represents gain of power system in Hz/p.u.MW. T_{PS} represents time constant of power system in sec. ΔF, ΔP_D are the variation in frequency and load respectively.

2.2 Controller design with objective function

Circuit diagram of PID controller is shown in Fig. 2.

Where K_P: Proportional gain, K_I: Integral gain and K_D: Derivative gains. The general s-domain PID controller transfer function is given by.

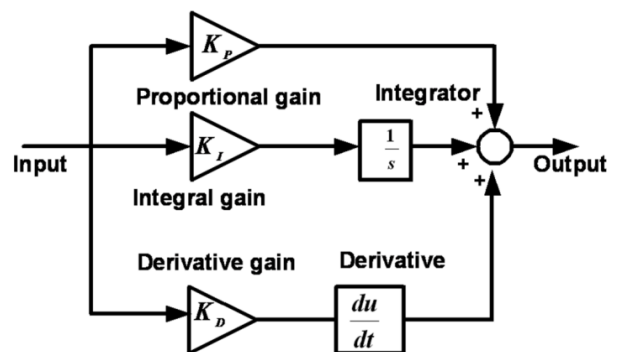$$TF_{PID} = K_P + \frac{K_I}{s} + K_D s \tag{1}$$

Fig. 2. PID controller structure

Errors inputs to the controllers of the corresponding ACE are mentioned in equations (2-3):

$$ACE_1 = e_1(t) = B_1 \Delta F_1 + \Delta P_{Tie} \tag{2}$$

$$ACE_2 = e_2(t) = B_2 \Delta F_2 - \Delta P_{Tie} \tag{3}$$

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The performance criteria suitable for AGC studies are Integral Time multiplied Absolute Error (ITAE) as reported in literature [15]. ITAE is used as objective function which is provided in equation (4):

$$J = ITAE = \int_0^{t_{sim}} \left(|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}| \right) \cdot t \cdot dt \quad (4)$$

Equation (5-6) represents the optimization problem for the design issue

Minimize the value of J (5)

Subject to

$$K_{P\min} \leq K_P \leq K_{P\max}$$
$$K_{I\min} \leq K_I \leq K_{I\max}$$
$$K_{D\min} \leq K_D \leq K_{D\max} \quad (6)$$

The minimum parameters values are chosen as -2.0 and maximum value is 2.0 of PID controller.

3 Search Group Algorithm

A population-based optimization method as Search Group Algorithm was being proposed by M.S. Goncalves et al. [13].The important function of SGA is categorized into five steps is depicted in below.

3.1 Phase-1: Initial Population

Randomly initial population P is chosen based on equation (7)

$$P_{ij} = X_j^{\min} + \left(X_j^{\max} - X_j^{\min} \right) U[0,1] \quad (7)$$
$$\text{Where } j = 1 \text{ to n}, i = 1 \text{ to } n_{pop}$$

P_{ij} represents as the jth design variable of population P for i^{th} individual. All design variables summation is n. n_{pop} signifies the total of population. The range of identical variable U [0, 1] is between 0 to 1 which is arbitrary in nature. The lower limit is $X_j^{\min}$ and the higher limit is $X_j^{\max}$ of jth design variable.

3.2 Phase-2: Initial search group selection

Initially the population has being formed after that objective function is evaluated, a benchmark tournament selection [13] is applied by selecting n_g individuals from the population P to build the search group R. In every cycle If R_i denotes the ith row of R, then R_I: denotes the finest design, R_{ng}: denotes the coarse design in R, n_g: denotes the members count in search group.

3.3 Phase-3: Selection of mutated search group

New offspring's (individuals) are generated by substituting n_{mut} individuals from R to increase the capabilities of global population search which is evolved from equation (8)

$$X_j^{mut} = E[R_j] + t\varepsilon\sigma[R_j], \text{ for } j = 1, \ldots, n \quad (8)$$

Where $X_j^{mut} \rightarrow j^{th}$ design variable of known mutated individual.

$E \rightarrow$ Mean, $\sigma \rightarrow$ Standard deviation, $\varepsilon \rightarrow$ random variable

Choosing of worst objective function is being replaced by "inverse tournament" selection.

3.4 Phase-4: Family generation of every search group member

Family defines as the generation of set of offspring's (individuals) from search group member using perturbation analysed by equation (9).

$$X_j^{mut} = R_{ij} + \alpha\varepsilon \quad \text{for } j = 1, \ldots n \quad (9)$$

Where $\alpha \xrightarrow{Controls}$ size of the perturbation

During the search process value of α reduces after subsequent iteration k. which is mentioned in equation (10):

$$\alpha^{k+1} = b\alpha^k \quad (10)$$

Where in every iteration α^k reduces in such a manner which is described by parameter b and controls the distance. Initially, value of α^k is chosen a maximum value to explore the design phase as a whole.

α^k ranges between $\alpha^0 \leq \alpha^k \leq \alpha_{\min}$

Where $\alpha_{\min} \rightarrow$ Minimum value of α^k to ascertain and nullify movement of new off springs (Individuals) also in last iteration of SGA.

$\alpha^0 \rightarrow$ Initial iteration value of α. Assume $F_i \rightarrow$ Family where i=1 to n_g. The objective function decides the creation of number of offspring by every search group members. Total count of offspring (Individuals) maximizes based on the superiority of objective function. Keeping constant by calculating total number of design in each iteration which is represents as (n_{pop} - n_g).

3.5 Phase-5: Selection of new search group

Global phase algorithm defines as the novel search group emerges by key (best) global member of individual family in the initial $it^{\max}$ iterations. Local phase of algorithm defines as the original search group is produced where $it_{global}^{\max}$ is less than iteration number by the better n_g individuals within the families. $it^{\max} \rightarrow$ Maximum iterations, $it_{global}^{\max} \rightarrow$ Maximum iterations in global phase.

4 Firefly Algorithm

Yang et al. [16] developed a meta-heuristic technique termed as Firefly Algorithm (FA) which is based on bioluminescence that is a biochemical process by the flashing characteristics (flashing light) of fireflies. For mating the flashing light may use as the main courtship signals [17, 18].It is based on the following three fire-flies characteristics:

Every firefly having unisex property gets attracted among them in spite of their sex.

Based on brightness the firefly gets attracted using distance parameters.

The optimized objective function decides the brightness of a firefly. The Firefly algorithm is elaborated detail in [12].

5 Analysis of results with discussion

In this paper MATLAB with SIMULINK is used to design and simulate the model for studying the system. SGA programs are written separately with MATLAB(.m) program file using control parameters and SGA parameter by taking step load perturbation of 2% at t=0.0 sec in area-1. SGA parameter plays a prominent role and it is chosen according to literature [13]. Table 1 includes the control parameter values of SGA which is applied in the algorithm.

Table 1. SGA Parameter.

Parameter	Value
α^o	2
n_{pop}	100
α_{min}	0.01
it^{max}	50
it_{global}^{max}	$0.5 \times it^{max}$
n_g	$0.2 \times n_{pop}$
n_{mut}	$0.03 \times n_{pop}$
t	t=1,t=2,t=3 are used for every mutated individual

SGA/FA is taken to tune parameters of the PID controller separately. The unknown parameters of PID controller are recorded at the end of it^{tmax}. A series of optimization process was conducted and the best final solution is chosen as final control parameters with minimum ITAE values. The optimized SGA based PID control parameter as well FA tuned PID control parameter are mentioned in Table 2.

Table 2. SGA and FA tuned controller Parameters.

FA:PID	SGA:PID
Unit1: Thermal KP1 = -1.9978 KI1 = 1.9978 KD1 = 1.0443	Unit1: Thermal KP1 = 1.9978 KI1 = 0.5126 KD1 = 1.991
Unit 2: Hydro KP2= 1.0443 KI2= -1.9959 KD2 = 1.6992	Unit 2: Hydro KP2= 1.9978 KI2= -0.1948 KD2 = 0.8454
Unit 3: Gas KP3 = 0.9696 KI3 = 1.2519 KD3= -0.4538	Unit 3: Gas KP3 = 1.6877 KI3 = 1.9978 KD3= -0.4538

At t = 0.0 sec a 2 % Step Load Perturbation (SLP) is applied in area-1, the SGA tuned PID controller and FA tuned PID controller system performance is demonstrated in Table 3. The superiority of SGA tuned PID controller with less ITAE value (ITAE=0.2947) than FA tuned PID controller (ITAE=1.6463) is depicted in Table 3 using the same controller with objective function. Again the settling times in frequency variation and deviations in tie power with SGA optimized PID controller are improved

compare to FA tuned PID controller. Hence it is clear that SGA superior than FA. The system dynamic response deviations in frequency & deviations in tie-line power is depicted in Figs. 3-5.

Table 3. Comparative performance index values.

Techniques/ parameters	Settling times T$_S$			ITAE
	ΔF_1	ΔF_2	ΔP_{tie}	
FA:PID	2.34	2.33	1.91	1.6463
SGA:PID	1.13	0.94	1.07	0.2947
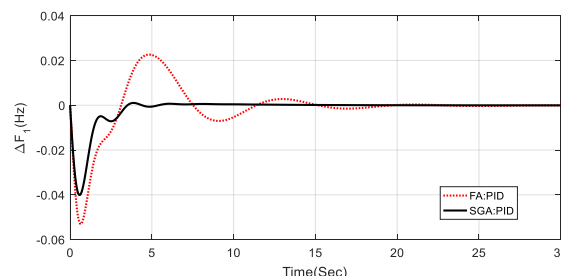
Fig. 3. ΔF_1 with 2% SLP in area-1.
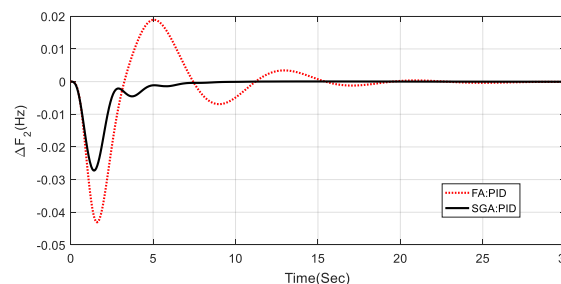

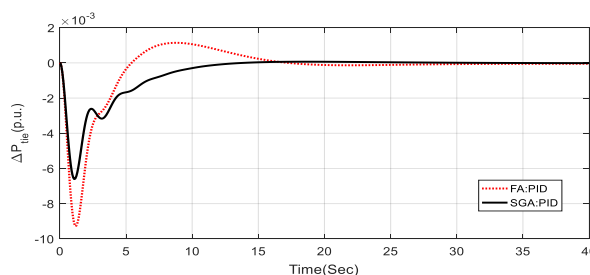**Fig. 3**. ΔF_2 with 2% SLP in area-1.

Fig .5. ΔP_{tie} with 2% SLP in area-1.

This clearly signifies from the Figs. 3-5 that best dynamic performance as well as better response is achieved by SGA compared to FA technique.

Further at t = 0.0 sec a simultaneous SLP of 2 %, 1 % in area-1 & area-2 respectively are applied. The dynamic performance with SGA tuned PID controller & FA tuned PID controller are demonstrated in Figs. 6-8. It is obvious from Figs. 6-8 that, proposed SGA optimized PID controllers based on the location of the disturbance changes also performs satisfactorily and gives robust result.

6 Sensitivity analysis

Sensitivity analysis is perform to test the robustness of the proposed approach with variation in the system parameters and operating conditions.
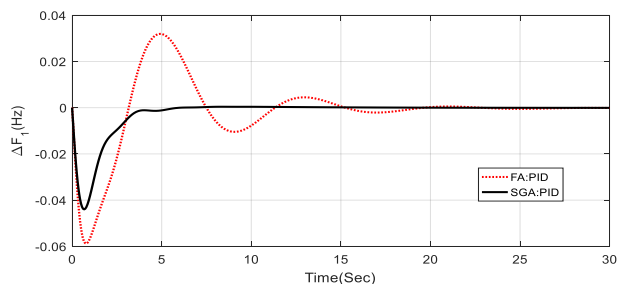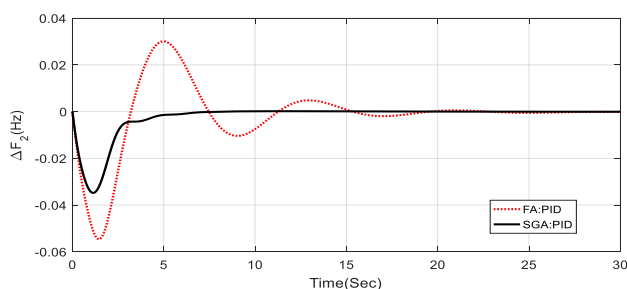

Fig. 6. ΔF_1 for 2 % & 1% SLP in area-1 and in area-2.

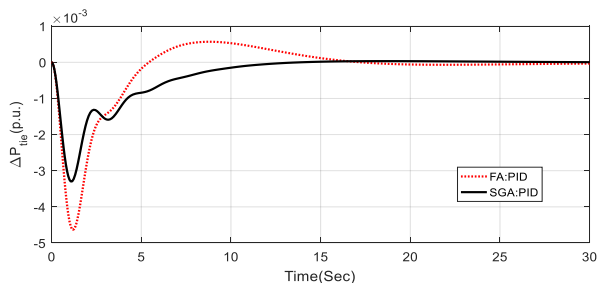**Fig. 7.** ΔF_2 for 2 % & 1% SLP in area-1 and in area-2.

Fig.8. ΔP_{tie} for 2 % & 1% SLP in area-1 and in area-2.

The nominal values varying from +25% to -25% in the operating load condition and system parameters (given in appendix) mentioned in Table 4. It is clearly depicts the system time constants and variations on operating loading conditions over the system performance are negligible as well as reflect the similarity in performance indexes values.

Fig.9 shows ±25% variations in the loading conditions with nominal parameters for the deviation in frequency response of area-1. From Fig. 9 it clearly reveals that the deviation in loading condition over the system performance is evaluated as negligible. To evaluate the supremacy of the proposed approach a random step load change is applied in area-1. Fig.10 depicts the random step load based pattern (magnitude and duration) applied to the test system [9]. Fig.11 shows the transient responses for ΔF_1. From which it can be conclude that the proposed SGA tuned PID controller which provides superior damping compare to other.

7 Conclusions

In the present work, SGA/FA methods are used to tune PID controller parameters in a two-area six-unit power system. The superiority of the SGA technique is demonstrated by comparing the results with a FA optimization technique. The result reveals that SGA tuned

Table 4. Sensitivity analysis.

| Parameter variation	%	Performance index			
		Settling time(2%band) T_s (Sec)			ITAE
		ΔF_1	ΔF_2	ΔP_{tie}	
Nominal	0	1.13	0.94	1.07	0.2947
Loading condition	+25	1.12	0.96	1.06	0.2949
	-25	1.14	0.93	1.07	0.2947
T_G	+25	1.15	1.01	1.09	0.2948
	-25	1.21	1.02	1.16	0.2954
T_{GH}	+25	1.12	0.93	1.07	0.2956
	-25	1.11	0.95	1.04	0.2935
T_T	+25	1.37	1.19	1.31	0.3061
	-25	1.07	0.91	1.02	0.2949
T_{RH}	+25	1.12	0.86	0.99	0.3028
	-25	1.24	1.13	1.22	0.2965
T_{CD}	+25	1.13	0.93	1.06	0.2943
	-25	1.14	0.99	1.08	0.2950
B	+25	1.05	0.85	1.00	0.2601
	-25	1.33	1.16	1.15	0.3701
R	+25	1.18	0.90	1.06	0.3020
	-25	0.77	1.03	1.08	0.2923
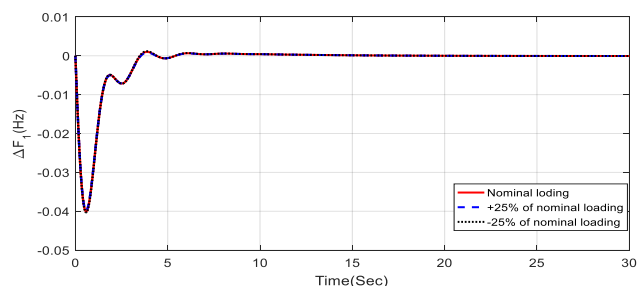
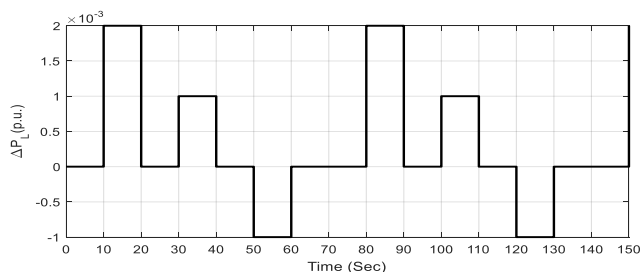**Fig. 9.** ΔF_1 with change of loading.

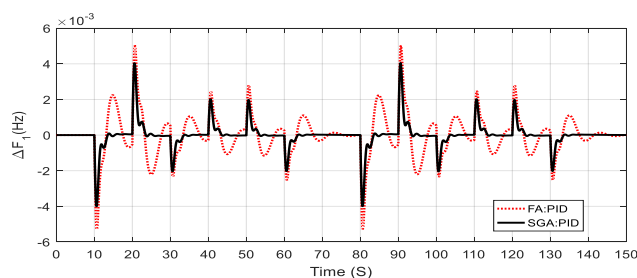**Fig. 10.** Stochastic step load based pattern

Fig. 11. Variation in F_1

PID controller offers significant improvement in the response than the FA tuned PID controller. After that sensitivity analysis is carried out to demonstrate the robustness of the proposed approach to wide variations of system parameter, operating loading conditions with respect to nominal values as well as random load disturbance. It is evident from simulation results that the proposed SGA optimized PID controller is much more effective, robust and furnish best system performance as comparison to FA tuned PID controller.

Appendix

The investigated system nominal parameters are: [14]
$R_1 = R_2 = R_3 = 2.4$ Hz/p.u; $B_1 = B_2$ 0.4312 p.u., $T_{12} = 0.0433$, $\alpha_{12} = -1$; $T_{SG} = 0.08$sec; $T_T = 0.3$s; $T_r = 10$ s; $K_r = 0.3$; $K_T = 0.543478$; $T_{PS} = 11.49$ s; $K_{PS} = 68.9566$ Hz/p.u. MW; $K_H = 0.326084$; $T_W = 1.0$s; $T_{RS} = 5$s; $T_{GH} = 0.2$s, $T_{RH} = 28.75$ s; $X_C = 0.6$s, $Y_C = 1$s, $T_F = 0.23$s; $T_{CD} = 0.2$s; $T_{CR} = 0.01$s, $K_G = 0.130438$; cg = 1, bg = 0.05s.

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