PID Parameters Improvement for AGC in Three Parallel-Connected Power Systems

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Abstract— In this research, the automatic generation control (AGC) of three parallel-connected power plants is utilized to tune the proportional-integral-derivative (PID) controller using Multistart algorithm (MS). The AGC loop is used to minimize the frequency deviation and control the power exchange in order to maintain them at their scheduled values due to the changes of the step-load disturbance. The optimal parameters of the PID scheme optimized by the proposed MS algorithm are compared with that one's obtained by GA algorithm, and the proposed method has proven that its performance is more efficient and improved as well. Integral Square Error (ISE) is considered as an objective function for both algorithms to determine its performance index value for the same parallel-connected power system. From combination sets MS_PID_ISE and GA_PID_ISE; the settling time, maximum deviation and peak time are analyzed and compared in the time domain. Based on the simulated results, MS_ISE has better settling time, lesser peak time, and lower maximum deviation as compared with GA_ISE. Both of MS and GA algorithms are coded using MATLAB software.

Keywords— *automatic generation control; Multistart optimization algorithm; PID controller; genetic algorithm; and integral square error*

1. Introduction

One of the most significant current discussions in power systems is the automatic generation control. Power systems consist of a number of generating units interconnected together in response to changes between the power demand and the power generated. To make the power system in an equilibrium status, the system frequency must be a balance among the utilities over the tie-line power transmission line. If there is any load disturbance, all areas which are interconnected together through the tie-lines will be affected as well [1]. Thus, the basic control mechanism of the automatic generation control (AGC) is used to keep the interchanges of the scheduled tie-line power and the system frequency values as close as possible to the specified limits as in multi-area power systems [2]. Meanwhile, AGC is a very important part in the operation of power systems to control the real power output and minimize the frequency deviation [3]. In more realistic, the errors in the power and the frequency of the system are adjusted to be zero depending on the ACE value which is represented as the controlled output of AGC [4].

In recent decades, the researchers in [5] are broadly presented several strategies for the solution of the automatic generation control problem especially during the small load disturbance to maintain the tie line power flow and the system frequency at their scheduled values. Based on this literature survey, it is noted that the most of the automatic generation control has carried out the decentralized methods based on artificial intelligence controllers such as; sliding mode control [6-8], artificial neural network (ANN) controller [9,10], fuzzy logic (FL) controller [11-14], and neuro-fuzzy controller [15,16]. To reduce the complicities of these techniques, many researchers have investigated the centralized method for tuning the PID parameters in multiple-interconnected power plants using trial-and-error approach [17, 18]. Additionally, one more offer to use the PID controller with optimization techniques is the reliability and its structure simplicity to get the desired performance of the optimal PID gains under different operation conditions. The optimization methods have the ability to tune the PID parameters for determining the minimum global optima such as Differential Evolution [19], Practical Swarm Optimizations [20-22], Ant Colony Optimization [23], and Genetic Algorithms [24,25].

In this paper, MS optimization algorithm has been employed to determine the optimal values of K_p, K_i , and K_d of the proposed PID controller for the automatic generation control in three parallel-interconnected power system plants. After that, dynamic performance of the proposed MS_PID algorithm is compared with GA_PID in terms of time settling, maximum deviation, and peak time for a step load change. An objective function is considered for both algorithms which is known as an Integral Square Error (ISE) to determine the minimum index value of the overall system performance.

2. Overall Power System with AGC Model

The overall power system of three parallel-interconnected plants including the AGC model and the PID controller is investigated as shown in figure 1. Each power plant has its primary regulation controller and secondary participation controller. U_1, U_2, and U_3 are the control outputs of the proposed PID controllers respectively, DPL_1, DPL_2 and DPL_2 are the disturbance load changes, DW_1, DW_2, and DW_3 are represented the frequency changes in the power system plants. The nominal parameters of the overall power system are given in [26]. An area control error (ACE) is used to reduce its own value to be zero as defined below:

$$ACE_1 = -\Delta P_{12} + \Delta P_{31} - B_1\Delta\omega_1 \quad (1)$$
$$ACE_2 = +\Delta P_{12} - \Delta P_{23} - B_2\Delta\omega_2 \quad (2)$$
$$ACE_3 = +\Delta P_{23} - \Delta P_{31} - B_3\Delta\omega_3 \quad (3)$$

Where ΔP_{12}, ΔP_{23} and, ΔP_{31} represent the changes in the tie line power plant, B_1, B_2 and B_3 are the bias frequencies for each plant, $\Delta\omega_1$, $\Delta\omega_2$ and $\Delta\omega_3$ represent the frequency deviation for each plant.

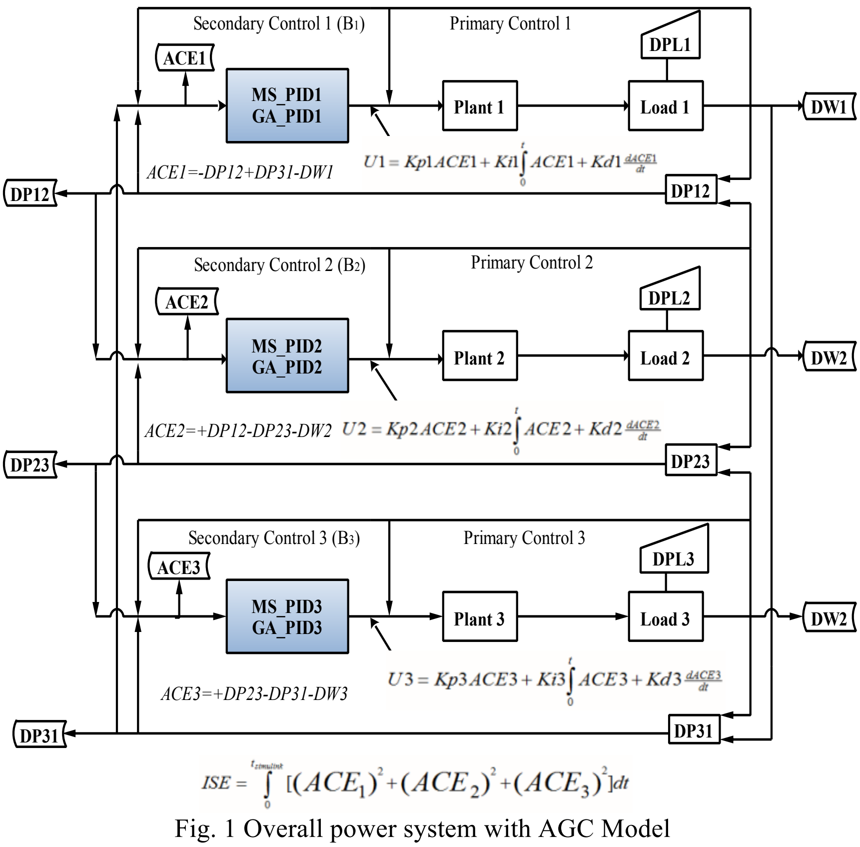

Fig. 1 Overall power system with AGC Model

Basically in multi-interconnected power system plants, the main objective of the AGC is to keep the system frequency at scheduled value, to divide the load between the plants, and to control the tie line power interchange [27]. When a change in step load input (DPL) occurs for each plant in the system, the generation of all plants is increased to meet the changing for the tie line power and the reduction in the system frequency as well. ISE criteria is interfaced with the M-file technique of the MS_PID heuristic optimization to generate the best optimized PID parameters based on its performance index value. The expression of the ISE objective function used in this research is shown as below [4]:

$$ISE = \int_0^{t_{simulink}} [(ACE_1)^2(t) + (ACE_2)^2(t) + (ACE_3)^2(t)]\, dt \tag{4}$$

where $t_{simulink}$ is the range of the simulation time. ISE (Integral Square Error) is used to determine the optimal values of the PID controller, which is explained as the sum of square of cumulative errors in area control errors (ACE_1, ACE_2, and ACE_3).

3. Improved Intelligent PID Parameters

PID controller is one of the popular feedback controller used with the automatic generation control for providing an excellent control performance and higher stability. The transfer function of the PID consists of three basic parameters; Proportional (P), Integral (I), and Derivative (D) as shown in figure 2. The advantages of each parameter are [28]; proportional is used to reduce the system peak overshoot, an integral is employed to eliminate the effect of the steady state error to be zero, and the system will be stable by using the derivative and its transient response will be improved as well.

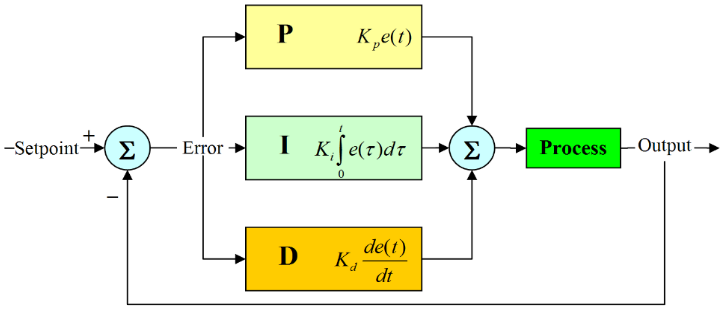

Fig. 2 Classical PID controller model

According to [29], the typical transfer function of the classical PID controller in terms of Laplace domain is described below:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \tag{5}$$

Where, $U(s)$and $E(s)$are the control signal and the error signal which is the difference between the input and the feedback correspondingly; K_p is the proportional gain, K_i is the integration gain and K_d is the derivative gain. Moreover, the output value of the proposed PID controller is given below which generates the proper control signal to keep the system parameters within the nominal values [30];

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{6}$$

where $u(t)$and $e(t)$ are the control and tracking error signal which is in the form of time domain.

For plant1

$$u_1(t) = K_{p1} ACE_1(t) + K_{i1} \int_0^t ACE_1(t)dt + K_{d1} \frac{dACE_1(t)}{dt} \tag{7}$$

For plant2

$$u_2(t) = K_{p2} ACE_2(t) + K_{i2} \int_0^t ACE_2(t)dt + K_{d2} \frac{dACE_2(t)}{dt} \tag{8}$$

For plant3

$$u_3(t) = K_{p3} ACE_3(t) + K_{i3} \int_0^t ACE_3(t)dt + K_{d3} \frac{dACE_3(t)}{dt} \tag{9}$$

Based on the researcher's survey, it usually refers to Ziegler-Nichols PID approach for tuning its parameters [31]. In this research, the optimal values of the proposed PID parameters can be tuned using an optimization technique such as Multistrat algorithm which can lead the controller to meet the desired control requirement [32, 33]. The Multistrat algorithm is one of the stochastic optimization algorithms, some of its advantages are; easy code, simplicity use, and it has the property of local searching. Its work depends on initial generation and next generation of the local search start, the size of local search is adjusted based on X0 parameter with bounds values which equals to the controller parameters. The basic principle of the tuning process for the MS algorithm to find the PID parameters is presented in figure 3. Three main procedures are conducted by means of start local search: generate start point, call the overall system, and run the local solver in order to find the best optimal value. If the generated optimal value has a less fitness value of ISE than the best optimal value, then it is replaces by each of them to find the optimal values of the PID parameters. Otherwise, update and generate a new start point and then call the overall system again.

4. Results and Discussions

Three parallel-interconnected power systems including the combination of MS_PID and GA_PID optimization algorithms with AGC system are implemented using Simulink/Code MATLAB program as shown in figure 1. For the MS algorithm, the step size is chosen as 0.01 and the optimization process is repeated around 30 iteration. The lower and upper boundaries values for PID parameters are -1 to 2 respectively. The simulation of the step load disturbance (DPL_1, DPL_2) at t=1 sec in plant1and plant2 which are 0.1 pu and 0.2 pu respectively is realized to check the effectiveness of the proposed MS_PID controller and compared with the GA_ PID controller. Table 1 shows the optimal values (K_p , K_i , and K_d) of the optimization process obtained by both algorithms to minimize the ISE value, which is explained as the sum of square of cumulative errors in each area control error.

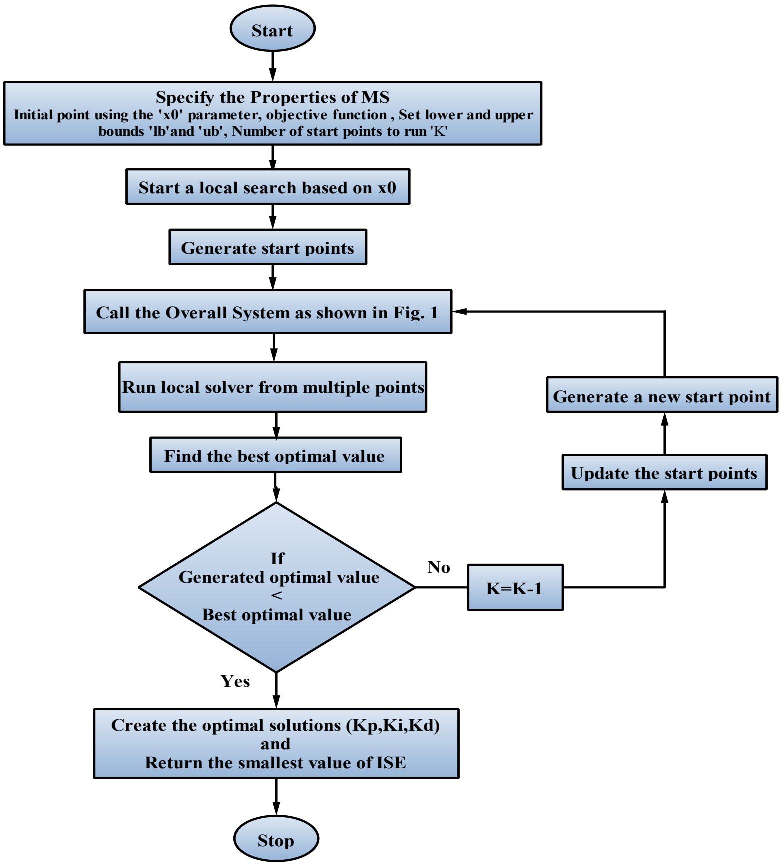

Fig. 3 Multistart optimization workflow

Table 1: Optimal values of tuning PID using Multistart and GA.

	PID Parameters	GA_ISE	Multistart_ISE
Plant 1	Kp1	0.434	1.0300
	Ki1	1.504	1.2817
	Kd1	1.108	1.4160
Plant 2	Kp2	1.092	2.0000
	Ki2	1.144	1.9740
	Kd2	0.950	2.0000
Plant 3	Kp3	0.805	-0.1314
	Ki3	-0.022	-0.01724
	Kd3	0.814	1.1749
	Min_ISE	**0.082**	**0.0346**
	Elapsed Time(sec)	**29.11**	**20**

In term of dynamic performance; the transient response specifications of the settling time, maximum deviation and peak time for, $\Delta\omega$, and ΔP_{ij} are given in tables 2-4. It is observed that the MS_PID control strategy with the objective function produces good dynamic performances. Meanwhile, it extracts a better solution as compared to GA_PID strategy.

Figures 4 to 6 give the response of $\Delta\omega$ obtained by GA and MS algorithm. It is observed from Figure 4 and 5 that the objective function produces good result as shown in $\Delta\omega1$ and $\Delta\omega2$. In addition, the maximum overshoot and settling time becomes low and also reduced. Based on figure 6, it is also cleared that the number of oscillation is more as in case of $\Delta\omega3$ for the GA_PID algorithm as compared with the MS_PID algorithm which make the system relatively unstable. This is to say that the ISE gives a better control performance by minimizing the system frequency.

Table 2: $\Delta\omega$ parameters using Multistart and GA based on ISE.

		Settling Time (sec)	Max.deviation (p.u)	Peak Time (sec)
GA_ISE	$\Delta\omega1$	26	-0.0022	2.2
	$\Delta\omega2$	18	-0.0095	3.75
	$\Delta\omega3$	33	-0.0031	6.1
Multistart _ISE	$\Delta\omega1$	24	-0.0015	1.5
	$\Delta\omega2$	14	-0.0062	1.65
	$\Delta\omega3$	17	-0.0016	5.2

Table 3- ΔP_{ij} parameters using Multistart and GA based on ISE.

		Settling Time (sec)	Max.deviation (p.u)	Peak Time (sec)
GA_ISE	ΔP_{12}	37	0.0136	6.5
	ΔP_{23}	40	-0.0105	6.9
	ΔP_{31}	50	0.00099	4.7
Multistart_ISE	ΔP_{12}	35	0.00725	5.3
	ΔP_{23}	38	-0.00642	5.8
	ΔP_{31}	46	0.00087	4.1

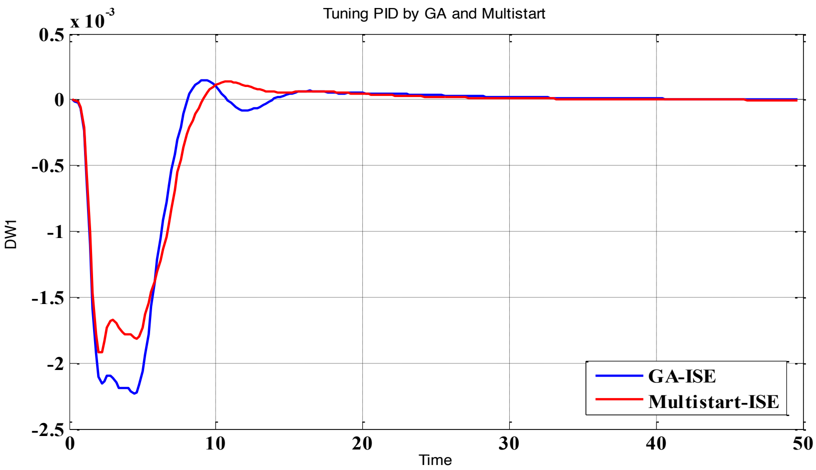

Fig. 4 $\Delta\omega1$ with PID tuning by MS and GA

Figures 7-9 give the responses of ΔP_{ij} obtained by GA and MS algorithms. Based on ΔP_{12} and ΔP_{23}; the settling time, maximum deviation and peak time which are reduced by MS for tuning of PID parameters are more effectively. Also, the stability and the damping characteristics of the power system are improved as compared to that's one obtained by GA algorithm. It is clearly seen that the MS based PID controller with the derived function gives a better control performance by minimizing the tie line power deviation to be zero. There is no oscillation in the transient part especially as in ΔP_{31} which make the system relatively more stable.

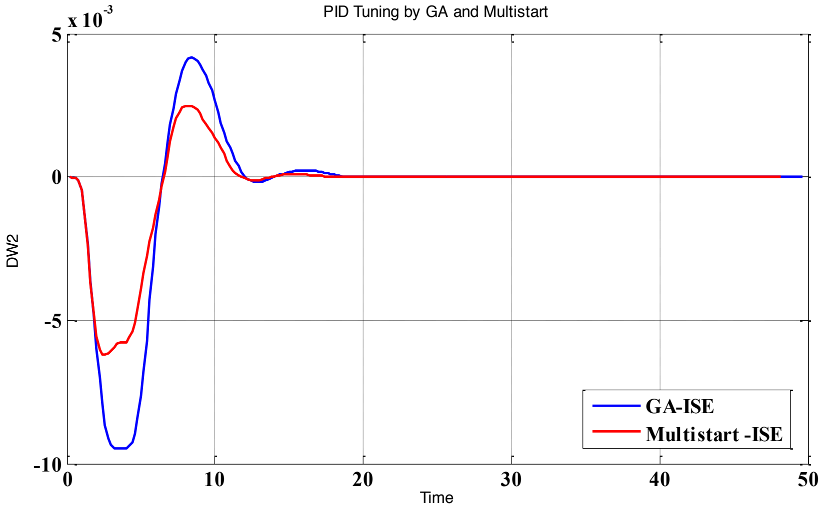

Fig. 5 $\Delta\omega 2$ with PID tuning by MS and GA

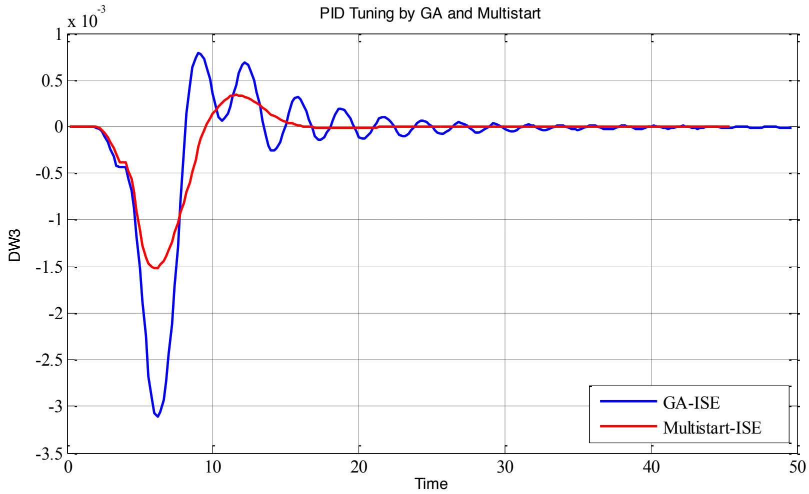

Fig. 6 $\Delta\omega 3$ with PID tuning by MS and GA

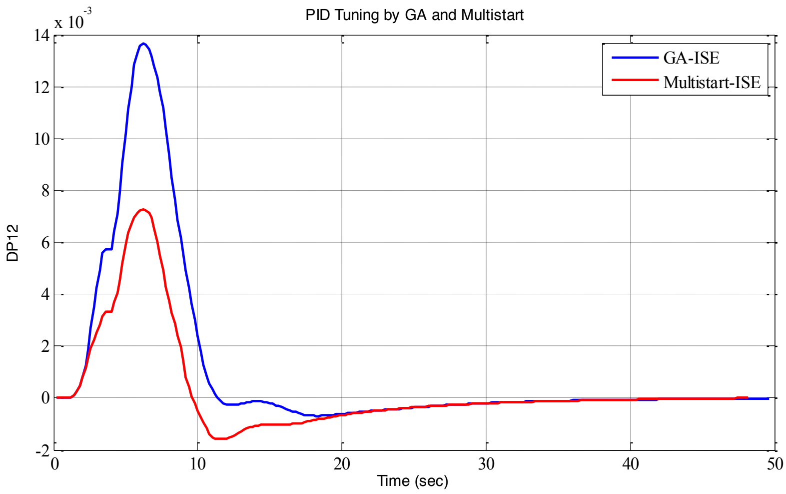

Fig. 7 $\Delta P_{12}$with PID tuning by MS and GA

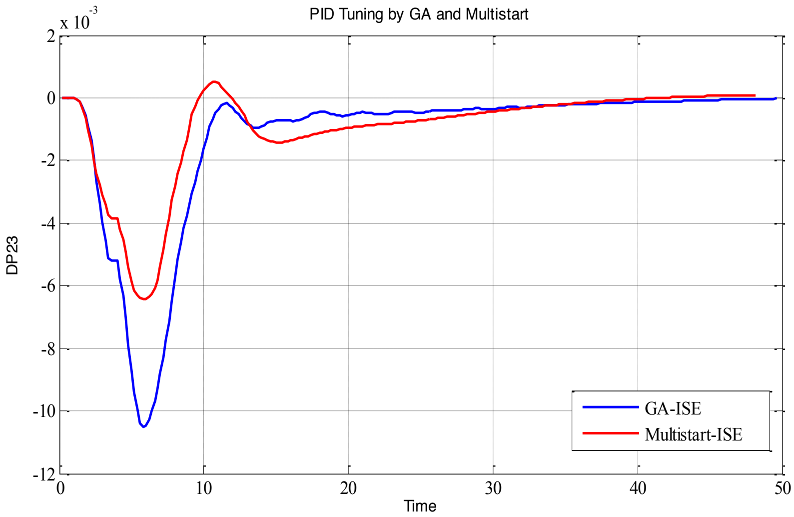

Fig. 8 $\Delta P_{23}$with PID tuning by MS and GA

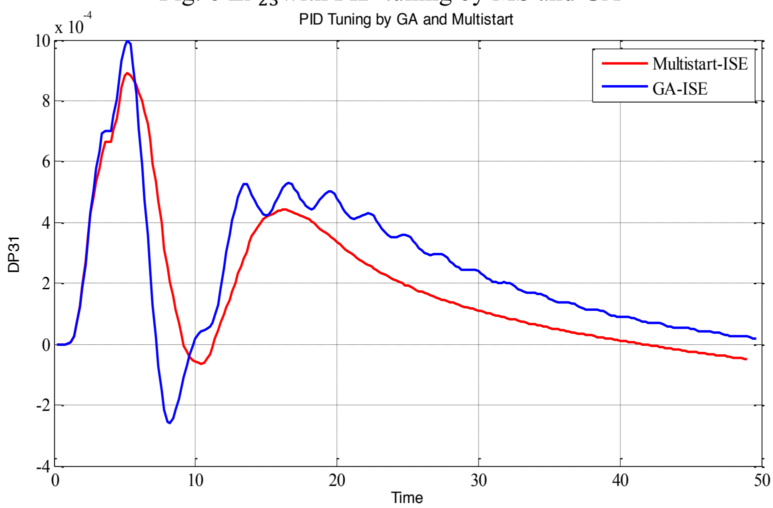

Fig. 9 $\Delta P_{31}$with PID tuning by MS and GA

5. Conclusion

In this paper, Automatic generation control of three parallel-connected power systems using Multistart optimization algorithm based PID controller has been proposed to demonstrate the methodology. It has formulated to optimize the optimal parameters of the PID controller by using the objective function (ISE) to improve the overall system performance. The results are concluded that, the proposed MS algorithm based PID controller has provided a very good transient specifications; better settling time, lesser peak time , lower overshoot, as well as the execution time is less than as compared with GA algorithm.

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