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PERFORMANCE ANALYSIS OF CLASSICAL CONTROLLERS IN LFC OF TWO AREA SYSTEM USING FPA TECHNIQUE

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ABSTRACT

This paper present Flower Pollination Algorithm (FPA) optimized classical controllers such as Proportional Integral Derivative (PID), Proportional Integral (PI) and Integral (I) for Load Frequency Control (LFC) of two area system. It also compares result obtained from FPA optimized PID controller with Genetic Algorithm (GA) optimized PID controller for LFC of two area system. Initially, the gains of different classical controllers are optimized using an Integral of Time multiplied Absolute value of Error (ITAE) criterion for equal two area non-reheat thermal interconnected power system. The simulation result conveys that PID controller gives better dynamic response in comparison to others and it also reveals that FPA optimized PID controller provide better result compared to GA optimized PID controller. Finally the robustness of PID controller is investigated by variation of Step Load Perturbation (SLP) in the system. Simulation results also show that the proposed PID controller can withstand variation of SLP made in the system for the same optimized values.

Keywords: Flower Pollination Algorithm (BA), Genetic Algorithm (GA), Proportional Integral Derivative (PID, Load Frequency Control (LFC), Tie line power, Fitness Function.

I. INTRODUCTION

The control of reactive and active power is vital issues to keep the power system in the steady-state. Since voltage magnitude is mainly influenced by changes in reactive power and frequency of power system is mainly influenced by changes in active power, they are controlled separately. Two control loops are used to achieve frequency control. They are primary frequency control loop and secondary frequency loop which is called Load Frequency Control (LFC) [1]. Based on classical control theory and modern control theory various controllers are designed to minimize frequency and tie line power deviations [2-3].

In an interconnected power system, the load changes continuously which results in the change in tie-line power and frequency. Generators need to produce more or less power to keep up with the load demand so that the power balance is maintained over the tie lines from which different area is connected. When generation is less than load applied, then generator frequency and speed will drop therefore system shows change in scheduled power levels. The generator frequency, speed and tie-line power are used as control signals which includes the area control error (ACE). The purpose of automatic generation control (AGC) is to ensure that the operating limit of the generator and tie-line is not exceeded.

To improve the efficiency and performance and to lower the cost, optimization is used. The important resources like money and time are to be used effectively and properly in real-world applications such as business planning, software development and manufacturing engineering design. Hence it is very important to get the solutions to effectively use these valuable resources under various constraints. Researchers have been discovering new ways of simplifying optimization problems due to inefficiency of conventional optimization algorithms especially to solve complicated and large problems. The prevalence of the Nature-Inspired Algorithms is firstly affected by the ability of biological systems to effectively adapt to frequently changeable environment**.**

During the last several years many techniques and researches had been applied to the LFC field. Various optimization and control techniques such as classical controllers, Ziegler Nichols method, optimal control theory, Fuzzy Logic Controller (FLC), Genetic Algorithm (GA), Artificial Neural Network (ANN), Bacterial Foraging Optimization Algorithm (BFOA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Artificial Bee Colony Algorithm (ABCA) etc., have been introduced for LFC [4-9]. Although ANN and FLC perform adequately for LFC problem, they require huge computation. The recent nature inspired algorithm is Flower Pollination Algorithm (FPA) which was introduced by Xin-She Yang in 2012 [10]. FPA that inspired from the flower pollination process of flowering plants. FPA testing results in many fields proved their ability to be used in a wide range of optimization problems and also their ability to provide better performance in comparison with other traditional optimization techniques [11].

II. SYSTEM INVESTIGATED

1. Power System Investigated

The two equal area non-reheat thermal power system is considered for present study as shown in Fig. 1. The interconnected two area system used in Fig. 1 is effectively used in literature for the design and analysis of LFC [8]. In Fig. 1, R_1 and R_2 are the governor speed regulation parameters in p.u. Hz; B_1 and B_2 are the frequency bias parameters; T_{G1} and T_{G2} are the speed governor time constants in sec; ACE_1 and ACE_2 are area control errors; u_1 and u_2 are the control outputs from the controller; T_{T1} and T_{T2} are the turbine time constant in sec; ΔP_{D1} and ΔP_{D2} are the change in load demands; ΔP_{Tie} is the incremental change in tie line power in p.u.; T_{PS1} and T_{PS2} are the power system time constants in sec; K_{PS1} and K_{PS2} are the power system gains; T_{12} is the tie-line synchronizing coefficient and ΔF_1 and ΔF_2 are frequency deviations of the system in Hz. The nominal values of parameters are given in appendix.

2. Control structure and objective function

A two equal area non-reheat turbine thermal power system is used for analysis and identical controllers are considered. Proportional-Integral-Derivative (PID), Proportional-Integral (PI) and Integral (I) controllers are used for investigation.

The proportional integral derivative (PID) controller is the most popular feedback controller in process industries. It is robust and can provide excellent control performance despite the varied dynamic characteristics of process plant. An integral controller can reduce the steady-state error, but it may make the transient response poorer. A proportional controller can minimize the rise time, but never reduces the steady-state error. A derivative control can increase the stability of the system, reduce the overshoot, and improve the transient

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response. When quick response of the system is not needed, noises and large disturbances are present during operation of the process and there are large time delays in the system a control without derivative (D) mode is used. When fast response and stability are required PID controllers are used. Stability of the system is improved by the derivative mode and it also enables decrease in integral gain and increase in proportional gain and thus speed of the controller response is increased. The PID controller design requires evaluation of the three main parameters, Derivative time constant (K_D), Integral time constant (K_I) and Proportional gain constant (K_P). The use of PID controller helps to achieve better settling time and improves the stability of the system compares to other controllers [9]. The eq. (1) given below shows the s-domain transfer function of PID controller.

$$TF_{PID} = K_p + \frac{K_I}{s} + K_D s \qquad (1)$$

The eq. (2) and (3) given below shows the respective area control errors (ACE) and it is fed as an input to the respective controllers.

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

$$e_2(t) = ACE_2 = B_2 \Delta F_2 + a_{12} \Delta P_{Tie} \qquad (3)$$

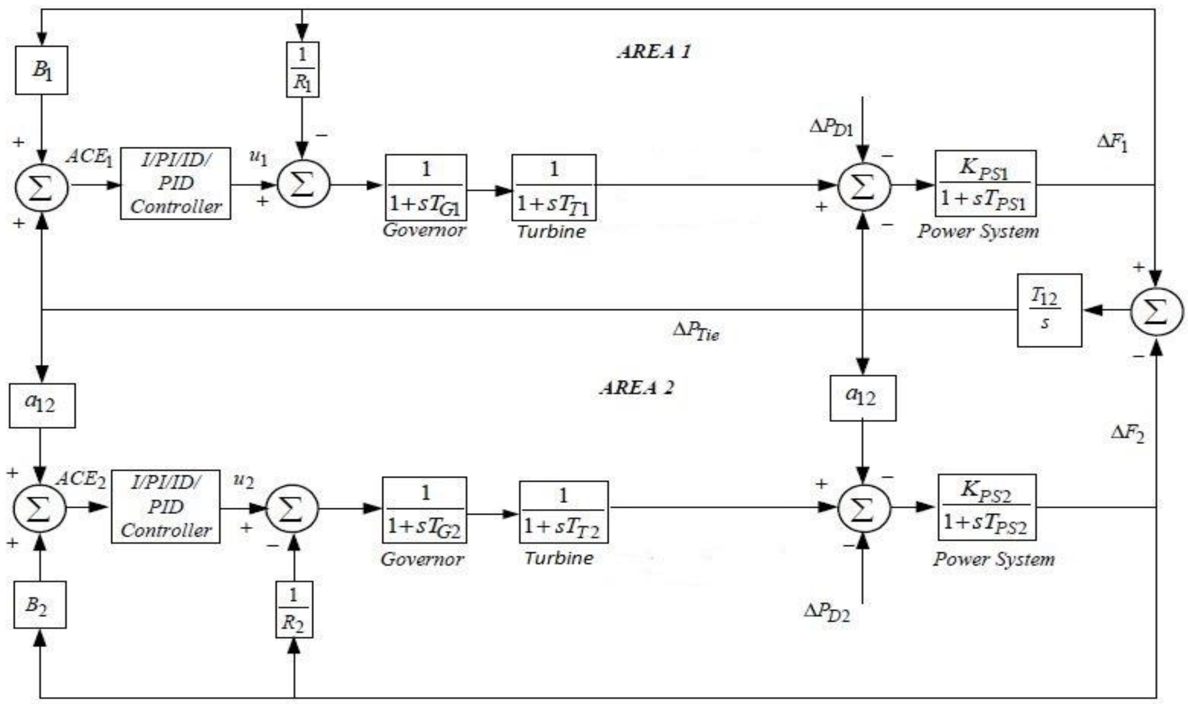

Figure 1. MATLAB/SIMULINK model of two area non-reheat thermal interconnected power system

ACE1 is used as a input of PID controller of area 1 and ACE2 is used as a input of PID controller of area 2. u_1 and u_2 are the outputs from the PID controller and are fed to the control inputs of the two areas respectively. At first, the objective function is calculated which is based on the desired specifications and constraints for the design of a controller based on modern heuristic optimization technique. Performance criteria generally used in the control design are as follows the Integral of Absolute Error (IAE), Integral of Time multiplied Absolute Error (ITAE), Integral of Time multiplied Squared Error (ITSE) and Integral of Squared Error (ISE).Settling time can be reduced by ITAE criterion which cannot be reduced with ISE or IAE based tuning. ITAE criterion also decreases the peak overshoot. Tuning based on ITSE criterion provides large controller output for a sudden change inset point which is not profitable in point of view of controller designing. It has already been reported that for LFC studies, ITAE is a better objective function. Therefore in this paper for optimizing the proportional, integral and derivative gains of PID controller, ITAE criterion is used as objective function. The eq. (4) shows the expression for the ITAE objective function.

$$J = ITAE = \int_{0}^{t_{sim}} \left(|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}|\right) t.dt \qquad (4)$$

In the above equations, ΔP_{Tie} is the incremental change in tie-line power; ΔF_1 and ΔF_2 are the system frequency deviations; t_{sim} is the time range of simulation. The PID controller parameter bounds are the problem constraints. Therefore, the following optimization problem shows the formulation of the design problem.

Minimize J

Subject to $K_{Dmin} \leq K_D \leq K_{Dmax}$, $K_{Imin} \leq K_I \leq K_{Imax}$,

$K_{Pmin} \leq K_P \leq K_{Pmax}$

The minimum and maximum gain values of controller parameters are chosen as -5 and 5 respectively.

III. OPTIMIZATION ALGORITHM

1. Flower Pollination Algorithm

Xin-She Yang is inspired by flowering plants follow pollination process to develop Flower Pollination Algorithm (FPA) in 2012. For simplicity, given below are four basic rules used in FPA.

- Cross and biotic-pollination can be considered processes of global pollination, and pollinators carrying pollen move in a way that confirms to Levy flights.
- For local pollination, abiotic pollination and self-pollination are used.
- Pollinators, like insects develop flower loyalty, which is comparable to the reproduction possibility proportional to the matching of two flowers considered.
- Switching or the interaction of global pollination and local pollination can be controlled by a switch probability $p \in [0, 1]$, slightly follows local pollination.

In order to formulate updating formulas, we have to convert the above rules into updating equations. For example, in the global pollination step, pollinators such as carries flower pollen gametes, and pollen can travel over a long distance because insects can often fly and move in a much longer range [11].Therefore, Rule 1 and flower constancy can be represented mathematically as:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - B) \qquad (5)$$

Where B is the current best solution found among all solutions at the current generation/iteration, and x_i^t is the pollen i or solution vector x_i at iteration t. Here $L(\lambda)$ is the parameter that corresponds to the strength of the pollination, which essentially is also the step size and γ is a scaling factor to control the step size. In addition, since insects may move over a long distance with various distance steps, we can use a Levy flight to imitate this characteristic effectively. That is, we draw $L > 0$ from a Levy distribution:

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$$, (S >> S_0 > 0) \qquad (6)$$

Here, Γ(λ) is the standard gamma function, and this distribution is valid for large steps s > 0.

Then, to model the local pollination, both Rule 2 and Rule 3 can be represented as:

$$x_i^{t+1} = x_i^t + U(x_j^t - x_k^t) \qquad (7)$$

Where x_j^t and x_k^t are pollen from different flowers of the same plant species. This essentially semblance the flower constancy in a limited neighbourhood. Mathematically, if x_j^t and x_k^t selected from the same population or comes from the same species, this equivalently becomes a local random walk if we draw U from a uniform distribution in [0, 1].Though Flower pollination activities can occur at all scales, both global and local, adjacent flower or flowers patches in the not-far-away neighbourhood are more likely to be pollinated by local flower pollen than those faraway. In order to semblance this, we can efficiently use the switch probability like in Rule 4 or the proximity probability p to switch between common global pollination to intensive local pollination. To start with, we can use a nominal value of p = 0.5 as an initial value. A preliminary parametric showed that p = 0.8 may work better for most application. The pseudo code of FPA is given below:

Min or max objective $f(x)$, $x = (x_1, x_2 \ldots x_d)$

Initialize n flowers or pollen gametes population with random solutions

Identify the best solution (g^*) in the initial population

Express a switch probability $p \in [0, 1]$

While (t < Max Generation)

for $i = 1 : n$ (all n flowers in the population)

if rand < p,

Draw a (d-dimensional) step vector L *from a* Levy distribution

Global pollination via $x_i^{t+1} = x_i^t + L(g^* - x_i^t)$

else

Draw u from a uniform distribution in [0,1]

Do local pollination via $x_i^{t+1} = x_i^t + u\,(x_j^t - x_k^t)$

end if

Evaluate new solutions

If new solutions are better, update them in population

end for

Find current best solution

end while

Output the best solution obtained

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Table 1. Optimal Gain Values of different controller

Controller/ Parameters	*I*	*PI*	*PID*
K_P	--	0.3039	-3.1377
K_I	-1.1318	-0.4556	-4.8186
K_D	--	--	-0.8738

Table 2. Overshoot and Settling time of different controllers

Controller/ Parameters	Peak overshoot x 10^{-3}			Settling time(sec) x 10^{2}		
	ΔF_1	ΔF_2	ΔP_{Tie}	ΔF_1	ΔF_2	ΔP_{Tie}
I	21.2	16.5	5.5	29.07	29.70	29.74
PI	24.5	20.5	7.3	5.89	6.15	6.60
PID	7.7	3.3	1.1	2.28	2.58	2.72

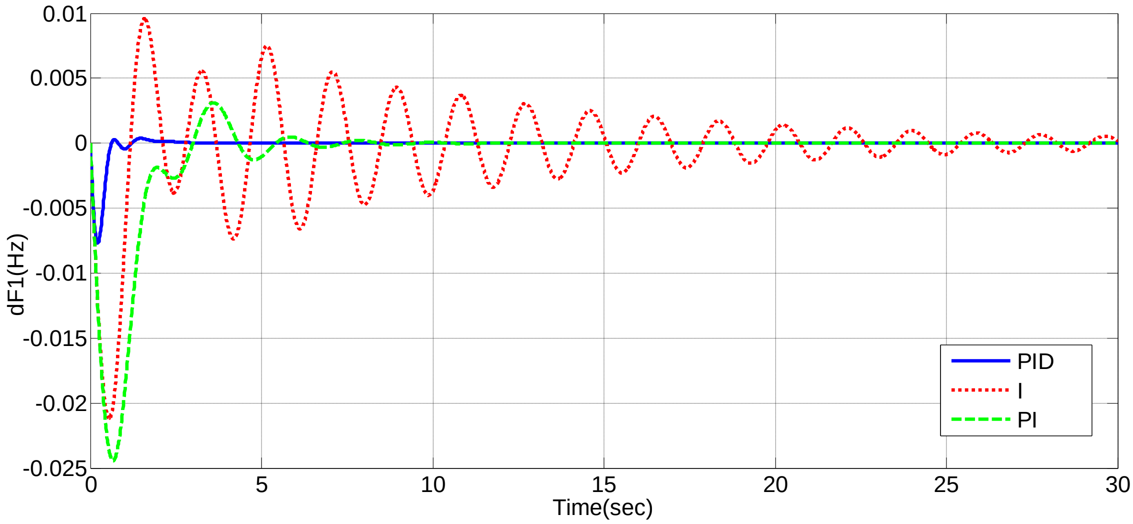

Figure 2(a). Change in freq in area 1 for 1% step load using FPA

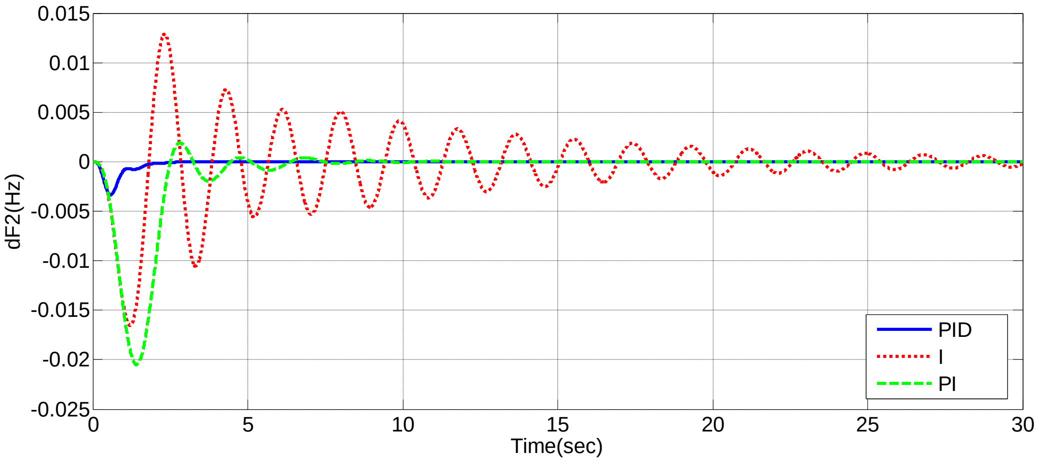

Figure 2(b). Change in freq in area 2 for 1% step load using FPA

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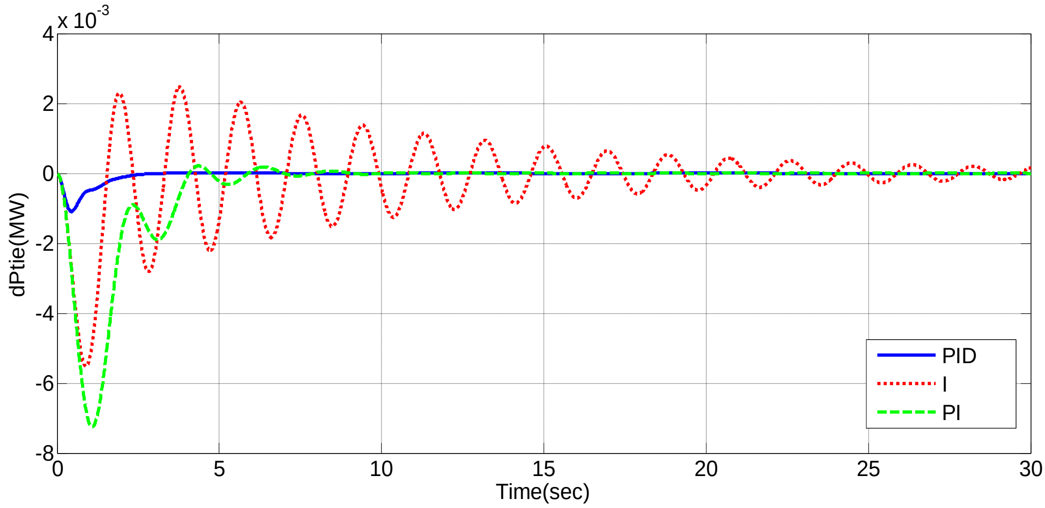

Figure 2(c). Change in Tie line power for 1% step load using FPA

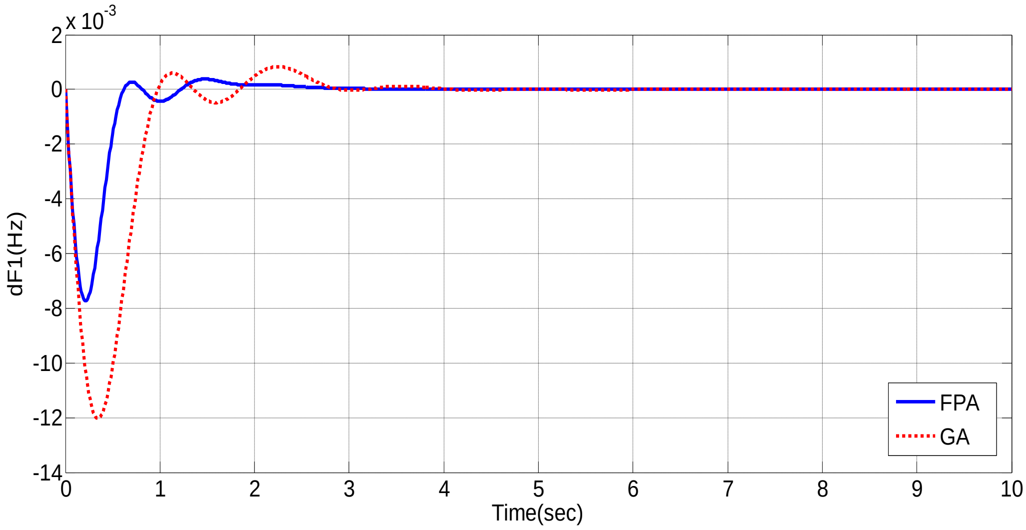

Figure 3(a). Change in freq in area 1 for 1% step load using PID controller

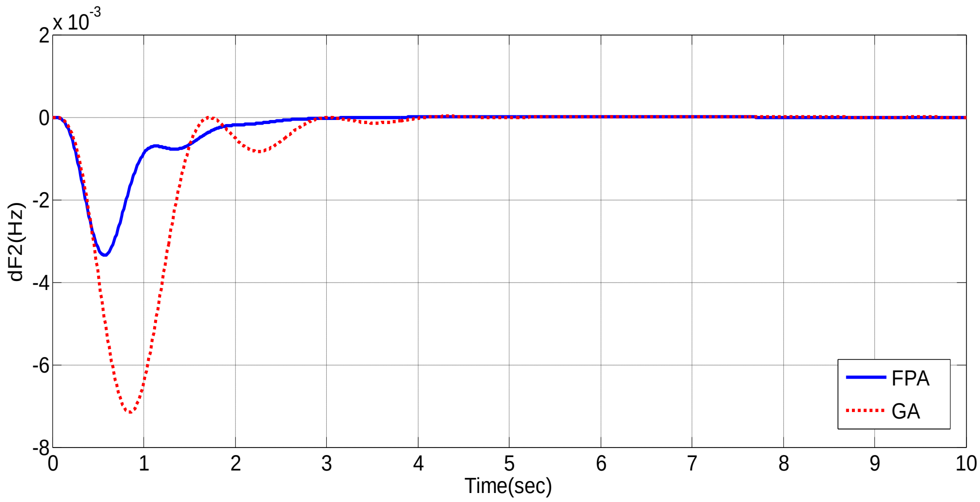

Figure 3(b). Change in freq in area 2 for 1% step load using PID controller

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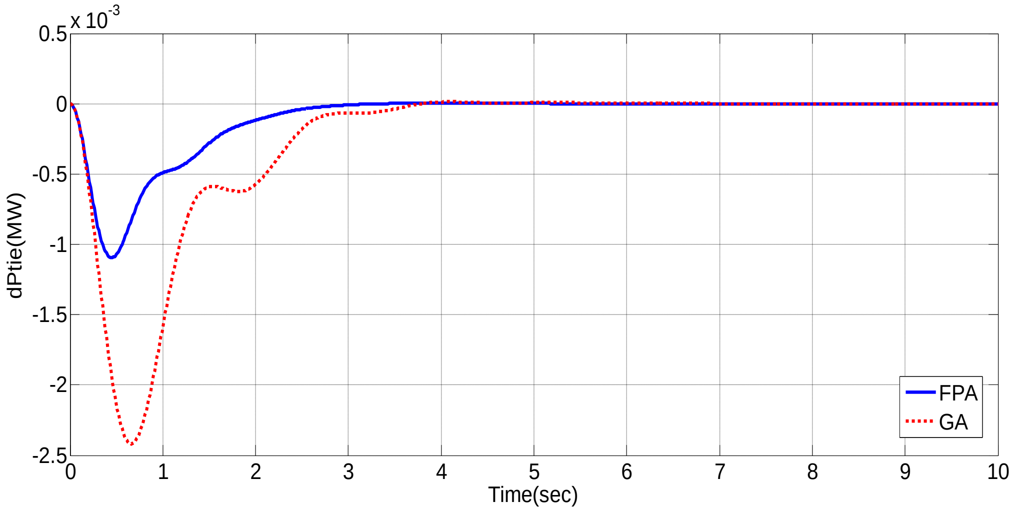

Figure 3(c). Change in Tie line power for 1% step load using PID controller

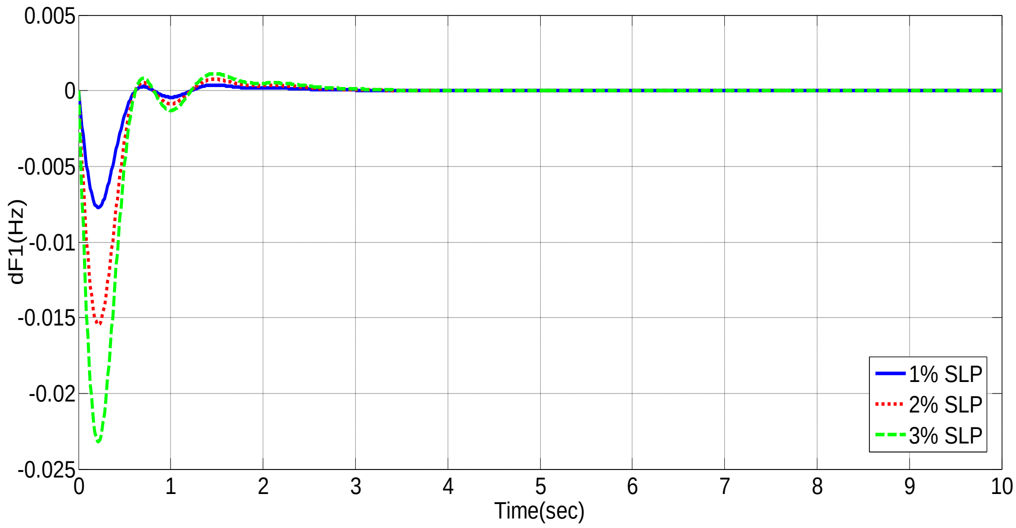

Figure 4(a). Change in freq in area 1 for 1-3% change in area 1 using FPA

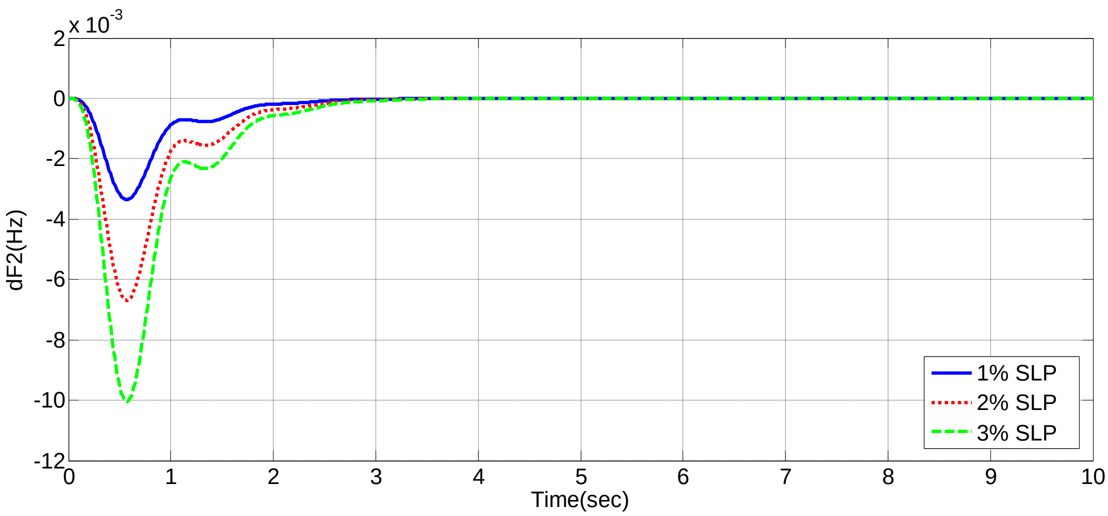

Figure 4(b). Change in freq in area 2 for 1-3% change in area 1 using FPA

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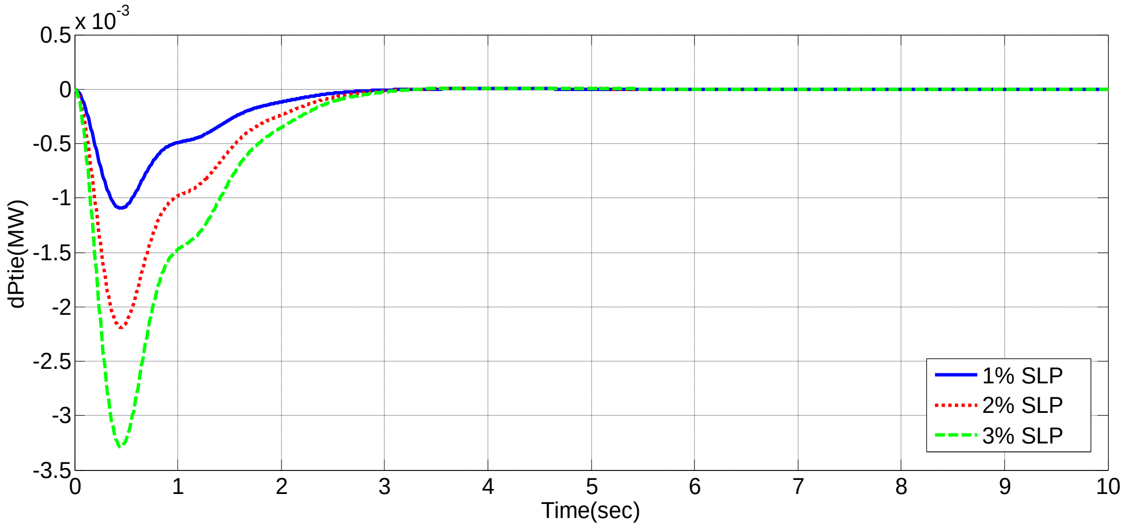

Figure 4(c). Change in Tie line power for 1-3% change in area 1 using FPA

IV. SIMULATION RESULT AND ANALYSIS

1. Analysis of Results

In the present study the controlled parameters of FPA is taken as population size = 20; maximum generation = 100; probability switch (p) = 0.8. At first, a two equal area power system is considered with integral controllers. MATLAB/SIMULINK environment is used to develop the model of the system under study and FPA program is written (in .mfile). In the present work, -5.0 and 5.0 are chosed as the minimum and maximum values respectively of the controller parameters. The gain values of the different controllers which we have calculated after running FPA program are given in Table 1. Eq. (4) shows the objective function (ITAE) value and it is determined by simulating the developed model by applying a 1% step increase in load in area1. The dynamic performance of the system of various classical controllers for the same system is shown in the Figs. 2(a)-2(c) and these figure shows the simulation result which conclude that PID controller performs better than I and PI and controllers. The dynamic performance of the system by GA and FPA optimised PID controller is shown in Figs. 3(a)-3(c) and these figures shows that FPA optimised PID controller gives better performance [12]. The corresponding performance indexes in terms of ITAE value, peak overshoot and settling times in frequency and tie line power deviations are shown in Table 2. From Table II, it is observed that PID controller gives better performance indexes.

2. Robustness Analysis

To demonstrate the robustness of proposed PID controller step load perturbation is varied from 1% to 3% in area 1. The dynamic responses of the system for different values of SLP are shown in the Figs. 4(a)-4(c). From these figure it is clear that the proposed controller performs well enough for different load disturbances. In most of the cases, the effect of Time Delay (TD) is not considered in LFC problem. TD degrades the system performance badly as TD value increasing but PID controller is robust and performs satisfactorily without resetting the optimal gain values.

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V. CONCLUSION

In this paper, Flower Pollination Algorithm (FPA) is proposed to optimize gains of different classical controllers such as Integral (I), Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) for Load Frequency Control (LFC) problem of two area system. Initially, two area non-reheat thermal power system is considered to demonstrate the performances of different classical controllers. From the simulation results, it is observed that significant improvements of dynamic performance of the system in terms Integral of Time multiplied by Absolute value of Error (ITAE), settling time and peak overshoot are obtained PID controller. Then this method is compared with the GA optimized PID controller for LFC of two area system, we get better result in this case. Finally, the system was analyzed in presence of different SLP values. Simulation results proved that the proposed PID controller can withstand the changes in the system.

APPENDIX

Nominal Parameters of the Power System: B_1= B_2 = 0.425 p.u. MW/Hz; R_1 = R_2 = 2.4 Hz/p.u.; T_{G1} = T_{G1} =0.08sec; T_{T1} = T_{T2} = 0.3s; K_{PS1} =K_{PS2} = 120Hz/p.u. MW; T_{PS1}= T_{PS2} = 20 s; T_{12} = 0.5438; a_{12} = -1.

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