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# A New Optimized PD-PI Controller using NSGA-II for Automatic Generation Control

Chittimuru.S.Reddy[1], Dr.B.Sarvesh[2]

Research Scholar, Dept. of EEE, JNTUA, Anantapur, Andhra Pradesh, India[1]

Professor, Department of EEE, JNTUK, Kakinada, Andhra Pradesh, India[2]

**ABSTRACT**: This paper introduces a new powerful cascaded PD-PI controller for solving load frequency control (LFC) problem in power system. A two area non-reheat thermal power plant is considered and gains of PI/PID controllers are optimized using non dominated sorting algorithm-II NSGA-II. This paper compares new controller effectiveness in solving LFC problem with the performances of controllers tuned with other optimization techniques reported in the literature

**KEYWORDS:** Automatic generation control (AGC); active power frequency control, cascaded controller; proportional integral derivative controller (PID); NSGA-II optimization algorithm

## I.INTRODUCTION

The role of automatic generation control (AGC) is very important in power system operation and control to ensure reliability and power quality of the grid by maintaining system frequency and tie line power at their schedule values. In a multi area interconnected system, all the units are connected synchronously and therefore they work with same frequency. Any abrupt change in load in one area or in different areas simultaneously and other abnormal conditions will cause a change in the frequency of the areas and in the transferred power of the tie-lines [1]. These changes must be reduced to zero or to be minimized to the maximum possible extent automatically.

The LFC problem of an interconnected power system network is enlarged by the several researchers from time to time over last few decades in order to present better dynamic responses. Several control mechanisms have been proposed in the literature to solve LFC problem, such as classical controller [2–5], non-integer controller [6–8], sliding mode controller (SMC) [9], robust controller [10], and intelligent controller [11–14]. The authors of [11–13] proposed non-integer controller to solve LFC problem for an interconnected multi-area power system network and showed better system dynamics than the results available in the literature. Several intelligent controllers based on fuzzy logic [11], neuro-fuzzy [12], advance fuzzy [13], artificial neural network [14] were presented in the area of LFC and demonstrated their applicability to improve dynamic performances of the same. Different optimization techniques which are population based such as differential evolution (DE) [4], genetic algorithm (GA) [16], particle swarm optimization (PSO) [17], artificial bee colony algorithm (ABCA) [18], bacteria foraging optimization algorithm (BFOA) [3], hybrid bacteria foraging optimization algorithm – particle swarm optimization (hBFOA-PSO) [2]. However, it was identified from recent research that all the above said algorithms had a drawback of dependency on initialization of input parameters and slow convergence rate. Also a particular evolutionary algorithm which gives better results on a set of problems may show poor performance on a different set of problems. Therefore an attempt has been made in this paper to design and implement a relatively new cascaded controller based on NSGA-II optimization technique to solve LFC problem of an interconnected power system. The dynamic responses are studied with step load perturbation (SLP) in area-1 considering overshoot, settling time of frequency and tie-line power deviations as performance indices. By minimizing time multiplied integral absolute error fitness function, stability of the interconnected system is improved. Dynamic performances of NSGA-II optimized PD-PI controller are compared with other algorithms available in the literature to prove its superiority.

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## II.SYSTEM INVESTIGATED

The power system under investigation consists of an interconnected two-area non-reheat thermal–thermal power system network, which is widely used in the literature for design and analysis of LFC problem [2] as shown in Fig. 1. Each area has a rating of 2000MW with a nominal load of 1000 MW. B1 and B2 are the frequency bias parameters; $AEC_1$ and $AEC_2$ are area control errors; $u_1$ and $u_2$ are the control outputs form the controller; $R_1$ and $R_2$ are the governor speed regulation parameters in p.u. Hz; $T_{G1}$ and $T_{G2}$ are the speed governor time constants in sec; $\Delta P_{G1}$ and $\Delta P_{G2}$ are the governor output command (p.u.); $T_{T1}$ and $T_{T2}$ are the turbine time constant in sec; $\Delta P_{T1}$ and $\Delta P_{T2}$ are the change in turbine output powers; $\Delta P_{D1}$ and $\Delta P_{D2}$ are the load demand changes; $\Delta P_{Tie}$ is the incremental change in tie line power (p.u.); $K_{PS1}$ and $K_{PS2}$ are the power system gains; $T_{PS1}$ and $T_{PS2}$ are the power system time constant in sec; $T_{12}$ is the synchronizing coefficient and $\Delta f_1$ and $\Delta f_2$ are the system frequency deviations in Hz. The relevant parameters are given in Appendix A

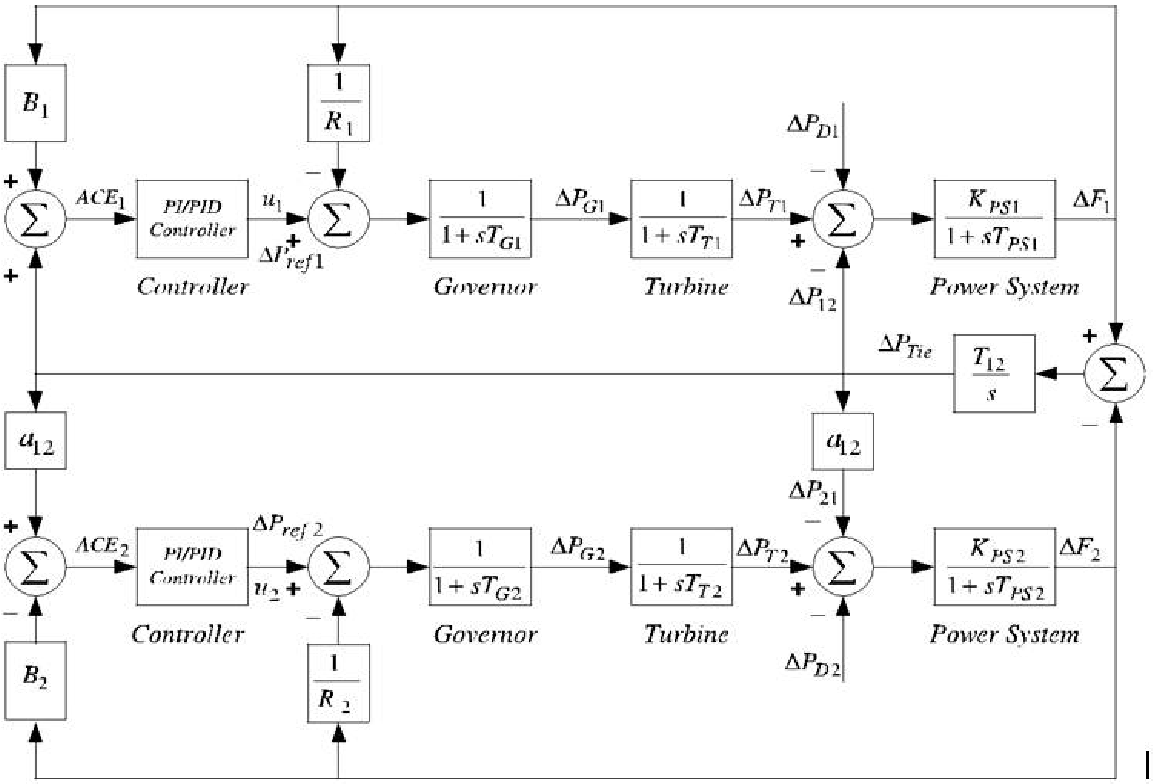

Fig. 1. Transfer function model of two-area non-reheat thermal system.

## III. THE PROPOSED APPROACH

The performance of the power system depends on the controller structure and selection of objective function. The details about controller structure and objective function employed in the present study are presented in this section.

**Controller structure**

Cascade control is one of the approaches used to enhance the system performance. As the number of tuning knobs is more in a cascade controller than a non-cascade controller, improved system performance is expected with cascade control system [17]. The concept of the cascaded controller comes from two combinational processes, where the inner process supplies its output to the outer process.

The main objective of the cascaded controller is to attenuate the effect of disturbance on the outer process. Structure of PD-PI cascaded controller is shown in Figure 2. Because of its advantages, and improved system performance cascade PI-PD controller for control systems have been proposed in recently in literature [19] and is chosen in the present study for AGC. The control input signals are the respective ACEs and controller output are the reference power settings of individual generating units.

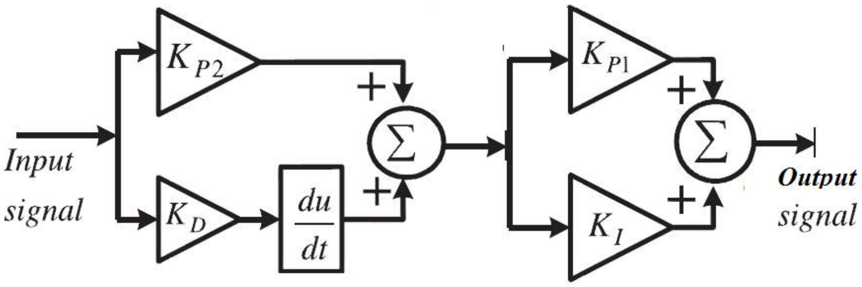

**Fig. 2 .** Structure of cascaded PD-PI controller.

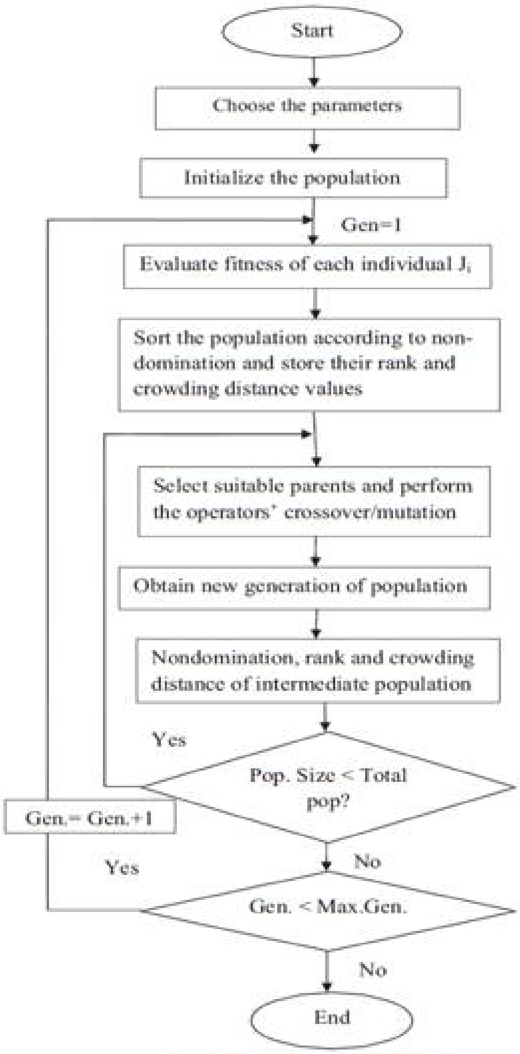

Fig 3: Flowchart of NSGA-II

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### Objective Function

For controller design employing optimization methods, the objective function is generally specified depending on some performance criteria such as Integral of Time multiplied Absolute Error (ITAE), Integral of Absolute Error (IAE), Integral of Squared Error (ISE) and Integral of Time multiplied Squared Error (ITSE). Detailed expression of these objective functions, their comparison on the system performance is available in literature [14–16]. It has also been shown in several studies that ITAE objective function offers improved system response than other alternatives [20].Hence ITAE is chosen as objective function in the present study which is written as:

$$J = \int_0^{Tsim} |\Delta f| \, . t . \, dt \qquad \ldots\ldots\ldots\ldots (1)$$

### Multi-objective optimization with NSGA-II

An optimization problem having multiple objectives can be formulated simplistically as a single objective problem as weighted sum of the individual objectives with suitably selected weights for each of them. However, a misjudgment in the ratio of different weights would skew the eventual solution more toward one among all the objectives. On the otherhand, there is a better chance of obtaining a more promising solution after suitably identifying it from those available from the set of Pareto optimal solutions. The later can be obtained with the help of a multi-objective optimization algorithm like NSGA-II. The flowchart of NSGA-II is given in Fig. 3[20].

## IV. RESULTS AND DISCUSSION

The objective function given in Eq. (1) is evaluated for each individual by simulating the system dynamic model considering a 10% step increase in load demand in area-1. The population of NSGA-II is taken as 10 individuals (real coded representation) and evolutionary cycle has stopping criterion of 100 generations. The parameters α, β, ϒ are taken as 1.5, 0.05 and 0.5 respectively. The upper and lower bounds of the PID controller parameters are chosen as (0, 2). Simulations were conducted on an Intel, core 2 Duo CPU of 2.4 GHz and 4 GB MB RAM computer in the MATLAB (R2013a) environment. To show the effectiveness of the proposed controller, results are compared with some recently published modern heuristic optimization methods such as Bacteria Foraging Optimization Algorithm (BFOA) and Genetic algorithm (GA) for the same interconnected power system [3] and are given in Table1. It is clear from Table 1 that tuned parameters are giving better solution than BFOA and GA when all the criteria (ITAE, minimum damping ratio and settling times) are considered simultaneously. It is also clear from Table 1 that ITAE values and settling times are further minimized with the use of NSGA-II optimized PD-PI controller.

Further, time domain simulations are performed for step load change at different locations. A step increase in demand of 10% is applied at t = 0 s in area-1. The system dynamic responses with proposed PD-PI controller are shown in Figs. 4–6. For comparison, the simulation results with BFOA optimized PI controller, GA optimized PI controller, NSGA-II optimized PI/PID controllers using the same ITAE objective function are also shown in Figs. 4–6. It is clear from Figs. 4–6 that the performance of the system is improved by the proposed NSGA-II optimized PD-PI controller compared to the recently reported results [3,20] and the best performance is obtained with NSGA-II PD-PI controller. The performance of the proposed controller is further investigated for simultaneous load increase at both areas. A step increase in demand of 10% in area-1 and 5% in area-2 are applied simultaneously at t = 0.0 s. The system responses under above disturbances are shown in Figs. 7–9. It is evident from Fig. 7–9 that the performance of the system is significantly improved by the proposed NSGA-II optimized PID controller compared to the recently reported results [3,20].

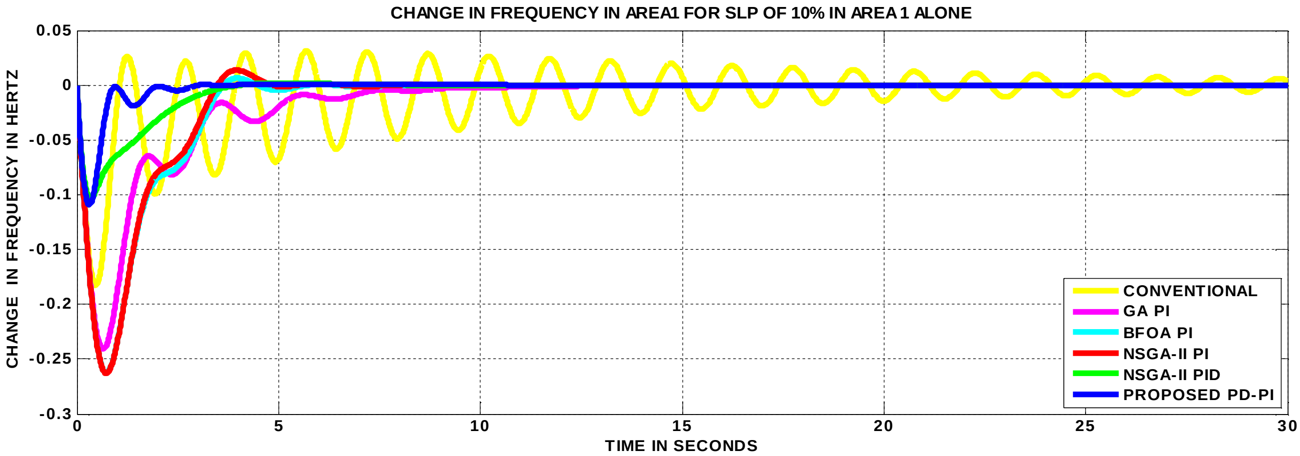

Figure 4: Change in frequency in area 1 for SLP of 10% in area 1 alone

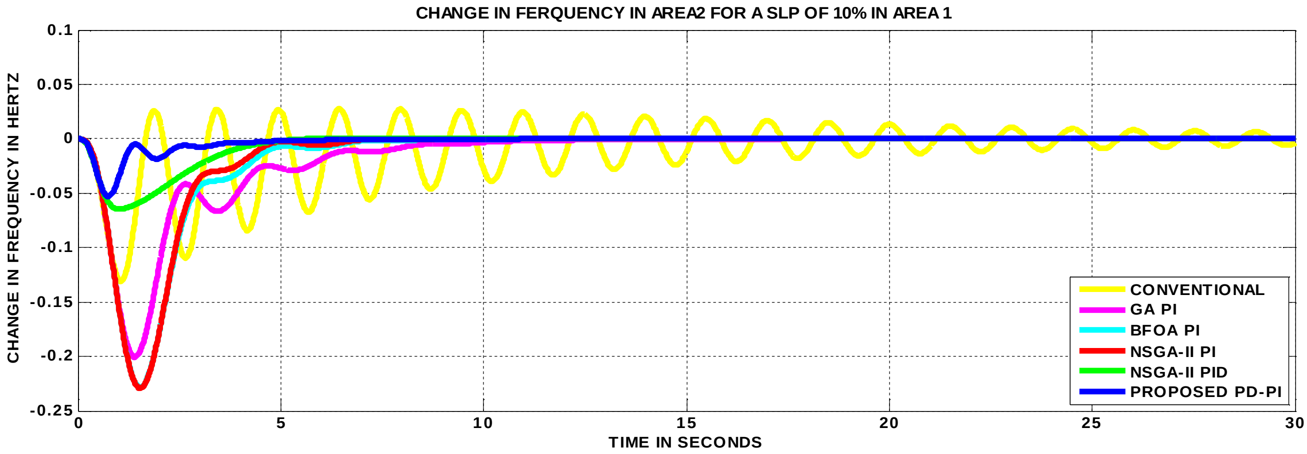

Figure 5: Change in frequency in area 2 for SLP of 10% in area 1 alone

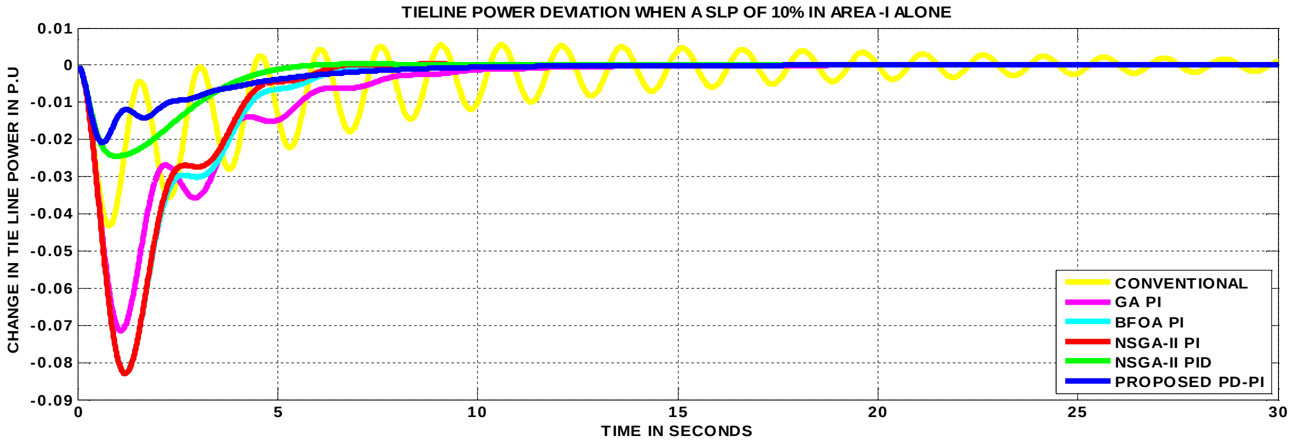

Figure 6: Change in tie line power for SLP of 10% in area 1 alone

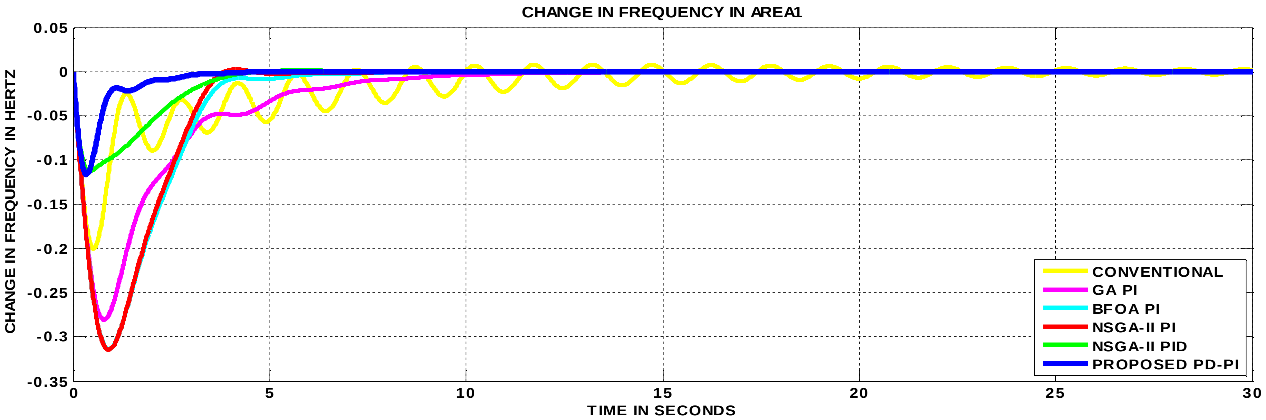

Figure 7: Change in frequency in area 1 for SLP of 10% in area 1 and 5% in area 2

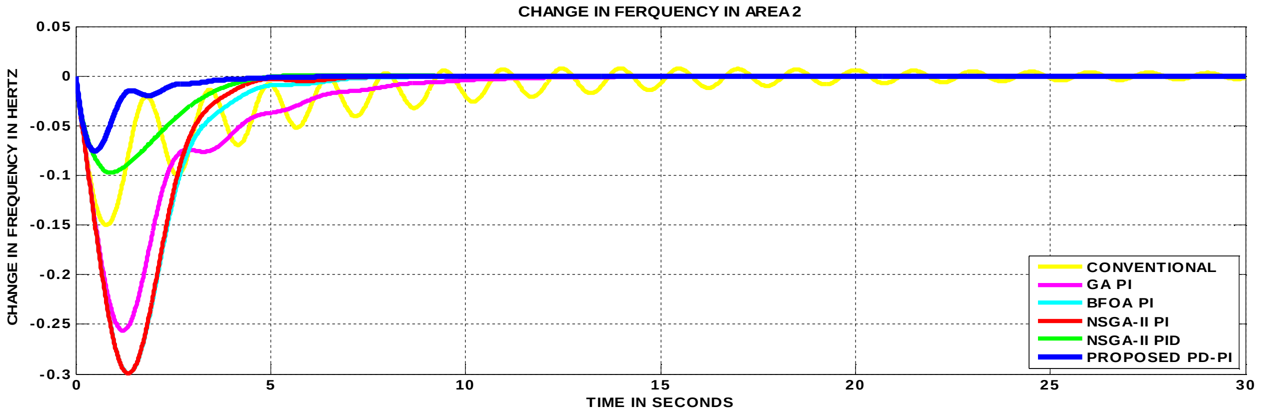

Figure 8: Change in frequency in area 2 for SLP of 10% in area 1 and 5% in area 2

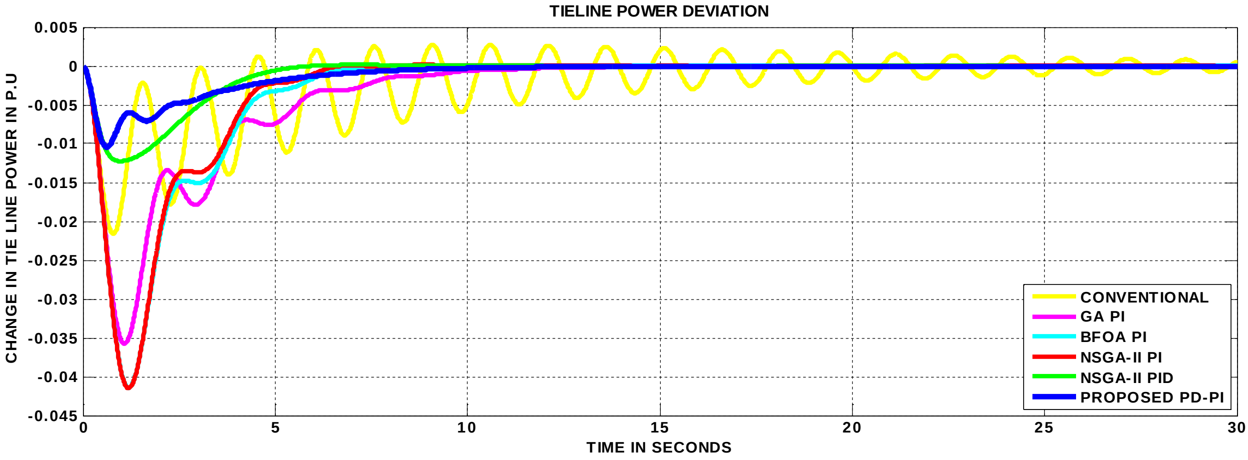

Figure 9: Change in tie line power for SLP of 10% in area 1 and 5% in area 2

## V.CONCLUSION

In this paper, cascaded PD-PI controller and was employed for AGC of two area interconnected thermal power system. The superiority of the proposed NSGA-II optimized PD-PI controllers is shown by comparing the results with some recently published modern heuristic optimization approaches such as Bacteria Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA) and NSGA-II PI and PID based controllers for the similar interconnected power system.

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