OPTIMAL DESIGN AND IMPLEMENTATION OF ALO BASED FOPID CONTROLLER FOR LOAD FREQUENCY CONTROL OF A TWO AREA POWER SYSTEM

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Abstract: In this article fractional order PID (FOPID) controller is optimally designed using Ant Lion Optimizer (ALO) and implemented to study load frequency control (LFC) issue in a two area thermal power system. Study of the transient analysis begins with realization of the two area thermal system from previously published articles based on conventional PI controllers. Then effort is made to improve the performance of the system employing ALO tuned conventional PID and FOPID controllers. Step load change of 1% in area1 of the power system is considered for transient analysis and integral time absolute error (ITAE) is selected as objective function in optimally designing PID and FOPID controllers. It is found that ALO tuned FOPID controlled AGC system performs better as compared to ALO tuned PID, hBFOA-PS, BFOA and GA based PI controller. Robustness analysis of the proposed ALO designed FOPID controller reveals that there is no need to retune the optimized controller parameters in case of system uncertainties and random load variation.

Keywords: Automatic Generation Control (AGC), Fractional Order PID (FOPID) controller, PID Controller, Ant Lion Optimizer (ALO).

1. Introduction:

Modern power system is an interconnection of multiple utilities. Each utility has its control area consisting of single/multiple generating units. Thus, the present day power system is a very large and complex network and as such its operation and control is a difficult task. The power system must be capable of delivering secure, reliable and uninterrupted power to the consumers maintaining a reasonably good quality of power. Frequency is an important parameter of the power system defining the power quality of the power delivered. Thus, the frequency must not deviate from its nominal value whenever there is any random variation of the load or sudden disturbance. If there is any mismatch between the supply and demand of active power than the system frequency deviates [1-2]. Automatic Generation Control (AGC) or Load Frequency Control (LFC) is a control technique used to adjust the active power generation according to the load demand thereby maintaining the frequency at its nominal value at any operating condition.

The first ever research on AGC was carried out by Concordia [3-4] and Cohn [5] in 1950's. In 1970's Fosha and Elgerd extended the work and proposed a state variable model with optimal feedback control for AGC of multi area interconnected power system [6]. A variable structure controllers for AGC for interconnected power system was developed by Chan and Hsu [7]. The concept of AGC was then extended to power system under deregulated environment [8-9]. Several studies were conducted on LFC problems by many researchers using different controller structures and optimisation algorithms. Application of different classical Controllers such as Proportional Integral (PI), Integral Derivative (ID), Proportional Integral Derivative (PID) and Integral Double Derivative (IDD) controllers to LFC have been reported in the literature [10,11,12]. Performance of different classical controllers in AGC have been studied in [12] and some new findings on AGC with conventional controller have been reported in [13]. Apart from conventional controllers, other controllers such as fuzzy logic controller [14] and Artificial Neural Network (ANN) controller [15] have also been used for AGC to improve the dynamic performance of the system. Literature survey reveals that hybrid control structures like fuzzy PID [16], multi stage fuzzy PID [17] and cascade control structures like PI-PD [18], PD-PID [19] have been implemented to address the LFC problems in interconnected power system. Various optimisation algorithms have been used to optimise the controller gains and other parameters in order to achieve superior dynamic performance of the system. The use of particle swarm optimization (PSO) for tuning the parameters Integral Controller and Proportional-plus-Integral (PI) controller have been explained in [20] for automatic generation control systems (AGC) of a two area reheat thermal power system. Gozde et al used Ant Bee Colony (ABC) algorithm to optimise the gains of PI and PID controller in AGC of power system and established its superiority over PSO [21]. Grey Wolf Optimizer algorithm (GWO) was used to tune the gains of conventional controllers like I, PI and PID controllers for AGC of multi area system including solar thermal power plant (STPP) [22].Whale Optimisation Algorithm (WOA) was applied in [23] for AGC in presence of Renewable Energy Sources (RES) to optimise the parameters of PID controller. Application of several other optimisation algorithms to optimise the controller and other parameters in AGC have been reported in the literature and most of these are bio-inspired algorithms. In recent years fractional order (FO) controllers have found wide application in AGC of interconnected power systems. The superiority of FO controllers over conventional integral order controllers in AGC was established in [24-25].

Therefore in this article an optimally designed ALO based FOPID controller is implemented for AGC study in a two area thermal power system. Salient features of the article are:

i. Simulation of the two area power system for AGC study in MATLAB Simulink environment.
ii. Validation of the developed Simulink model with two articles published in reputed international journals.
iii. Realization of ALO algorithm in .m file (MATLAB 2016).
iv. Optimal design of conventional PID and FOPID controller for AGC of the same power system.
v. Justification of superiority of ALO designed FOPID controller over ALO based PID and hBFOA-PSO, BFOA, & GA tuned conventional PI controller.
vi. Robustness analysis of the ALO based FOPID controller.

2. System under study:

In this study LFC of a three area reheat type thermal power system with GRC of 3% is considered. Area1, area2 and area3 having generating capacity of 2000 MW, 6000 MW and 12000 MW respectively are taken in the transfer function model as shown in the Figure 1. Each area is equipped with a PD-FPID cascaded controller and a sudden step load change of 1% is applied in area1 to study the behaviour of the overall system. The proposed controller is designed by taking integral time absolute error (ITAE) as objective function and it is minimized using hybrid LUS-TLBO algorithm to find optimum gains of the proposed controllers. Inputs to the projected PD-FPID controller are area control errors (ACEs) of the respective areas. The proposed hybrid LUS-TLBO optimisation technique is employed to optimally tune the controller gains to reduce the ACEs to zero. Expressions of ACEs for different control areas are given by

$$ACE_1 = B\Delta f_1 + \Delta P_{tie,13} \quad (1)$$

$$ACE_2 = B\Delta f_2 + \Delta P_{tie,21} \quad (2)$$

Various parameters of the three area power system are depicted in Table1.

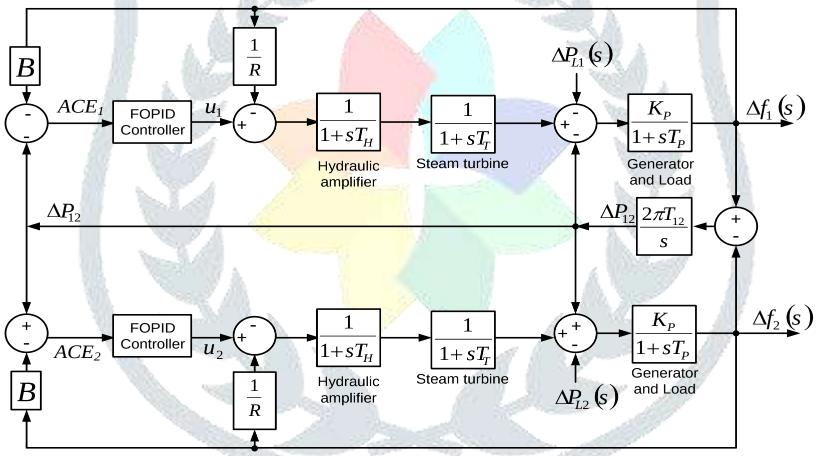

FIGURE 1: Transfer function model of the two area thermal power system [26, 27].

TABLE 1: Parameters of the two area power system [26, 27].

Parameters	Nominal values
Governor time constant (T_g)	0.08 sec
Turbine time constant (T_t)	0.3 sec
Power system time constant (T_P)	20 sec
Power system gain (K_P)	120 Hz/pu
Synchronizing coefficients (T_{12}, T_{13} and T_{23})	0.425 pu
Governor speed regulation (R)	2.4
Frequency bias constant (B)	0.425

3. Optimal design of conventional PID and FOPID controllers:

3.1 Overview of conventional PID and FOPID controllers

To obtain the desired response from any process control under normal and perturbed conditions controllers plays a significant role. PID controller is one of the most popular controller because of its simplicity. It consists of three modes of operation like P (Proportional) mode, I (Integral) mode and D (Derivative) mode. Proportional mode adjusts instances of error, integral mode corrects accretion of error, and derivative mode minimizes the difference between present error and previous error. The outcome of the derivative mode is to neutralise the overshoot initiated by P and I modes. Time domain output of a PID controller is expressed in equation (3) and its structure is shown in Figure 2.

$$u(t) = K_p.e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{3}$$

Where K_p, K_i and K_d are the controller's gains.

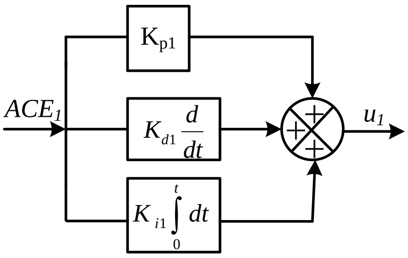

FIGURE 2: Structure of PID controller.

Enormous growth in load demand and the demand for good quality continuous power supply, has made the power system very complex. Due to increased complexity it is not advisable to expect satisfactory performance from conventional PID. Therefore in this article an optimally designed FOPID controller is introduced to tackle the AGC issues which ensured improved power quality. Besides PID controller gains, FOPID controller has two more parameters like fractional integral order (λ) and fractional derivative order (μ). Structure of FOPID controller is shown in Figure 3. Output of FOPID controller in time domain is expressed in equation (4).

$$u(t) = K_p.e(t) + K_i \frac{d^{-\lambda}}{dt^{-\lambda}} e(t) + K_d \frac{d^{\mu}}{dt^{\mu}} e(t) \tag{4}$$

In Laplace domain transfer function of FOPID controller is written as:

$$H(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} \tag{5}$$

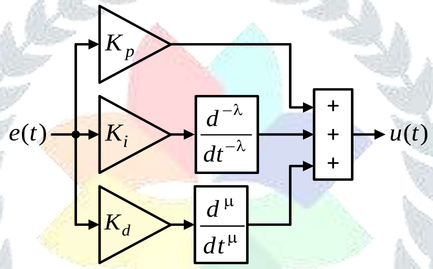

FIGURE 3 Structure of FOPID controller.

3.2 Overview of Ant Lion Optimizer (ALO) algorithm:

ALO algorithm [28] simulates the hunting mechanism of antlions. Various steps followed by hunting prey such as random walk, building traps, entrapment of ants in trap, catching prey and rebuilding traps are mathematically modelled to deal with various optimization related problems. Various steps involved in this algorithm are:

i. Random initialization of antlions & ants and determination of their finesses.
ii. For every ant
   a. Select an ant lion using Roulette Wheel.
   b. Update the position of ant using the following equations:

$$c_i^t = Antlion_j^t + c^t \tag{6}$$

$$d_i^t = Antlion_j^t + d^t \tag{7}$$

Where c^t & d^t vectors representing minimum and maximum values respectively of all variables in t^{th} iteration.

$$c^t = \frac{c^t}{I} Antlion_j^t + c^t \tag{8}$$

$$d^t = \frac{d^t}{I} Antlion_j^t + d^t \tag{9}$$

Where I is a ratio expressed as:

$$I = 10^w \times \frac{t}{T} \tag{10}$$

Where $t\,\&\,T$ are current and maximum number of iteration respectively, and w is taken as 2,3,4,5, or 6 when the current iteration t is $> 0.1T, > 0.5T, > 0.75T, > 0.9T, or > 0.95T$. Respectively.

c. Update the ant position using equation:

$$Ant_i^j = \frac{R_E^t + R_A^t}{2} \tag{11}$$

Where $R_A^t\,\&\,R_E^t$ are the random ant selected by Roulette Wheel and the best performing solution at t^{th} iteration.

iii. Calculate the fitness of the newly generated ant and replace it with the position of antlion if it performs better.

iv. Select the best performing solution

v. Repeat steps ii-iv until the termination criteria is reached.

In this article conventional PID and FOPID are optimally designed and ALO algorithm and their gains are depicted in Table 2. Number of population and maximum number of iterations are taken as 100. Gains of PID and FOPID controllers are taken in the range of [0-2] and those of integral and derivative order are taken in the range [0-1]. ITAE expressed in equation (12) is taken as objective function in designing the controller gains.

$$ITAE = \int_{t=0}^{t_{sim}} \left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|\right).t dt \tag{12}$$

TABLE 2: Optimal gains of conventional PID and FOPID controller designed through ALO algorithm.

Optimal gains

ALO based FOPID controller

Area1					**Area2**				
K_{p1}	K_{i1}	K_{d1}	λ_1	μ_1	K_{p2}	K_{i2}	K_{d2}	λ_2	μ_2
1.4089	2.0000	1.0129	1.0000	0.8991	0.0100	1.5774	0.9601	0.9464	0.7184

ALO based conventional PID controller

K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
1.0662	1.9860	0.3036	1.8696	0.1000	1.5701

PI Controllers

	Area1		**Area2**	
	K_{p1}	K_{i1}	K_{p2}	K_{i2}
hBFOA-PSO	-0.4383	0.3349	-0.4383	0.3349
BFOA	-0.4207	0.2795	-0.4207	0.2795
GA	-0.2346	0.2662	-0.2346	0.2662

4. Simulation Results and Discussion:

4.1 Transient Performance Analysis:

In this section comparative performance analysis of transient behaviour of the AGC system for two area thermal power system is presented. Gains depicted in Table 2 are used to study the transient behaviour of the system. Sudden step load change of 10% is applied in area1 in the study. Initially conventional PID controller is optimally designed and then the study is extended to design optimal FOPID controller. Frequency deviation in area1 (Δf_1), area2 (Δf_2) & tie-line power deviation (ΔP_{tie}) due to 10% step load change in area-1 are shown in Figures 4-6 respectively. In the same plots the corresponding deviations obtained implementing hBFOA-PI [26], BFOA-PI [27] and GA-PI [27] are also plotted to claim the dominance of proposed FOPID controller over other controllers.

Undershoot (U_{sh}), overshoot (O_{sh}) and settling time (T_s) (0.5% band) with various controllers are given in Table 3. It is clearly seen in Figures 4-6 and Table 3 that the presented ALO based FOPID and conventional PID controller exhibit significant improvements in frequency and tie-line power deviations and FOPID controller outperforms all other controllers. All the transient parameters i.e. U_{sh}, O_{sh} and T_s are less when the AGC system is equipped with FOPID controller.

TABLE 3: Transient Performance Analysis.

Controller	Δf_1			Δf_2			ΔP_{tie}		
	$U_{sh} \times 10^{-2}$ in Hz	$O_{sh} \times 10^{-2}$ in Hz	T_s in sec	$U_{sh} \times 10^{-2}$ in Hz	$O_{sh} \times 10^{-2}$ in Hz	T_s in sec	$U_{sh} \times 10^{-2}$ in pu	$O_{sh} \times 10^{-2}$ in pu	T_s in sec
ALO-FOPID	**-8.4317**	**0**	**2.07**	**-4.2220**	**0**	**2.51**	**-1.4618**	**0**	**2.34**
ALO-PID	-12.3694	2.1860	2.07	-5.9852	0.0012	2.53	-2.3529	0	2.51
hBFOA-PSO PI [26]	-26.3407	2.7112	4.88	-22.9593	0.4815	4.2	-8.2980	0.1113	4.24
BFOA-PI [27]	-26.2474	0.6423	4.18	-22.8621	0.0022	6.5	-8.2872	0.0137	5.62
GA-PI [27]	-24.0733	0	8.53	-20.0647	0	8.63	-7.1513	0	7.33

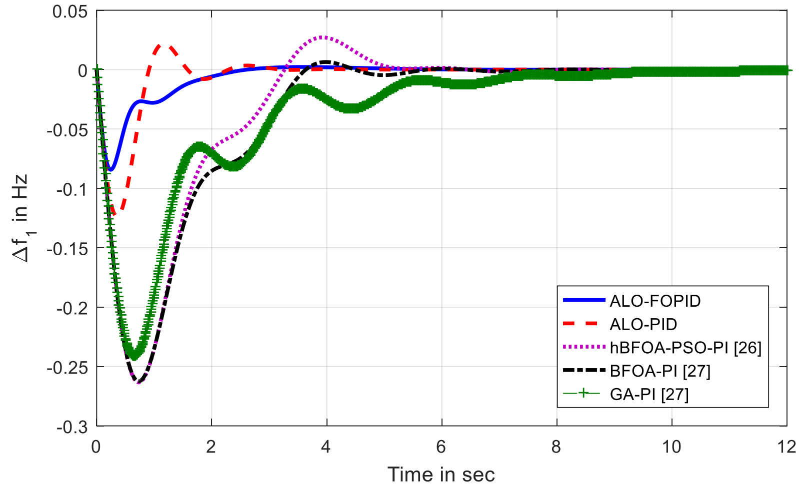

FIGURE 4: Frequency deviation in area1.

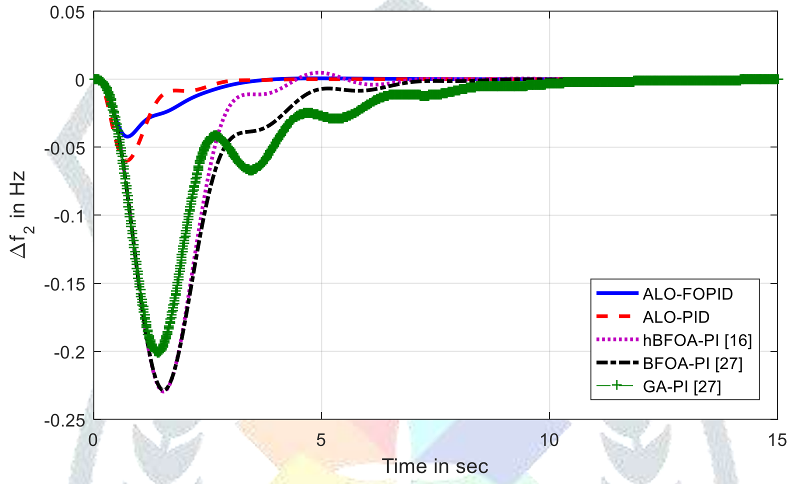

FIGURE 5: Frequency deviation in area2.

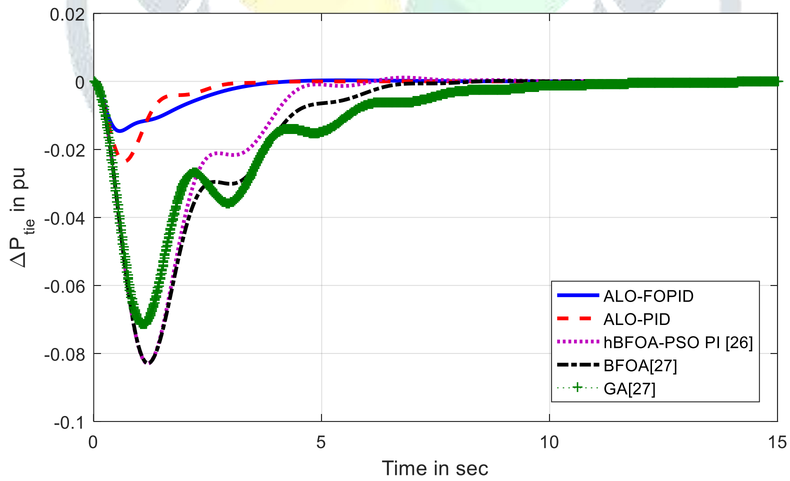

FIGURE 6: Tie-line power deviation.

Table 4 represents percentage improvements in various transient parameters ALO-FOPID controller in comparison with other controllers. Table 4 clearly ensures that there is as high as 67.9898 % improvement in U_{sh} of Δf_1 , 75.7327% in T_s of Δf_1 , 81.6109 % in U_{sh} of Δf_2 , 66.2804 % in T_s of Δf_2 and 82.3607% in U_{sh} of ΔP_{tie} & 68.0764% in T_s of ΔP_{tie} .

TABLE 4: Percentage improvements in transient parameters.

CONTROLLER	Δf_1		Δf_2		ΔP_{tie}	
	U_{sh}	T_s	U_{sh}	T_s	U_{sh}	T_s
As compared to ALO-PID	31.8342	0	29.4593	0.7905	37.8724	6.7729
As compared to hBFOA-PSO PI	67.9898	57.5820	81.6109	30.7143	2.3837	44.8113
BFOA-PI	67.8761	50.4785	81.5328	55.2308	82.3607	58.3630
GA-PI	64.9749	75.7327	78.9581	66.2804	79.5590	68.0764

4.2 Robustness Analysis:

Robustness of ALO-FOPID controller is studied by randomly varying the step load in area-1 and some of the important parameters of the power system in the range of -20% to 20% in steps of 10%. The randomly varied load applied in area-1 of the power system is shown in Figure 7. The corresponding variations in Δf_1 , Δf_2 and ΔP_{tie} are shown in Figures 8-10. Figures 11-13 represents deviation in Δf_1 , Δf_2 and ΔP_{tie} due to variation in systems parameters K_{ps}, T_{12} and B.

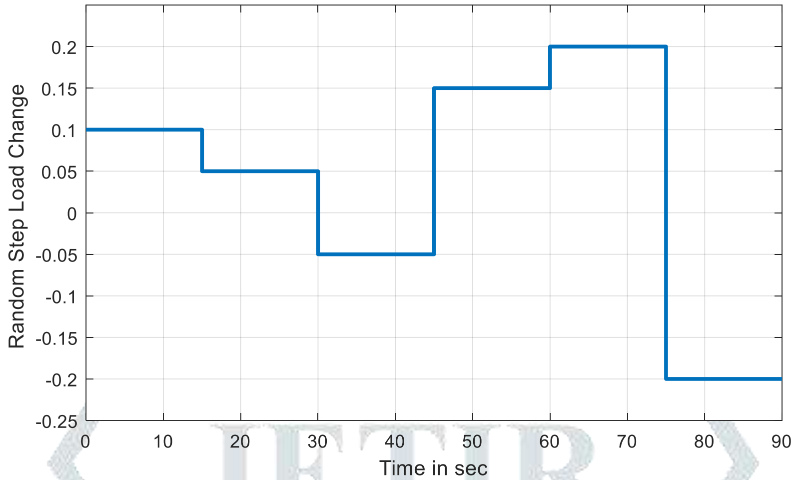

FIGURE 7: Randomly varying load applied to area1.

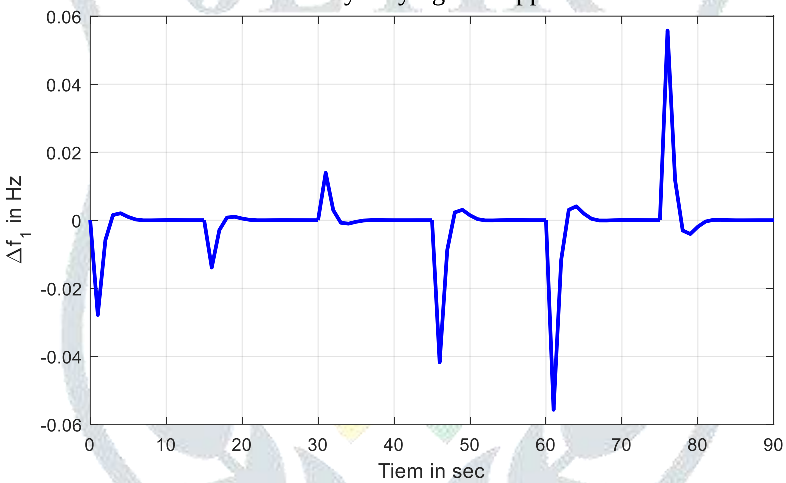

FIGURE 8: Frequency deviation in area1 due to random load variation.

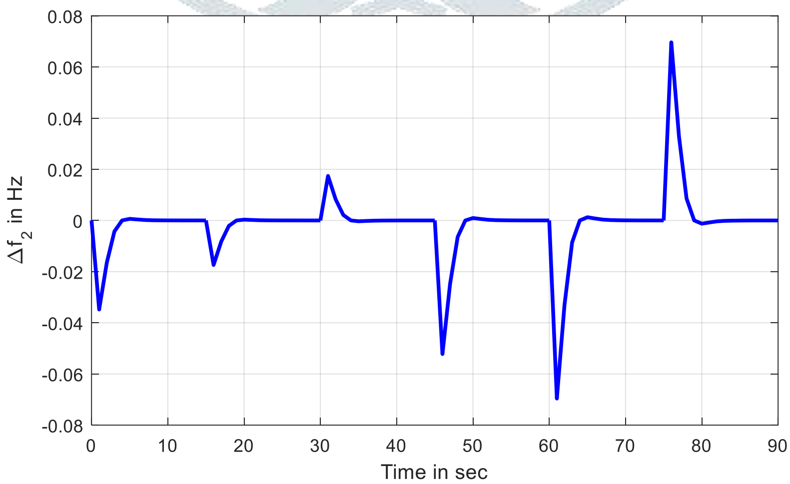

FIGURE 9: Frequency deviation in area2 due to random load variation.

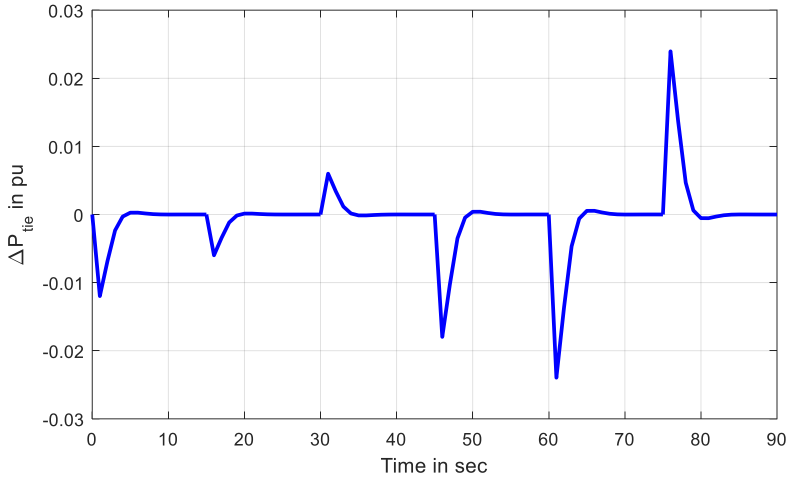

FIGURE 10: Tie-line power deviation due to random load variation.

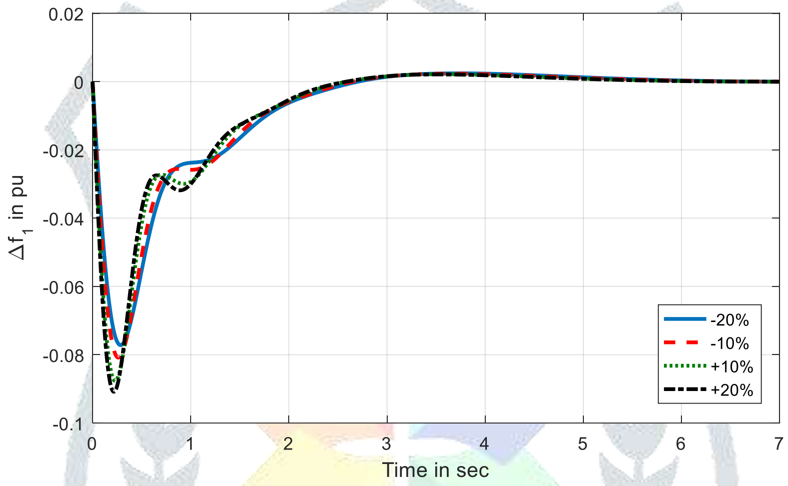

FIGURE 11: Frequency deviation in area1 due to variation in K_{ps}.

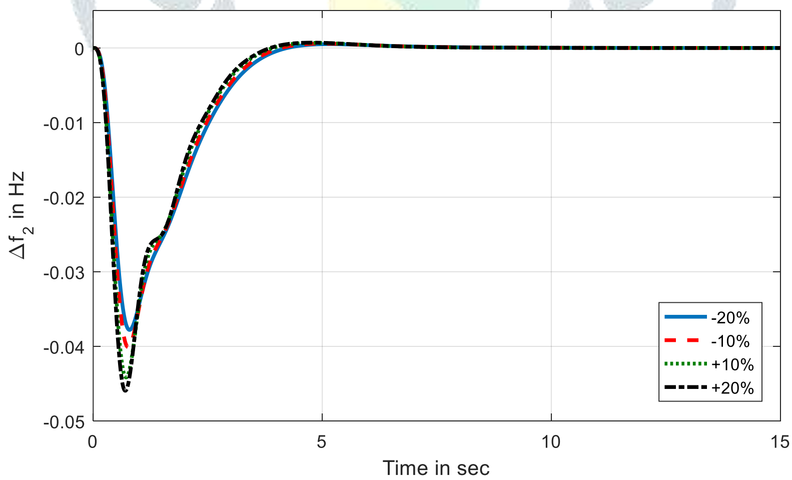

FIGURE 12: Frequency deviation in area2 due to variation in T_{12}.

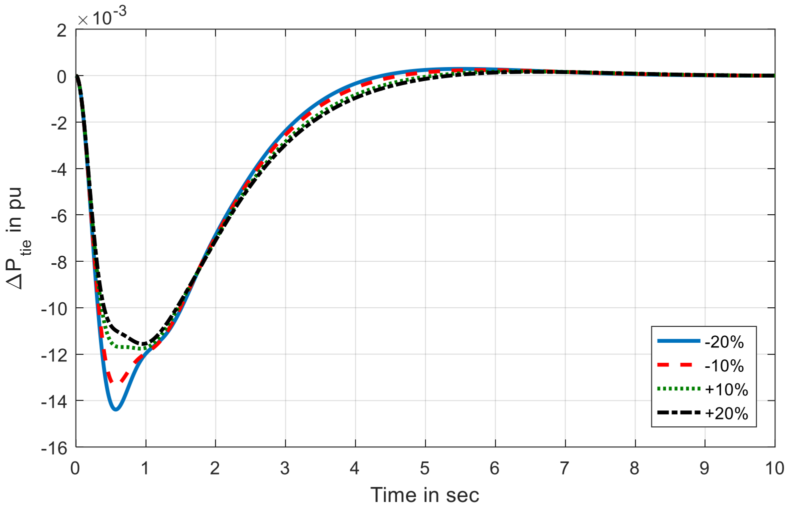

FIGURE13: Tie-line power deviation due to change in B.

In Figures 8-10 it is seen that there is a small variation in frequency and tie-line power deviations due to randomly varying load applied in area1 and some of the important parameters of power system which proves that the proposed ALO-FOPID controller is quite robust against load and parametric variations.

5. Conclusion:

An attempt is made in this article to optimally design fractional order PID (FOPID) and conventional PID controllers for AGC of a two area thermal power system using Ant Lion Optimizer (ALO) algorithm. Step load change of 10% is applied in area to analyse the transient stability study. Results obtained are compared with previously published articles based on hBFOA-PI, BFOA-PI and GA-PI controllers. It is proved that ALO designed FOPID controller yields better dynamic performance as compared to other controllers. Finally robustness analysis is carried out by randomly varying the load applied to area1 and some of systems parameters in the range of -20% to 20% in steps of 10%. It is proved that the proposed controller is quite enough robust to handle the system uncertainties.

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