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Two Area Load Frequency Control Using DE Tuned PID Controller with Nonlinearity

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Abstract: A coordinated operation of two or more than two power area is essential today for fulfilling the end consumers load demand for which this kind of structure in power system is termed as interconnected area. Their proper and successful operation requires minimal changes in the frequency and tie line power flow among their tie lines. Hence, keeping the frequency and tie line power flow close to constant is of key significance here. Normally, for a single area system load frequency control (LFC) is quite simple, but for such an interconnected area it is quite a task. Like in single area system too, the LFC in case of two area interconnected system can be bettered with the inclusion of controller. Therefore, PID controller is used in the presented work in LFC loop. Its performance could further be enhanced by the use of some optimization technique for which Differential Evolution (DE) algorithm has been put to use and it will help to reduce the time domain objective of the work. In the process of analysis the generation rate constraint (GRC) is also considered to account for the non linearity present in the interconnected system going closer to real practical scenarios.

For the LFC PID controller is used here with the optimization provided by DE (Differential Evolution) and BOFA (Bacteria Foraging Optimization). Later both these techniques were compared with each other and with conventional controller and with Genetic algorithm (GA) based controller. The simulation of the two area non reheat thermal interconnected system is carried out in MATLAB/SIMULINK under different cases. The cases falls under two category of saturation limit one with α=±0.05 and other with α=±0.025. The case are, 5% step change in load of both the areas, change in the system parameters by 50% (either increasing it or decreasing the particular parameter) and observing the settling time for deviation in frequency and tie line flow for both the areas. To evaluate the usefulness of the proposed method, we compare the answer of this method Differential Evolution (DE) with the Bacteria Foraging Optimization (BFOA) method of the PID controller technique for the same composite system. Investigations show that the proposed DE algorithm is superior to the BFOA technique. Simulation results show that the differential evolution-based tuning of the PID controller performs better than the BFOA optimization-based PID controller.

Keywords: Automatic Generation Control; Load Frequency Control; Generating Rate Constraint Differential Evolution; Bacteria Foraging Optimization

I. INTRODUCTION

A. Introduction

We can easily understand the PI and PID controllers by looking at the current scenario in rapidly growing interconnected systems in Power System. Both in the power flow and in the load there are dynamic fluctuations in the connection line. We know that the charge cannot be the same. It varies with time. In the case of orthodox controllers, however, gain constants do not match the load value, but remain, as the name implies, constant. Here we can use the proportional PI and PID controllers for proper control of the grid and system frequency. There are many kinds of literatures about other ways to reduce or eliminate the characteristic inability of orthodox systems. In this approach, d. H. load frequency control problem, the PID base controller has been considered here. In order to minimize the error, queried rules regarding the load variation are executed. Compared to other membership functions, the formulation of the rule base in the triangular membership function is fairly simple. The same thing was considered here in the PID base controller. MATLAB / SIMULINK software is used for simulation purposes. Adjustment of the controller parameters of the differential evolution (DE) algorithm and its application for automatic generation control (AGC) of a connected power supply system [1][2]. In the proposed approach, the design problem is formulated as an optimization problem control, and DE is used to search for optimal control parameters. The performance of this type of heuristic algorithm depends heavily on the setting of control parameters, since the correct selection of control parameters requires the success of the algorithm. Three different target functions are used to design PID controllers. The superiority of the proposed approach was demonstrated by comparing the results with a recently published BFOA technique (BFFA) for the same composite system. The result shows that the dynamic performance of the DE-optimized PID controller is better than that of the BFOA-optimized PID controller [3].

It is of utmost importance to safeguard the territory and keep the frequency close to the booked qualities, especially in large power plants with interconnected control area, load frequency. A well-defined performance framework should be able to achieve the satisfactory quality of the power supply by maintaining the frequency and voltage within the core as much as possible [4].

The system frequency is affected by changes in the network load, essentially the system frequency. However, reactive power is not significantly affected by frequency changes, but variations in voltage magnitude have a major impact on them. Consequently, there is an independent management of control in the energy system on the reactive and true power. Therefore, system frequency and active power are essentially controlled by load frequency control, while reactive power and voltage are essentially managed by a programmed voltage regulator.

A high quality power system must have controllers that maintain the superior performance despite the fact that the load varies randomly. The purpose of AGC in an interconnected system is to control frequency and power flow so that the system frequency is immune to interference [4].

B. Objective Function

For both the areas frequency deviation and tile line flow a performance index is defined using Integral of Time multiply Absolute Error (ITAE) of these two parameters. Objective function is,

$$J=\int_0^\infty t(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|dt \qquad (1)$$

Hence the design problem of PID controller is stated as

Minimize J subjected to

$$K_{Pmin} \le K_P \le K_{Pmax}, K_{Imin} \le K_I \le K_{Imax}, K_{Dmin} \le K_D \le K_{Dmax} \qquad (2)$$

II. SYSTEM MODEL

A. AGC in Two Area System (Thermal Thermal System without Heat Turbine)

Fig.1 shows two area interconnected by tie line & fig.2 shows The area 1 & area2 shows different parameters where f_1 & f_2 is the system frequency (Hz), R_1 & R_2 is the regulation constant (Hz/unit), T_{G1} & T_{G2} is the speed governor time constant (s), T_{T1} & T_{T2} is the turbine time constant (s), T_{P1} & T_{P2} is the power system time constant (s), ACE_1 & ACE_2 is the area control error, ΔP_{D1} & ΔP_{D2} is the load demand change, ΔP_{C1} & ΔP_{C2} is the change in speed changer position, ΔP_{G1} & ΔP_{G2} is the change in governor valve position, K_{P1} & K_{P2} is the power system gain, and ΔP_{tie} is the change in tie line power for area1 & area2 . In addition, nonlinear model shows in fig.2 (with $\alpha = \pm0.05$ and $\alpha=\pm0.025$) the linear model of a non-reheat turbine. This is to take into account the generating rate constraint (GRC), where PID controller represent by K_P is proportional gain, K_I is the integral gain, and K_D is differentia l gain, respectively. The PID controllers in both areas were considered to be identical. The real power transfer between the tie line of two area system [5],

$$P_{12} = \frac{|E_1||E_2|}{X_{12}}\sin\delta_{12} \qquad (3)$$

$(X_{12}=X_1+X_{tie}+X_2, \delta_{12}=\delta_1+\delta_2)$

Tie line flow changes by small amount $\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}}\Big|_{\delta_{12}} \Delta\delta_{12} = P_s\Delta\delta_{12} = P_s(\Delta\delta_1 - \Delta\delta_2)$

The below figure represents the system that has to be focused and examined here containinf PID as controller and two area non reheat thermal system.
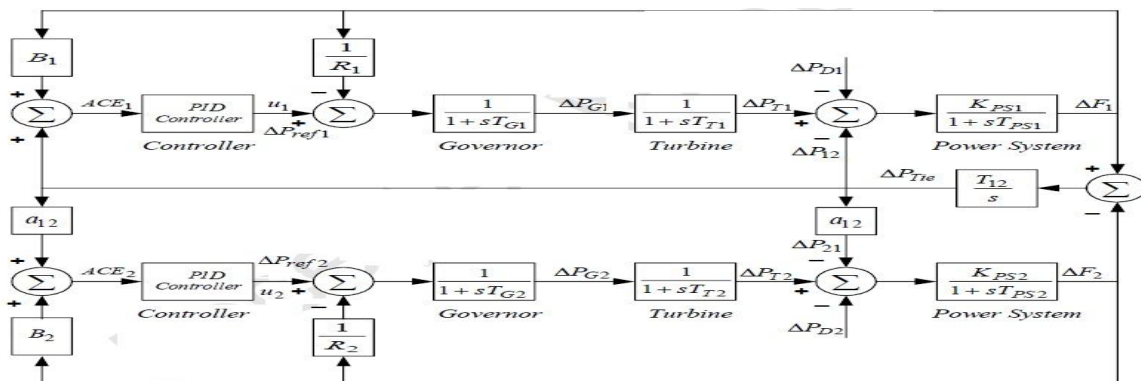

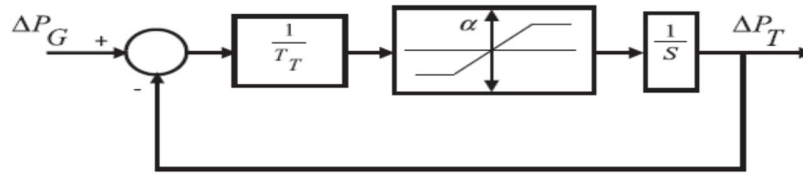Fig.1: Two Area Non Reheat Thermal System.[5]

Fig.2 Nonlinear Turbine Model with GRC [5]

III. DIFFERENTIAL EVOLUTION (DE) TUNED PID CONTROLLER

A. Proportional Integral Derivative Controller

Fig. 3 shows PID controller block diagram. The output in the given controller depends upon the error signal e(t) generated by comparing the desired set point with the processed variable. The error is then corrected based on integral, proportional and derivative control that's why it's named as PID controller [21].
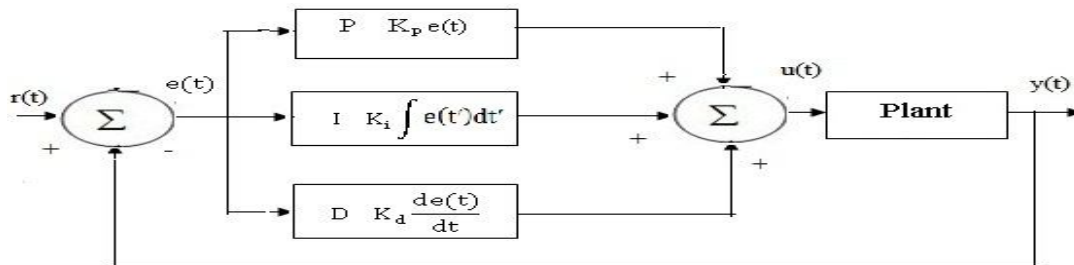

Fig. 3: PID controller Block Diagram

Fig.4 shows DE-tuned PID controller shows. The subject here is the parameters of the controller which should have a value close to or nearly equal to the best possible value i.e. optimal solution. There are namely three parameters K_p, K_i and K_d gain of PID controller
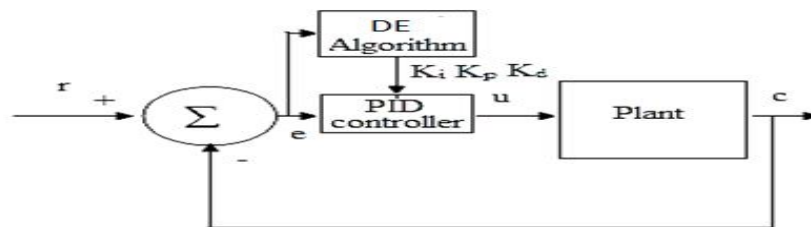

Fig. 4: DE Tuned PID Controller

B. DE Optimization Technique

Optimization is the process of getting the solution which is best applicable at a time. There are many ways; one of it is metaheuristic techniques that improve the given solution by iteration with respect to quality of measures. It uses no or very few assumption about the concerned problem and can search through large space of candidate solution. But it doesn't ensure optimal solution[26].

One such technique falling under this category is Differential Evolution (DE). It utilizes real valued functions that are multidimensional. Although, it doesn't involve gradient of the problem in optimization i.e. it doesn't require problem to be differentiable as with the case in classical optimization. Therefore, optimizations of non continuous and noisy problem are possible through it.

It is a population based stochastic algorithm given by Storm and Price in 1996. The optimization problem can be stated as,

Minimize f(X)

Where X=[x_1, x_2, x_3,. . ., x_d], d= number of variables.

DE is different from Evolution algorithm in the matter of application of mutation, as it is applied first to obtain the trial vector. Then, it is used within the crossover for the production of one offspring. Also, mutation steps are not sampled from the already known probability distribution function[2].

1) *Process:* DE is different from Evolution algorithm in the matter of application of mutation, as it is applied first to obtain the trial vector. Then, it is used within the crossover for the production of one offspring. Also, mutation steps are not sampled from the already known probability distribution function[26]. The DE algorithm is a population-based algorithm, similar to genetic algorithms that use similar operators. Crossover, mutation and selection. The main difference in creating better solutions lies in the fact that genetic algorithms rely on crossing, whereas DE relies on mutation operations. This main operation is based on the differences of pairs of solutions chosen at random in the population. The algorithm uses a mutation operation as a search mechanism and a selection operation to direct the search to the prospective regions of the search space. The DE algorithm also uses a non-uniform crossover, which allows child vector parameters to be taken more frequently by one parent than by others. By using the components of the existing population members to construct the test vectors, the recombination operator (crossover operator) effectively mixes information on successful combinations, thus enabling the search for a better solution space[6].

2) *Algorithm*

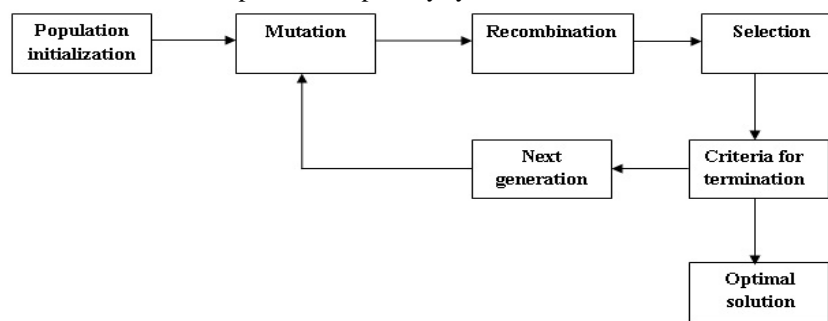Fig.5 shows DE flow chart and defines different process adopted by system.

Fig. 5: DE Flow Chart

Let population size = N

Population matrix,

$$x_{n,i}^g = [x_{n,1}^g, x_{n,2}^g, x_{n,3}^g, \dots, x_{n,d}^g] \tag{4}$$

g= number of generation and n= 1,2,3,…., N

a) *Initial Population:* The population at the initial point is generated between upper and lower bound.

$$x_{n,i} = x_{n,i}^L + rand(\ ) * (x_{n,i}^U - x_{n,i}^L) \quad i= 1,2,3, \dots .D \tag{5}$$

$x_{n,i}^U = x_i$ variable upper bound

$x_{n,i}^L = x_i$ variable lower bound

b) *Mutation:* Randomly three other vectors x_{r1n}^g, x_{r2n}^g and x_{r3n}^g are chosen from each parameter vector.

$$v_n^{g+1} = x_{r1n}^g + F(x_{r2n}^g - x_{r1n}^g) \tag{6}$$

v_n^{g+1} = donor vector

F varies from 0 to 1.

c) *Recombination:* From donor and target vector i.e. $v_{n,i}^{g+1}$ and $x_{n,i}^g$ respectively a trial vector is developed $u_{n,i}^{g+1}$.

$$u_{n,i}^{g+1} = \begin{cases} v_{n,i}^{g+1} \ if \ rand(\ ) \leq C_p \ or \ i = I_{rand} \\ x_{n,i}^g \ if \ rand(\ ) > C_p \ or \ i \neq I_{rand} \end{cases} \tag{7}$$

I_{rand} = random number which is an integer [1, D]

C_p = recombination probability

d) *Selection:* The comparison of target vector is taken with trial vector and which ever has the lowest function value is selected for next population.

$$x_n^{g+1} = \begin{cases} u_{n,i}^{g+1} \ if \ f(u_n^{g+1}) < f(x_n^g) \\ x_n^g \ otherwise \end{cases} \tag{8}$$

The optimal solution is obtained when the criterion for termination is met and then it won't go the next generation[2].

IV. RESULT ANALYSIS AND DISCUSSIONS

This result represents a benefit of the novel artificial intelligent search approach to discover the parameter optimization of the non-linear LFC taking into account the proportional integral derivative control (PID) for an two area non reheat system. A two-zone non-reheat system is contemplated to be equipped with a PID controller. The contrast of the bacterial foraging (BFOA) and differential evolution (DE) optimization algorithm is used to search for optimal control parameters to reduce the time domain objective function. The overall performance of the proposed approach was evaluated by the performance of the DE algorithm with the purpose of demonstrating the advanced performance of the proposed DE regulations in tuning the PID controller. In contrast to the BFOA PID method and DE PID, the effectiveness of the proposed DE PID over different running situations and device parameter variations is verified.

Table 1 shows PID parameters at different GRC & The two area thermal-thermal non reheat system tested with two nonlinearity as different GRC as α=±0.05 & α=±0.025

Table 1: PID Parameter of when GRC α=±0.05 & α =0.025

S. N.	PID Parameter	With GRC α=±0.05		With GRC α=±0.025	
		BFOA PID Controller	DE PID Controller	BFOA PID Controller	DE PID Controller
1	K_P	0.1317	0.4238	0.1317	0.3433
2	K_I	0.41873	0.7649	0.41873	0.3385
3	K_D	0.2506	0001	0.2506	.01000

A. Result of DE Optimized PID Controller

Fig.6 shows the best cost function with an iteration of DE algorithm and its definitely the best value gets by DE algorithm.
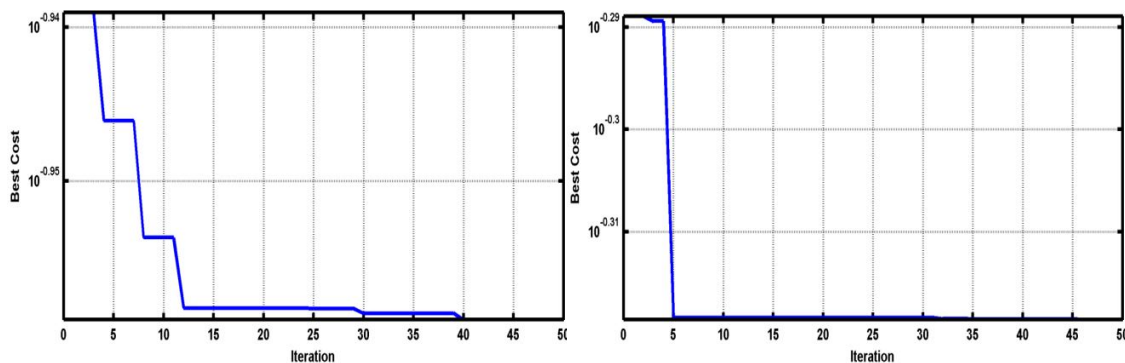

Fig.6: Convergence of objective function for g$_{best}$ Load Frequency Control system at GRC **α=±0.05 & α=±0.025**

1) Case-1: 5% Step Increase in Demand of the Area-1 (ΔPD₁)

Fig. 7 to 9 shows frequency deviation of area-1, 2, tie line power deviation of 5% step load change in area-1 with α = ±0.05 & α = ±0.025. The system shows less settling times compared to modern optimization approaches BFOA optimized PID controllers.
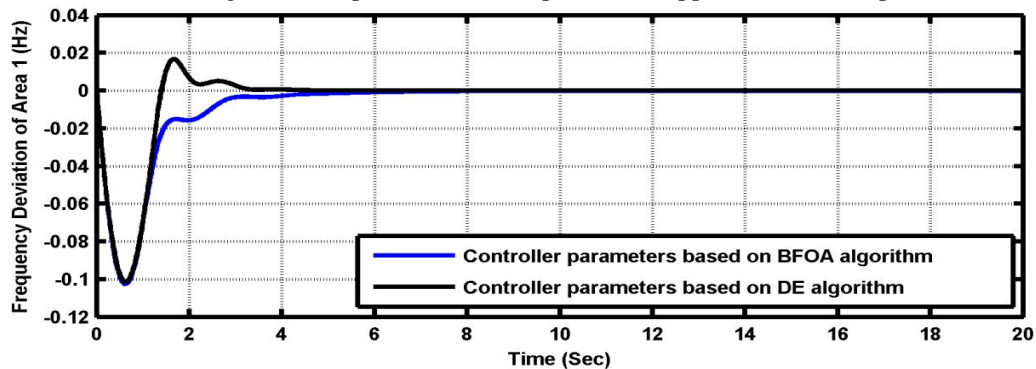

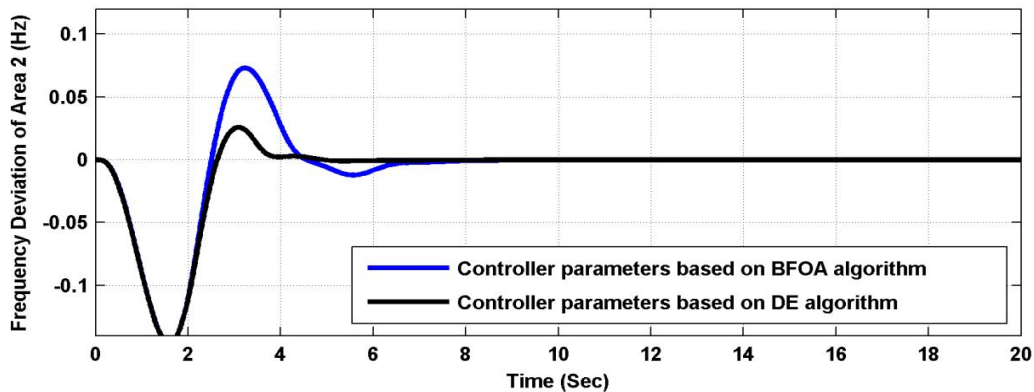Fig. 7: Frequency Deviation of Area-1 for 5% Step Load Change in Area-1 at α=±0.05

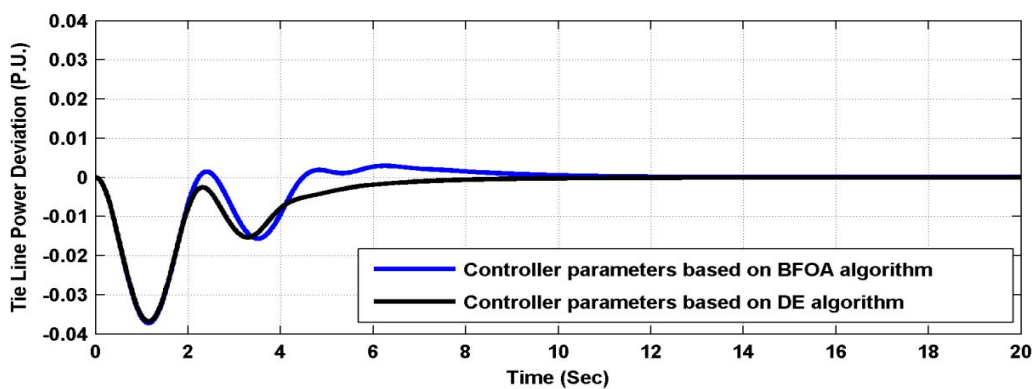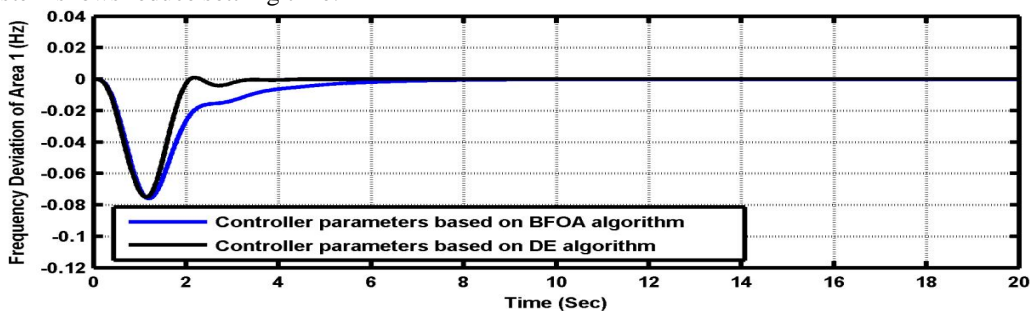Fig. 8: Frequency Deviation of Area-2 for 5% Step Load Change In Area-1 at $\alpha=\pm0.025$

Fig. 9 Tie Line Power Deviation for 5% Step Load Change in Area-1 at $\alpha=\pm0.025$

2) Case-2 :5 %Step Increase in demand of the area-2 (ΔPD_2)

Fig.10 to 12 shows response area1, 2, tie line power deviation .The proposed DE optimized PID controllers show best dynamic performance compared to BFOA optimized PID controllers. The DE PID controller is shown superior response than BFOA PID controller and system shows reduce settling time.

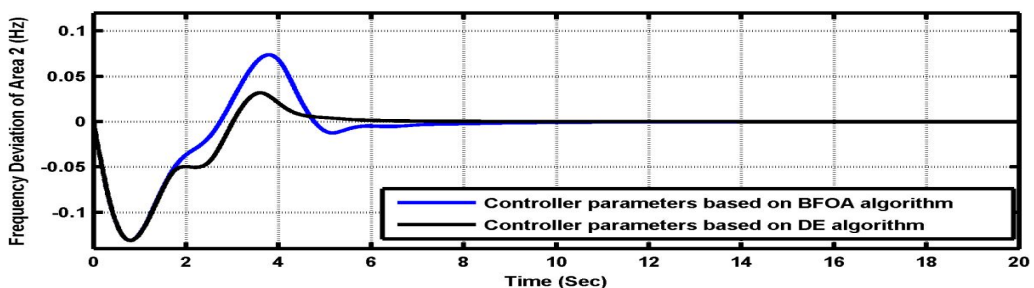Fig. 10: Frequency Deviation of Area-1 for 5% Step Load Change In Area-2 at $\alpha=\pm0.05$

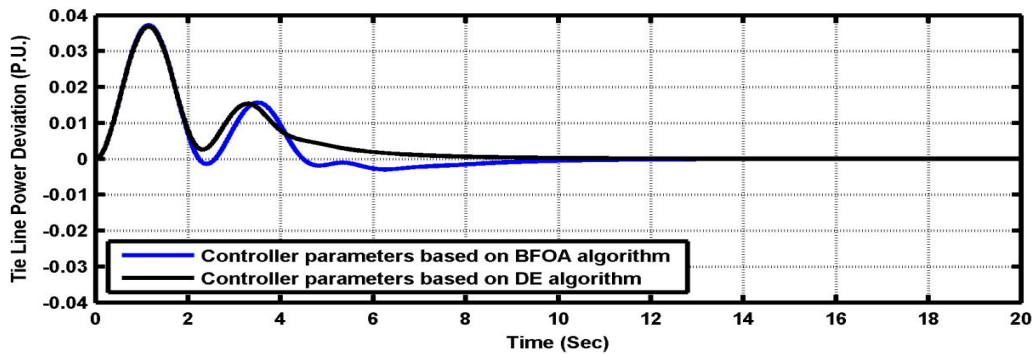Fig. 11: Frequency Deviation of Area-2 for 5% Step Load Change In Area-2 at $\alpha=\pm0.025$

Fig. 12: Tie Line Power Deviation for 5% Step Load Change in Area-2 at α=±0.025

3) Case-3 Effect of Parameter Variation on System Response

Fig.13 to fig, 16 shows response area1,2,tie line power deviation with a 50% increase, decrease in T_{12} & 50% increase, decrease in T_g at α= ±0.005 & α= ±0.025 . It is obvious that the dynamic performance with proposed DE optimized PID controller is superior to BFOA optimized PID controller Hence, it can be concluded that the proposed control approach provides a strong control under large changes in the system parameter variations.
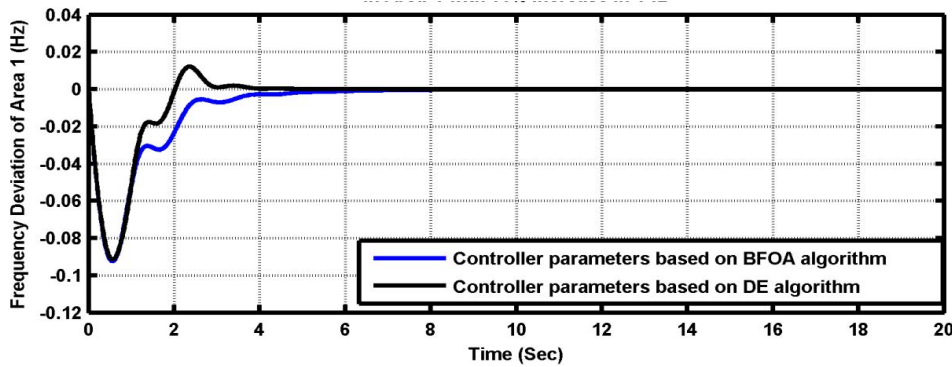

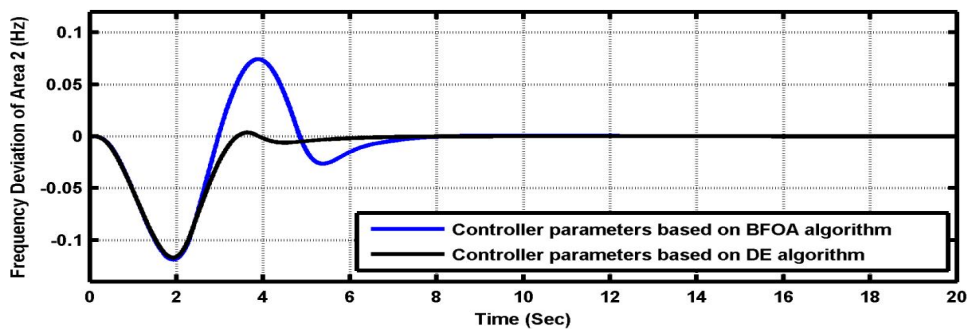Fig. 13: Frequency Deviation of Area-1 for 5% step change in area-1 with 50% Increase in T_{12} at α=±0.05

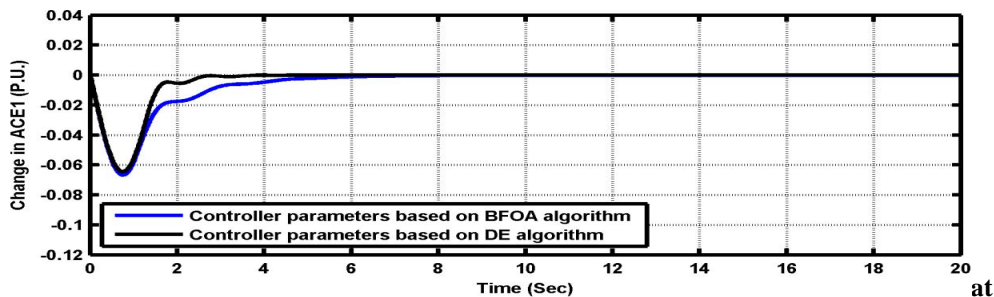Fig. 14: Frequency Deviation of Area-2 for 5% step change in area-1 with 50% Decrease in T_{12} at α=±0.025

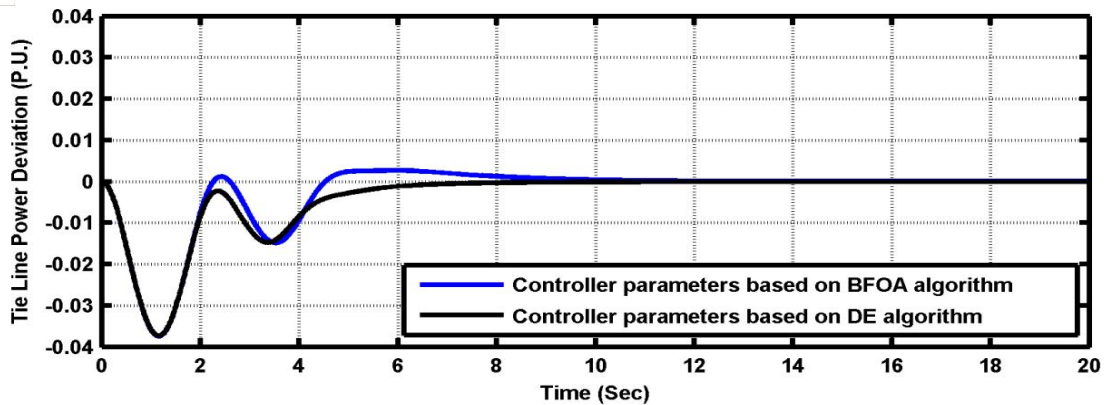Fig. 15: Tie Line Power Deviation for 5% step change in area-1 with 50% Increase in T_g α=±0.05

Fig. 16: Tie Line Power Deviation for 5% step change in area-1 with 50% Decrease in T_g at α=±0.025

Table 2: Performance Indices Different GRC at α=±0.005 & α=±0.025

S.N.	Saturation	Parameter change	BFOA PID Controller	DE PID Controller
1	Step increase in demand of the second area (ΔPD_1)	Area-1 at α=±0.05	4.3604	3.0630
		Area-2 at α=±0.025	6.5512	3.7986
		Strap line power deviation at α=±0.025	9.3116	7.6439
2	Step increase in demand of the second area (ΔPD_2)	Area-1 α=±0.05	6.3275	3.1147
		Area-2 at α=±0.025	7.4855	5.4959
		Strap line power deviation at α=±0.025	9.3121	7.6436
3	Effect of parameter variation on system response	By 50% T_{12} Increase at α=±0.05	Unstable	0.5905
		By 50% T_{12} Decrease at α=±0.025	3.7706	3.1066
		By 50% T_g Increase α=±0.05	Unstable	0.6793
		By 50% T_g Decrease at α=±0.025	2.4102	1.8270

V. CONCLUSIONS

The given system of two interconnected area of non reheat thermal type has employed PID controller in its both areas LFC loop which was further add on the DE algorithm for optimization of controller parameters and analyzed using MATLAB/SIMULINK. It is compared with the same system with the difference of only being in the use of optimization i.e. BFOA. The system response tested at different GRC and various cases as step increase of demand area1,2 and parameter variations. Finally DEPID shows superior response than BFOAPID system.

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