Application DE Optimization Algorithm based Automatic Generation Control of Interconnected Multi Area Power System

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Abstract

This paper presents an application of population based Differential Evolution (DE) optimization algorithm is proposed for solving the load frequency control problem of two area system. The Proportional-Integral-Derivative (PIDF) controller with derivative filter of two area non reheat thermal system is taken both area of the purpose system. To optimize the parameters of the PIDF controller, DE optimization algorithm is employed. The disturbance of 0.01pu injected in control area-1, area-2 separately and also simultaneously both the area. The dynamic simulation responses of PIDF based controller are compared with PI controller of the same system.

Keywords: Automatic Generation Control (AGC); Proportional-Integral (PI) controller; Proportional Integral Derivative controller with derivative Filter (PIDF); Differential evolution algorithm

1. Introduction

In interconnected control area for a large scale power system tie line power and the sytem frequency in load frequency control try to make a closed to nominal value[1].To maintain the above nominal value we are trying to used different types of controller in automatic generation control of intercoonected power system for making the balance between generation and variation of load[2].It has been proposed by many researcher in AGC by considering diffrenet types of controller and optimization technique are analyzed in single area thermal,hydro,two area thermal-hydro interconnected power system[3-4].The conventional PI type of controller attempt in different load frequency control of single and two area power system[5].It has been shows that in convention PI type of controller the dynmaic performace is very poor interm of settling time and overshoot.In the literacture survey,the automtaic generation control of fuzzy PI based tabu search algorithm applied in two area interconnted power system[6].In the literacture survey,it has been proposed that the different controller with optimization techniques in AGC system with generalized neural network, fuzzy logic control of interconnected power system, Particle swarm optimization(PSO),Genetic Algorithm (GA),Bacteria Foraging Optimization Algorithm (BFOA) etc [7-10].The purpose analysis, two area automatic generation control of interconncted power sytem by using DE optimization algorithm design of PID controller with derivative filter is considered. DE algorithm is applied and find out the controller parameters of PIDF controller of AGC of two area power system. The advantage of PIDF based LFC of the purpose system compared with PI based controller in term of settling time and overshoot of frequency deviation and tie line power of two area power system. The effectiveness of purpose system with both PI and PIDF controller is studies under different loading of interconnected two area system.

2. System modelling

The system under investigation consists of two area interconnected power system of non reheat thermal plant as shown in Fig. 1. Each area has a rating of 2000 MW with a nominal load of 1000 MW. The system is widely used in literature is for the design and analysis of automatic load frequency control of interconnected areas . In Fig. 1, B_1 and

B_2 are the frequency bias parameters; ACE_1 and ACE_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 pu Hz; T_{G1} and T_{G2} are the speed governor time constants in sec; ΔP_{V1} and ΔP_{V2} are the change in governor valve positions (pu); ΔP_{G1} and ΔP_{G2} are the governor output command (pu); T_{T1} and T_{T2} are the turbine time constant in sec; ΔP_{T1} and ΔP_{T2} are the change in turbine output powers; ΔP_{D1} and ΔP_{D2} are the load demand changes; ΔP_{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 Δf_1 and Δf_2 are the system frequency deviations in Hz,. The relevant parameters are given in Appendix A.

Each area of the power system consists of speed governing system, turbine and generator as shown in Fig. 1. Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (denoted as u_1 and u_2), load disturbances (denoted as ΔP_{D1} and ΔP_{D2}), and tie-line power error ΔP_{Tie} . The outputs are the generator frequency deviations (denoted as ΔF_1 and ΔF_2) and Area Control Error (ACE) given by.

$$ACE = B\Delta F + \Delta P_{Tie} \tag{1}$$

Where B is the frequency bias parameter.

To simplicity the frequency-domain analyses, transfer functions are used to model each component of the area. Turbine is represented by the transfer function:

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+sT_T} \tag{2}$$

From [2], the transfer function of a governor is:

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+sT_G} \tag{3}$$

The speed governing system has two inputs ΔP_{ref} & ΔF with one out put $\Delta P_G(s)$ given by :

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \tag{4}$$

The generator and load is represented by the transfer function :

$$G_P(s) = \frac{K_P}{1+sT_P} \tag{5}$$

Where $K_P = 1/D$ and $T_P = 2H/fD$.

The generator load system has two inputs $\Delta P_T(s)$ & $\Delta P_D(s)$ with one out put $\Delta F(s)$ given by :

$$\Delta F(s) = G_P(s)[\Delta P_T(s) - \Delta P_D(s)] \tag{6}$$

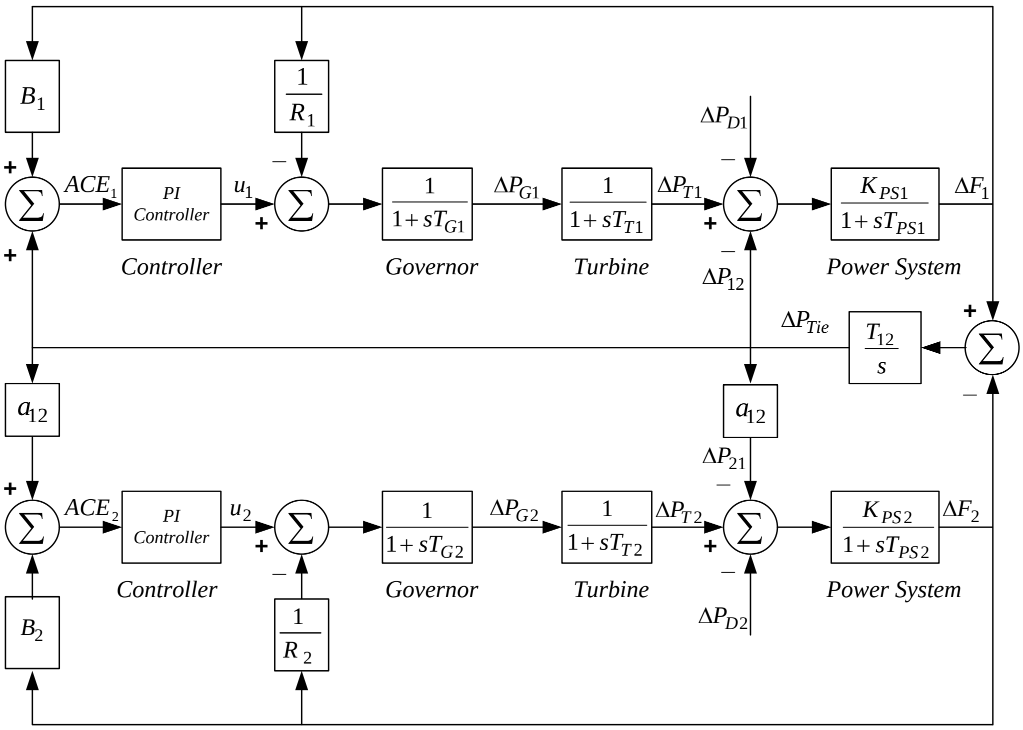

Fig. 1. Transfer function model of two-area non reheat thermal system

3. Overview of DE Optimization Algorithm

The process of optimization refers to the study of problems in which an aim or objective function is to be minimized or maximized by choosing the values of real and integer variables from an allowed set systematically. Many real-world problems can be modelled as optimization problems and can be solved to get desirable output. Power system is one of the complex fields where optimization process helps a lot. Economic Load Dispatch (ELP) , Unit Commitment (UC) , Optimal Power Flow (OP) are some of the basic problems of power system. The solution of power system optimization problems is very difficult because of large size, wide geographical distribution and complexity and influence of many unexpected events. The large number of equality and non- equality constraints further adds to these complexities. Over these years, heuristic methods are applied in solving such problems. When simulated on a computer, this results in stochastic optimization techniques that can perform quite better than conventional methods of optimization. These methods are quite efficient but time consuming. There are various evolutionary techniques like Genetic Algorithm (GA), Evolutionary Programming, Evolutionary Strategies (ES), Particle Swam optimization which have been applied to power system optimization problems. The Differential Algorithm is a new evolutionary algorithm proposed by Storm and Price which is quite simple and powerful in cracking complex optimization problems. The presence of multiple objective function give rise to set of optimal solution known as Pareto-optimal solution instead of single optimal solution. The absence of any further information makes it difficult to decide which Pareto-optimal solution is best. Hence it is important to find as many pareto-optimal solutions so that the most suitable solution is opted for a particular requirement. DE algorithm is an evolutionary technique which is quite similar to classic genetic algorithm which is beneficial in cracking global optimization problems. DE belongs to class of GAs which uses operations like crossover, mutation, selection of a population in order to minimize an objective function over the course of successive generation. These processes are biology-inspired operations. In DE algorithm a set of population which is considered as candidate solution is selected by using alteration and selection operation. The main difference between Differential Algorithm and Genetic

Algorithm is that DE algorithm uses floating point instead of bit string encoding of population members and arithmetic operations instead of logical operations in mutation in contrast to Genetic Evolution algorithm.

Differential Evolution (DE) algorithm is a population-based stochastic optimization algorithm recently introduced [11-12]. Advantages of DE are: simplicity, efficiency & real coding, easy use, local searching property and speediness. DE works with two populations; old generation and new generation of the same population. The size of the population is adjusted by the parameter N_P. The population consists of real valued vectors with dimension D that equals the number of design parameters/control variables. The population is randomly initialized within the initial parameter bounds. The optimization process is conducted by means of three main operations: mutation, crossover and selection. In each generation, individuals of the current population become target vectors. For each target vector, the mutation operation produces a mutant vector, by adding the weighted difference between two randomly chosen vectors to a third vector. The crossover operation generates a new vector, called trial vector, by mixing the parameters of the mutant vector with those of the target vector. If the trial vector obtains a better fitness value than the target vector, then the trial vector replaces the target vector in the next generation. The evolutionary operators are described below;

4.1 Initialization

For each parameter j with lower bound X_j^L and upper bound X_j^U, initial parameter values are usually randomly selected uniformly in the interval [X_j^L , X_j^U].

4.2 Mutation

For a given parameter vector $X_{i,G}$, three vectors ($X_{r1,G}$ $X_{r2,G}$ $X_{r3,G}$) are randomly selected such that the indices i, $r1$, $r2$ and $r3$ are distinct. A donor vector $V_{i,G+1}$ is created by adding the weighted difference between the two vectors to the third vector as:

$$V_{i,G+1} = X_{r1,G} + F.(X_{r2,G} - X_{r3,G}) \quad (7)$$

Where F is a constant from (0, 2)

4.3 Crossover

Three parents are selected for crossover and the child is a perturbation of one of them. The trial vector $U_{i,G+1}$ is developed from the elements of the target vector ($X_{i,G}$) and the elements of the donor vector ($X_{i,G}$).Elements of the donor vector enters the trial vector with probability CR as:

$$U_{j,i,G+1} = \begin{cases} V_{j,i,G+1} & if \quad rand_{j,i} \le CR \quad or \quad j = I_{rand} \\ X_{j,i,G+1} & if \quad rand_{j,i} > CR \quad or \quad j \ne I_{rand} \end{cases} \quad (8)$$

With $rand_{j,i} \sim U(0,1)$, I_{rand} is a random integer from $(1,2,....D)$ where D is the solution's dimension i.e. number of control variables. I_{rand} ensures that $V_{i,G+1} \ne X_{i,G}$.

4.4 Selection

The target vector $X_{i,G}$ is compared with the trial vector $V_{i,G+1}$ and the one with the better fitness value is admitted to the next generation. The selection operation in DE can be represented by the following equation:

$$X_{i,G+1} = \begin{cases} U_{i,G+1} & if \;\; f(U_{i,G+1}) < f(X_{i,G}) \\ X_{i,G} & otherwise. \end{cases} \quad (9)$$

where $i \in [1, N_P]$.

4. The proposed approach

4.1 Controller structure

In the present paper, identical controllers have been considered for the two areas as the two areas are identical. The structure of PID controller with derivative filter is shown in Fig. 2 where K_P, K_I and K_D are the proportional, integral and derivative gains respectively, and N is the derivative filter coefficient. When used as PI controller, the derivative path along with the filter is removed from Fig. 2. The error inputs to the controllers are the respective area control errors (ACE) given by:

$$e_1(t) = ACE_1 = B_1 \Delta F_1 + \Delta P_{Tie} \quad (10)$$

$$e_2(t) = ACE_2 = B_2 \Delta F_2 - \Delta P_{Tie} \quad (11)$$

The control inputs of the power system u_1 and u_2 are the outputs of the controllers. The transfer function of the controller is given by:

$$TF_{PID} = \left[K_P + K_I \left(\frac{1}{s} \right) + K_D \left(\frac{Ns}{s+N} \right) \right] \quad (12)$$

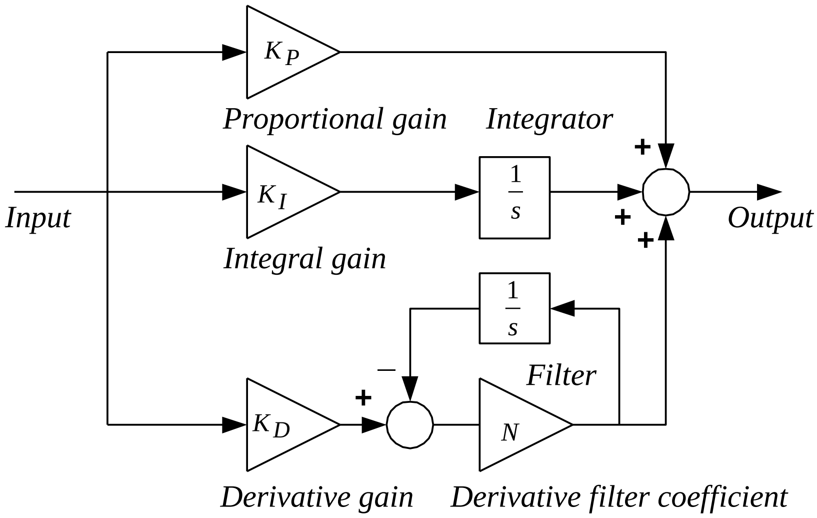

Fig. 2. Structure of PID controller with derivative filter

4.2 Objective function

While designing a controller, the objective function is first defined based on the desired specifications and constraints. The design of objective function to tune controller parameters is generally based on a performance index that considers the entire closed loop response. Some of the realistic control specifications for automatic generation control (AGC) are :

To determining the optimum values of controller parameters conventional objective functions are considered at the first instance. The objective functions considered as ITAE as given below:

$$J = ITAE = \int_0^{t_{sim}} \left(|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}| \right) \cdot t \cdot dt \quad (13)$$

In the above equations, ΔF_1 and ΔF_2 are the system frequency deviations; ΔP_{Tie} is the incremental change in tie line power; t_{sim} is the time range of simulation.

The problem constraints are the PI/PIDF controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem.

Minimize J (14)

Subject to

For PI controller: $K_{P\min} \le K_P \le K_{P\max}$, $K_{I\min} \le K_I \le K_{I\max}$ (15)

For PIDF controller: $K_{P\min} \le K_P \le K_{P\max}$, $K_{I\min} \le K_I \le K_{I\max}$, $K_{D\min} \le K_D \le K_{D\max}$ (16)

Where J is the objective function (J_1 , J_2 , J_3 and J_4) and $K_{PID\min}$ and $K_{PID\max}$, are the minimum and maximum value of the PI/PID control parameters. As reported in the literature, the minimum and maximum values of PID controller parameters are chosen as -2.0 and 2.0 respectively. The range for filter coefficient N is selected as 1 and 100.

5. Results and discussions

The DE is applied to the AGC of interconnected of two non reheat power system process to optimize the gains of PI and PIDF controllers. The results are obtained by MATLAB/SIMULINK environment to run on the computer.The performance of simulation result of purpose two area system can be checked in three cases (1) step incease in demand in area-1 (2) step increase in demand in area-2(3) step increase in demand in area-1 and area-2 simulantenously.The optimization controller parameter can be obatined by using DE optimization techniques and the best value of can be taken in the table-1.The settling time of tie line and frequency deviation as taken in table-2.

Table 1. Optimization controller parameters

Controller	Parameters	Value
PID controller employed with DE	K_P	0.78921
	K_I	0.8801
	K_D	0.7634
	N	86.98
PI controller employed in DE	K_P	-0.2156
	K_I	0.3471

Table 2. Different value of settling time of the system

Parameters		DE Optimized PI Controller	DE Optimized PIDF Controller
Ts Sec.	Δf_1	9.2	3.66
	Δf_2	8.6	3.13
	ΔPtie	9.1	4.34

Case-1: *Step increase in demand of the area-1*

In the case-1 the 10% of step increase in demand in the area-1 at time t=0sec applied at the same operating condition. It can be seen from figure-3-5 that in both the cases frequency deviation and tie line power are satbility of the sytem maintain in PI controller. However the stability of the system improved in PID controller with dervative filter case better than PI controller in term of settling time and overshoots.

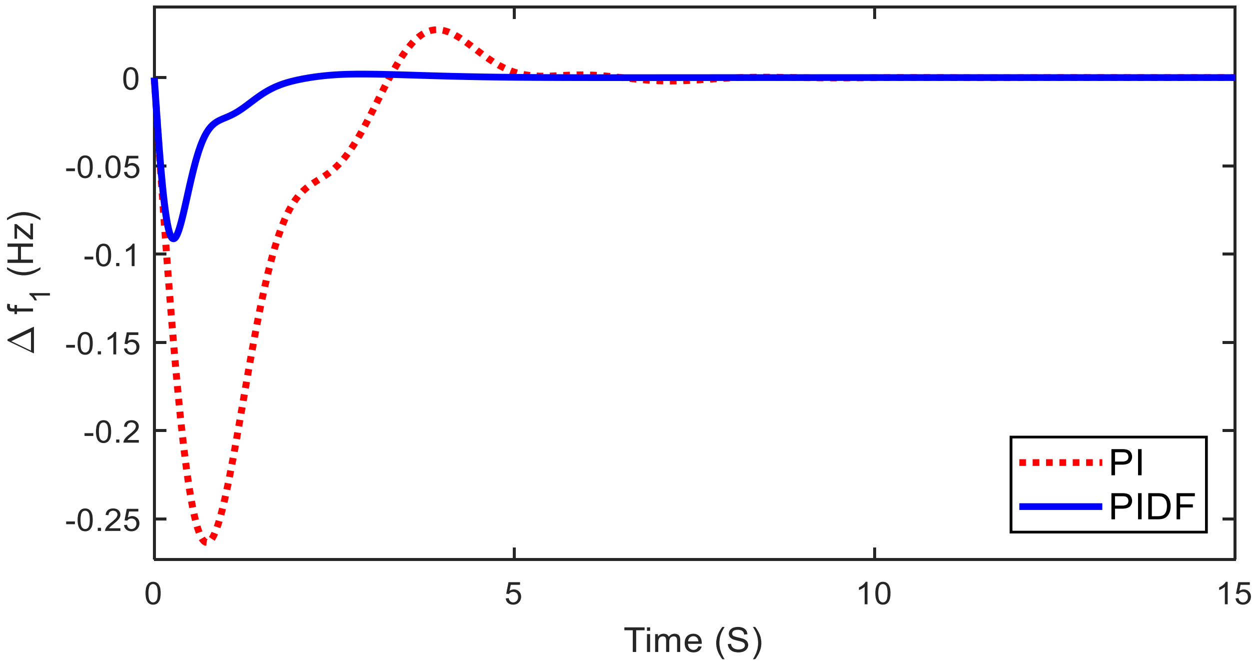

Fig.3. Frequecy changes of the area-1 due to disturbance in area-1 as per case-1

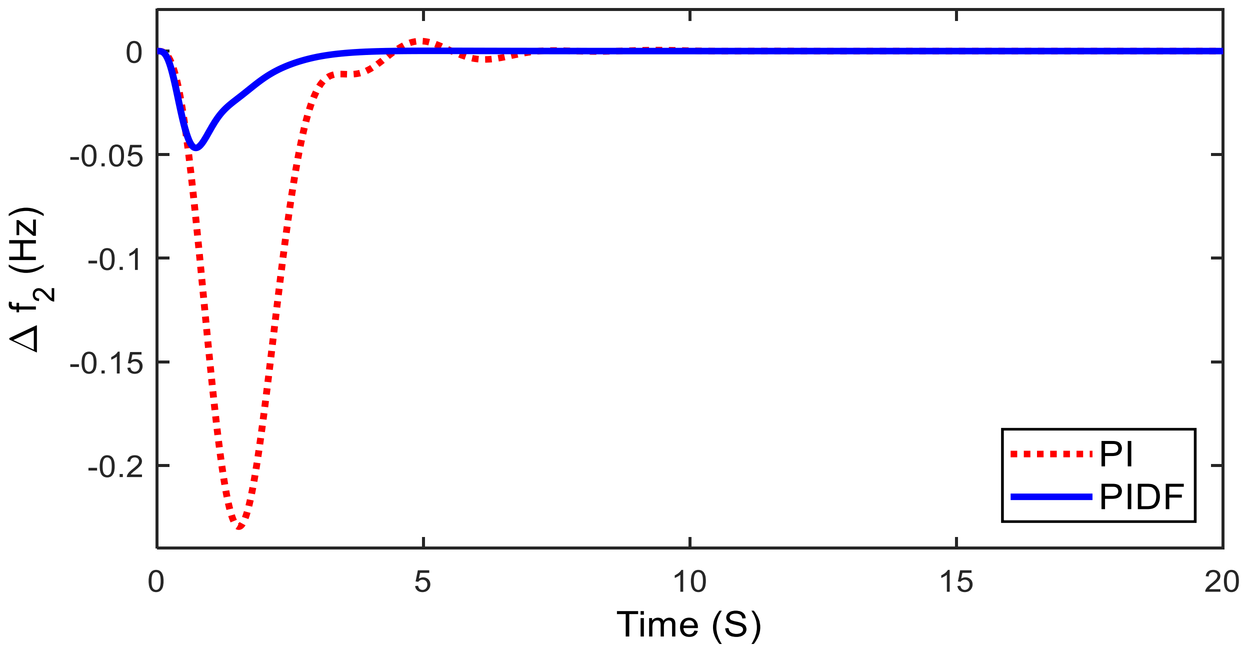

Fig.4. Frequecy changes of the area-2 due to disturbance in area-2 as per case-1

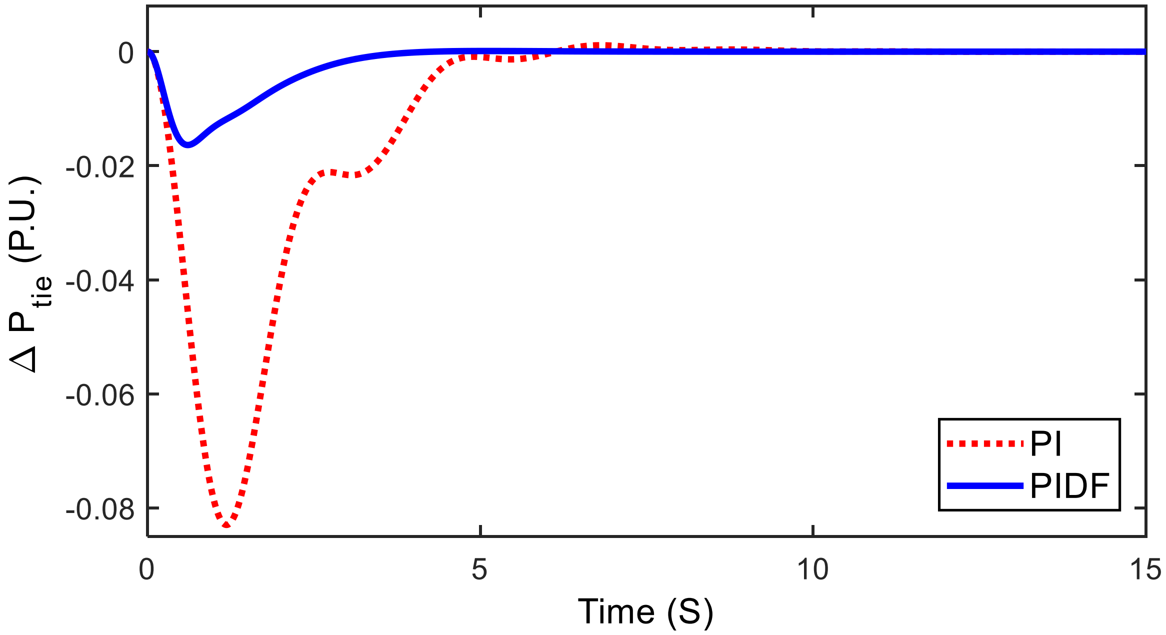

Fig.5. Tie line power changes of the area-1 due to disturbance in area-1 as per case-1

Case-2: *Step increase in demand of the area-2*

In the case-2, the 10% of step increase in demand in the area-2 at time t=0sec applied at the same operating condition. It can be seen from figure-6-8 that in frequency deviation and tie line power performances of PIDF better trasient perforamnce as compared to PI controller of same power system.

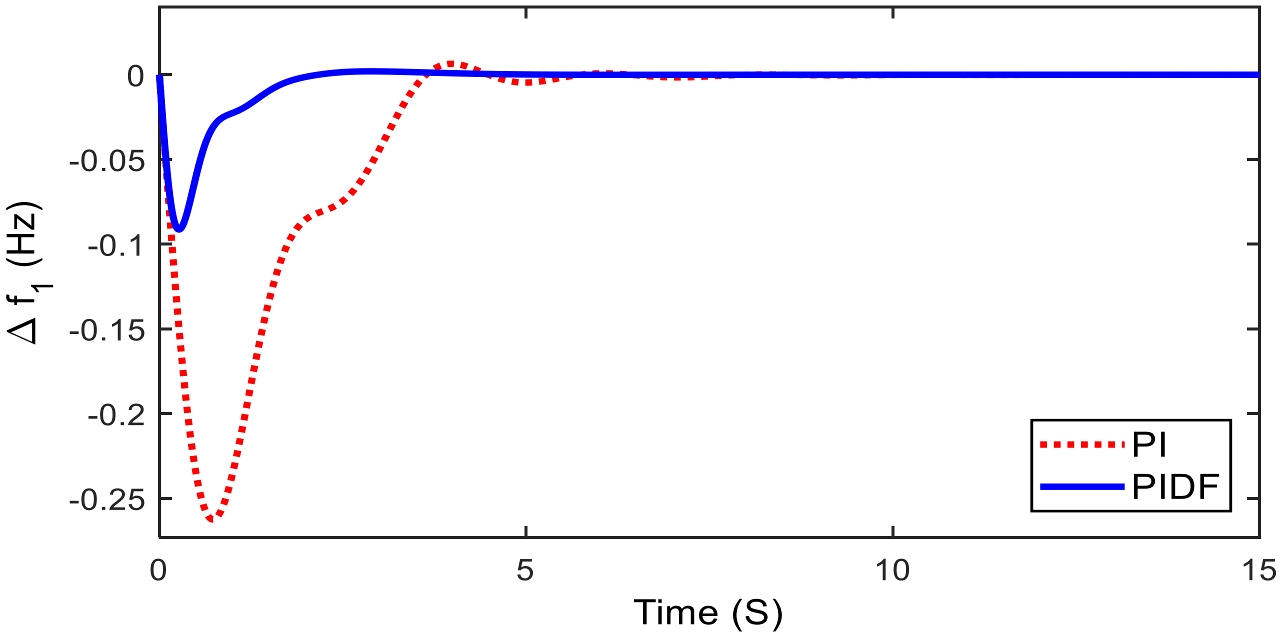

Fig.6. Frequecy changes of the area-1 due to disturbance in area-1 as per case-2

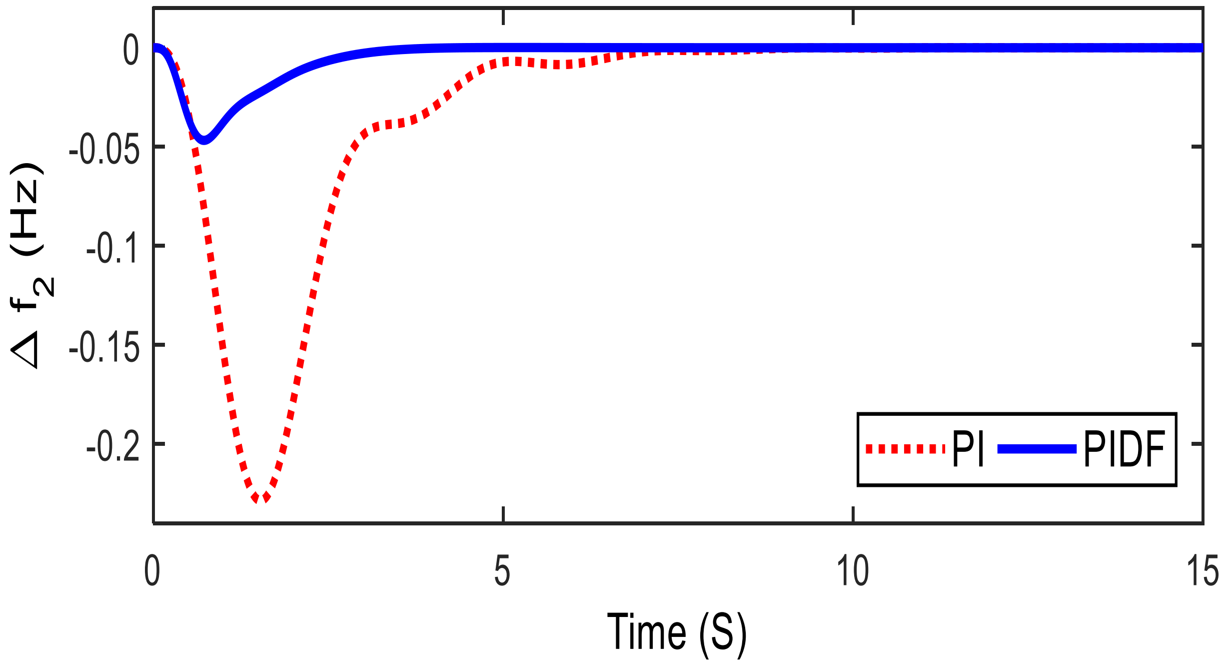

Fig.7. Frequecy changes of the area-2 due to disturbance in area-1 as per case-2

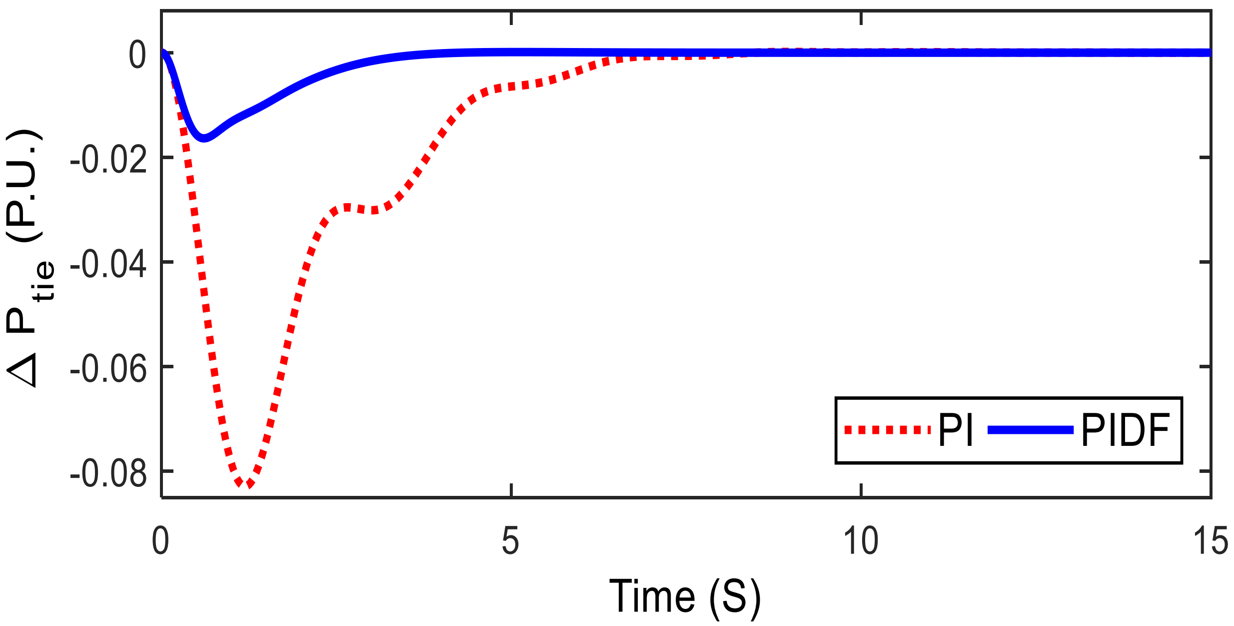

Fig.8. Tie line power changes of the area-2 due to disturbance in area-2 as per case-2

Case-3 :Step increase in demand of the area-1 and area-2 simultaneously

Similarly in case-3, for the effectiveness of the proposed system the step increase in demand is considered both the area-1 and area-2 simultaneously. The frequency deviation (Δf1) in area-1, frequency deviation (Δf2) in area-2 in the closed loop system are shown in Figs.-8.It is clear from figs 2-8 the oscillation of the system is very poor with PI controller. However PIDF controller gives much better response than PI controller of the same system as system response quickly reaches steady state.

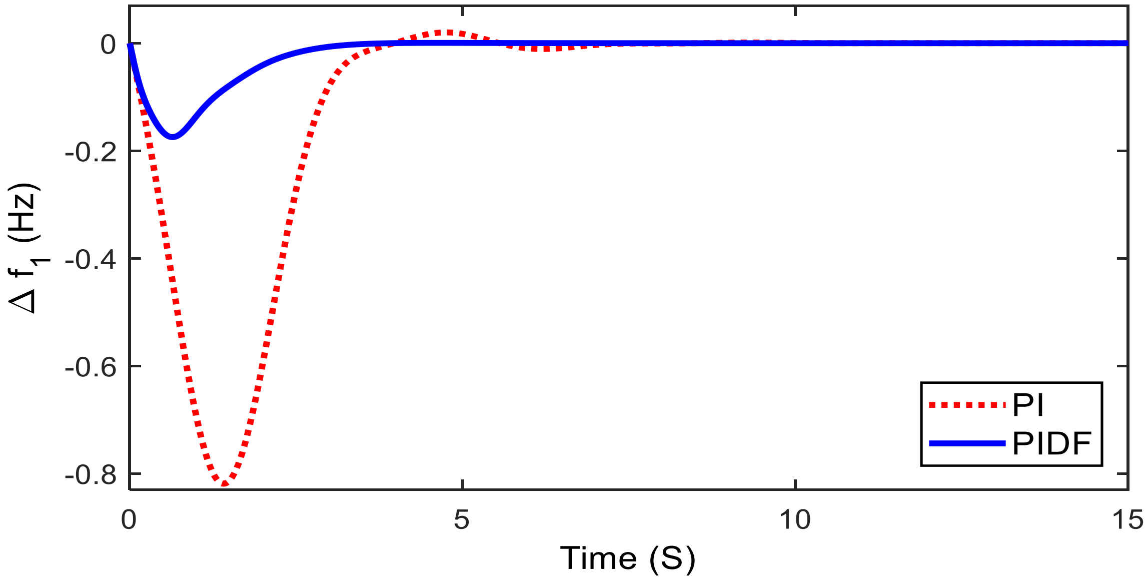

Fig.9.Frequency changes of area-1 due to disturbance in area-1 and area-2

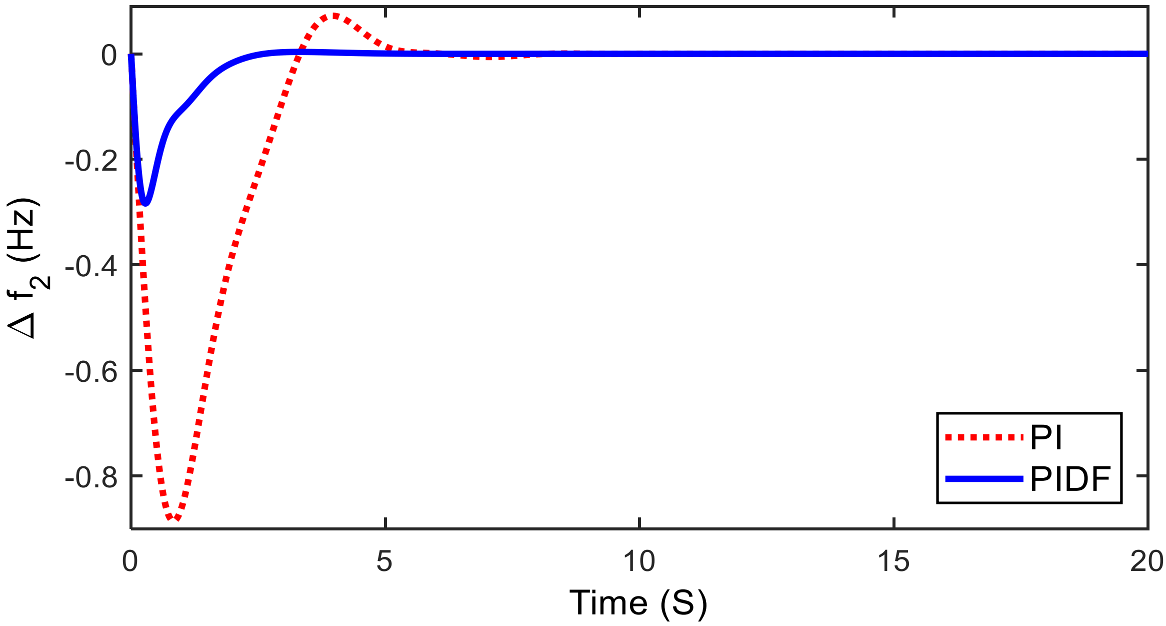

Fig.10. Frequency changes of the area-2 due to disturbance in area-1 and area-2.

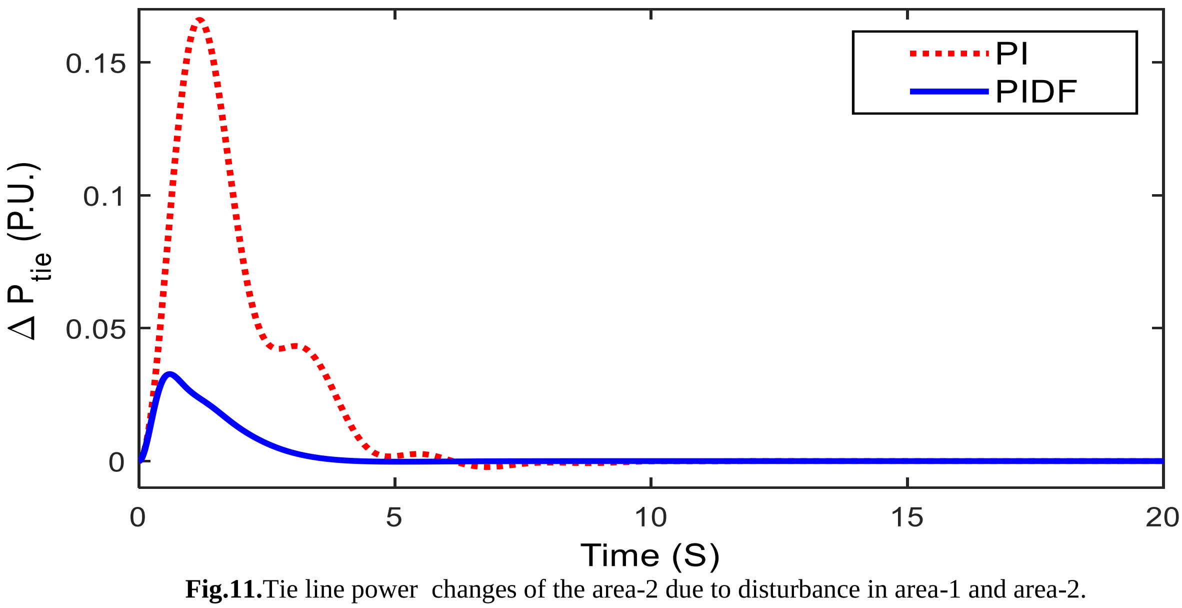

Fig.11. Tie line power changes of the area-2 due to disturbance in area-1 and area-2.

5 Conclusıon

This study presents the Diffrential Evolution Algorithm) based Proportional-Integral-Derivative controller with deravtive filter(PIDF) by using the Automatic Generation Control (AGC) of the interconnected two reheat thermal power system. The PID controller parameters are obtained by using the objective function ITAE of frequency deviation and tie line power in the both the area are taken in the purpose system. The tuning controller parameters give reduction of overshoot and converging to steady state without much oscillation and very less settling time. This study shows that tuning of PIDF controller gives better performance as compared with PI controller.

Appendix

Nominal parameters of the system investigated are: P_R = 2000 MW (rating), P_L = 1000 MW (nominal loading); f = 60 Hz, B_1, B_2 = 0.045 p.u. MW/Hz; $R_1 = R_2$ = 2.4 Hz/p.u.; T_{G1} = T_{G2} =0.08 s; $T_{T1} = T_{T2}$ = 0.3 s; $K_{PS1} = K_{PS2}$ =120 Hz/p.u. MW; T_{PS1} = T_{PS2} = 20 s; T_{12} =0.545 pu; a_{12} = -1, $K_{r1} = K_{r2}$ =0.5, $T_{r1} = T_{r2}$ = 10.

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