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Research Article

Modelling of Differential Evolution Based Automatic Generation Control for Two Area Interconnected Power Systems

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Abstract. This study demonstrates *Automatic Generation Control* (AGC) of Differential Evolution(DE) tuned two degree of freedom of proportional integral derivative (2DOF-PID) controller of a 2 area interrelated power structure. The 2 area based non reheat thermal power plant model is considered for the study and performance is compared with proposed controller over traditional controller configuration. The designed controller parameters are tuned through DE optimization algorithm in which objective function is formulated with help of ITAE function. Finally diverse loading condition (1%, 5% and 10% SLP) is applied in both areas to analyses the robustness of the proposed controller. The performance signifies the improved response with use of proposed controller over other controller.

Keywords. Automatic generation control; Differential evolution; Two degree of freedom controller; Integral of time multiplied absolute error

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1. Introduction

For a reliable power system, the frequency deviation and exchange power among the multiple control areas called tie line power should be under permissible limit. Generally, several control areas interrelated through tie line to form a complex interconnected power system [2]. AGC is included in each of the control area to regulate and monitor the frequency and exchanged power between the diverse control loops. It also simultaneously computes the total generation required so as to meet the load demand and normally called as area control error (ACE). So that generators are scheduled economically in beforehand keeping the view of expected demand. Hence ACE is the sum of frequency variation of each area and net change in power in tie line which is normally opted from the output of each area through controlled regulator. As the AGC keep on reducing the ACE to zero, the frequency deviation and tie line power also becomes zero that is the primary objective of AGC [6]. Moreover, AGC can be defined as a supervisory control over all the control area with expectation of power generation equals to power demand at any instance of time. As the magnitude and growth of the power sector increases with expected demand of electricity, it is suggested by many literatures to adopt intelligent system with support of advance optimization technique and from various real time robust power sources used in power sector. Researchers across the globe trying to study various techniques and strategies to control the AGC so that the frequency deviation and tie line power is restricted even in small load perturbation. The literature survey present in [8], where author provides detailed information related to schemes, AGC control strategy with flexible ac transmission equipment, energy storage devices and various distributed generations system like wind power plant and solar photo voltaic power plant through MPPT control mechanism. However, literature survey also suggests that, there are lots of research works on improvement of AGC by using modern control approach, artificial neural network, fuzzy controller and reinforcement learning etc. The objectives of AGC are:

- With load disturbances, the frequency deviation should be with in prescribed limit and it comes back to steady state within specific time interval.
- The area control error (ACE) should be as low as possible.
- Each control area should be stable such that it can withstand the load disturbances.
- Each area must meet its load demand apart from the load sharing as per the area participation contract.

It may be suggested from literature that there are lots of opportunity present in the field of controller optimization which not only enhance the system response but also system stability. For doing this, new type of evolutionary optimization can be developed and used [1]. Although fuzzy and artificial neural network are used extensively in AGC study but it has some disadvantages such as need of expert system during the formal design and proposed stage and uncertainty of its mathematical rigors [9, 13]. That's why; the modification or change in that type of design cannot be done by the person who has no knowledge of such systems. In contrast, heuristic optimization techniques are followed a basic well established model based on deep knowledge of system definition which will find its importance in power system optimization problem. Examples of such methods are particle swam optimization, differential evolutionary algorithm, bacteria foraging methods and others [11, 15].

Differential evolutionary algorithm was suggested by Rainer Stron and Kennath Price in 1995 is a simple yet influential optimization technique and is a part of evolution algorithm. Its profound importance can be found in diverse research area like designing of filter, learning in neural structure and deciding the appropriate dimensions of aerodynamic shapes. The differentiation of DE over other technique is in mutation stage and recombination stage. To evaluate the population, DE uses guided difference of selection of vector where as other algorithm evaluate their population in accordance with random variation. Also, DE has inherent features of greedy selection process and minimum no of control quantity which can be optimized effectively. By observing such classic features of DE, a maiden attempt has been taken to tune the proposed controller parameters for frequency regulation of two area based power network by applying small load disturbances in single along with all area simultaneously.

The outline of this paper is as follows. Section 2 shows the definite representation of associated AGC system subjected to investigation. Section 3 describes the optimal controller design followed by brief discussion on DE optimization algorithm in Section 4. Detailed analysis regarding system behaviour with various loading condition is presented in Section 5 and concluding remarks of the proposed study is given in Section 6.

2. System Under Study

This section deals with mathematical modelling of dynamic AGC of a 2 area interrelated power network regulated by DE algorithm based 2DOF-PID controller. The inputs of each area are the load disturbances (ΔP_D), the input signal of controller (ACE) and tie line power (ΔP_{tie}). Similarly, the outputs of the plants are frequency deviation (ΔF) of that area and ACE. As both areas are equal, hence the input and output of both areas remain constant [11].

Hydraulic amplifier presents in speed governor mechanism helps the governor against the high pressure steam and the mathematical expression is given by:

$$\Delta P_G = \frac{1}{1+sT_G}.$$

The speed of non-reheat turbine is controlled by the governor steam control mechanism which ultimately runs the generator. The mathematical expression of non- reheat turbine is

$$\Delta P_T = \frac{1}{1+sT_t}.$$

The expression of transfer function of the power network is depicted as:

$$\Delta P_{p.s} = \frac{K_{p.s}}{1+sT_{p.s}}.$$

The mathematical expression of the tie-line power linking area-1 and area-2 is represented by:

$$\Delta P_{tie} = \frac{2\pi T_{12}}{s}(\Delta F_1 - \Delta F_2).$$

This paper followed Cohn control strategy otherwise named as Area Control Error represented by:

$$ACE = \Delta P_{tie12} + \beta\Delta f.$$

Two area non reheat thermal power plant is projected in this study for extensive analysis purpose. The system is a generalized structure of two area system taken for analysis and design of AGC problem which can be found in recent literatures [5]. The two area system is displayed in Figure 1 with detail mathematical notation. B_1 and B_2 are referred as frequency bias parameters. ACE_1 and ACE_2 are the area control error which fed into the controller and output is u_1 and u_2 which control the corresponding area. R_1 and R_2 are the speed governor droop characteristics which control the inlet valve of turbine for raising or lowering the power. Time constant of governor is referred as T_G and its output power is represented as ΔP_G. Similarly, turbine time constant is referred as T_T and output power is ΔP_T. ΔP_D and ΔP_{tie} are called as variation of load demand and incremental deviation of power in tie line. Power system gain value and time constant is depicted as K_{ps} and T_{ps}. Likewise, T_{12}, F_1 and F_2 are called as synchronizing time constant and frequency fluctuation in area-1 and 2. The detailed values of all these parameter are provided in appendix.

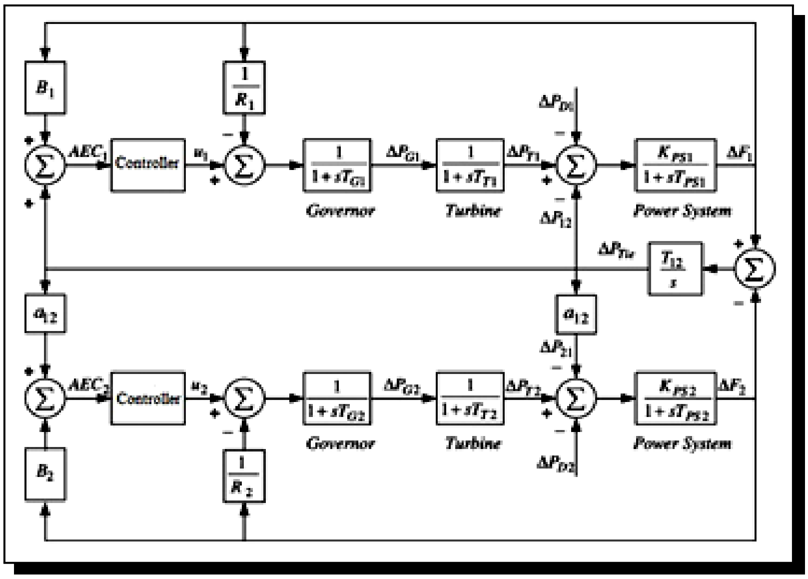

Figure 1. Block diagram of two area inter connected power system

3. Selection of Controller

The attractiveness towards the use of 2DOF-PID controller is increasing rapidly due to its advance control ability for better tracking of set point as well as good noise cancellation caused by disturbances [12]. Although, a simple PID controller is easy to optimize through diverse optimization methods but its control is not as good as like 2DOF-PID controller when subjected to change in load perturbation [4].

The output of the 2DOF controller solely depends upon the reference setting and the measured output signal of the plant. So this weighted difference signal follows the process of application of proportional, integral and derivative gain of the respective signal in step by step throughout the process [7]. This gives more flexibility to tune the controller effectively as it involves as usual three parameters (proportional, integral, derivative gain) with additional two weighted gain (α, β). So that even in dynamic load disturbances or complex plant arrangement, 2DOF-PID controller efficiently control and enhance the performance [10]. The most common form of representation of controller is $PI^{\alpha}D^{\beta}$, where P, I, D refers to proportional, integral and derivative gain respectively with two additional non integer parameters α and β. The transfer function of this controller is represented by:

$$TF_{2DOF\text{-}PID} = K_P + \frac{K_i}{s^{\alpha}} + K_d s^{\beta}.$$

General control orientation of 2DOF PID controller arrangement is presented in Figure 2, in which $Y(s)$, $R(s)$, $C(s)$, $D(s)$ represents feedback gain signal, reference signal and signal for conventional PID controller and disturbances signal, respectively.

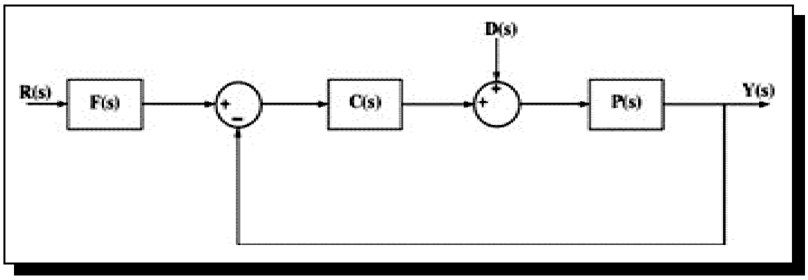

Figure 2. Block diagram of proposed controller

Integral time multiplied absolute error (ITAE) is selected as cost criteria as shown below in which ΔF_1, ΔF_2 are the variation in frequency in control area 1 and 2 respectively with incremental power variation in tie line ΔP_{tie} and maximum and minimum value of gain parameters are the constraints.

$$ITAE = \int_0^t t \times (\Delta f_1 + \Delta f_2 + \Delta P_{tie})dt.$$

4. Optimization Technique

Differential evolutionary algorithm is similar to population based algorithm that follows the similar stages: crossover, mutation and selection [14]. The key contrast found in DE algorithm is that, it adopts mutation whereas other algorithms such as genetic algorithm rely on crossover process for providing better solution. In the process of optimization, DE passes through non uniform cross over stage where vector parameter of child from parent can be taken more than once. By using the generated population size for formulating the trial vector, the crossover operators effectively adjust the data about the successful combination, providing the road map for optimum solution region for effective selection [3]. An optimization problem of N parameter is called as N-dimensional vector. In the initialization process of DE algorithm, the numbers of population are randomly generated at beginning. By applying the crossover, mutation and selection process in step by step, the population is enhanced to its highest successful level. The stages that are used to formulate DE is prescribed as:

- Initialization
- Computation
- Repeat the following steps: Mutation, recombination, evaluation and selection.
- End, if termination principles is followed

A. Mutation

Generally for a target vector $X_{P,T}$, a mutant vector generated by the following equation

$$V_{P,T+1} = X_{P,T} + K(X_{a1,T} - X_{P,T}) + F(X_{a2,T} - X_{a3,T}).$$

In which P, $a1$, $a2$, $a3$ are the random distinct number in the range $1,2,\dots,NP$.
F and K termed as scaling factor and combination factor that affects the difference vector.

B. Crossover

In this stage, parent vector clubbed with mutant vector to form the trial vector C_{qp}, $T+1$.

$$C_{qp,T+1} = \begin{cases} V_{qp,T+1} & \text{if } (rnd_q \le CR) \text{ or } q = ct_i \\ W_{qp,T} & \text{if } (rnd_q > CR) \text{ and } q \ne ct_i\,, \end{cases}$$

where $q = 1,2,\dots,N$ and CR is crossover constant between 0 and 1 and ct_i is randomly chosen constant between $1,2,\dots,N$.

C. Selection

In this stage fitness is evaluated on the population regardless of the type, i.e., parent or child, as all the population will get the chance to participate in mutation and crossover process. The best fitness function of corresponding vector is retained for next stage and other are discarded. The flow chart of this technique is presented in Figure 3.

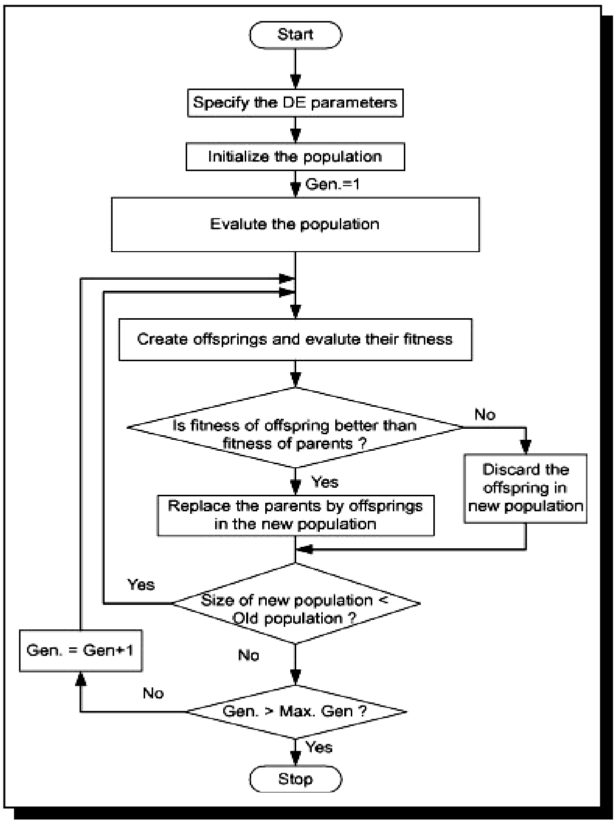

Figure 3. Steps of DE algorithm

5. Result Analysis

The two area system has thermal plants in both the area. Here, 2DOF-PID controller is used and DE technique is engaged for tuning of the controller constraints. The range of controller parameters is: $-2 < K_P, K_i, K_D < 2$. The DE tuned parameters for controllers are specified in Table 1.

Table 1. DE optimized controller parameters

Controller	Parameter value				
	K_p	K_i	K_d	α	β
2DOF-PID	1.604	0.698	1.522	0.421	0.697
PID	1.552	0.857	1.651	-	-
PI	1.984	0.985	-	-	-

The system is verified by taking different cases as presented in below. The mathematical survey of the system performance such as overshoot (OS), undershoot (US) and settling time (Ts) is indicated in Table 2.

Table 2. System response parameters for various loading conditions

Case	Controller	Peak over/under Shoot ($\times 10^{-3}$)			Settling time (2%) (sec)		
		Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}
I	2DOF-PID	14.4	5.98	7.11	11.1	7.2	13.8
	PID	25.1	17.2	8.3	24.8	24.1	23.3
	PI	29.8	26.3	10.2	24.9	24.5	23.1
II	2DOF-PID	1.53	1.64	38	6.85	5.98	16.86
	PID	2.04	1.95	41.25	7.31	10.22	-
	PI	3.67	4.82	58.6	11.3	12.61	-
III	2DOF-PID	12.2	78.3	0.42	17.87	20.69	19.53
	PID	13.82	81.8	0.51	-	-	-
	PI	16.4	88.4	0.83	-	-	-

Case I: 1% loading in both area 1 and 2 as shown in Figure 4.

Case II: 5% loading in both area as shown in Figure 5.

Case III: 10% loading in both area as displayed in Figure 6.

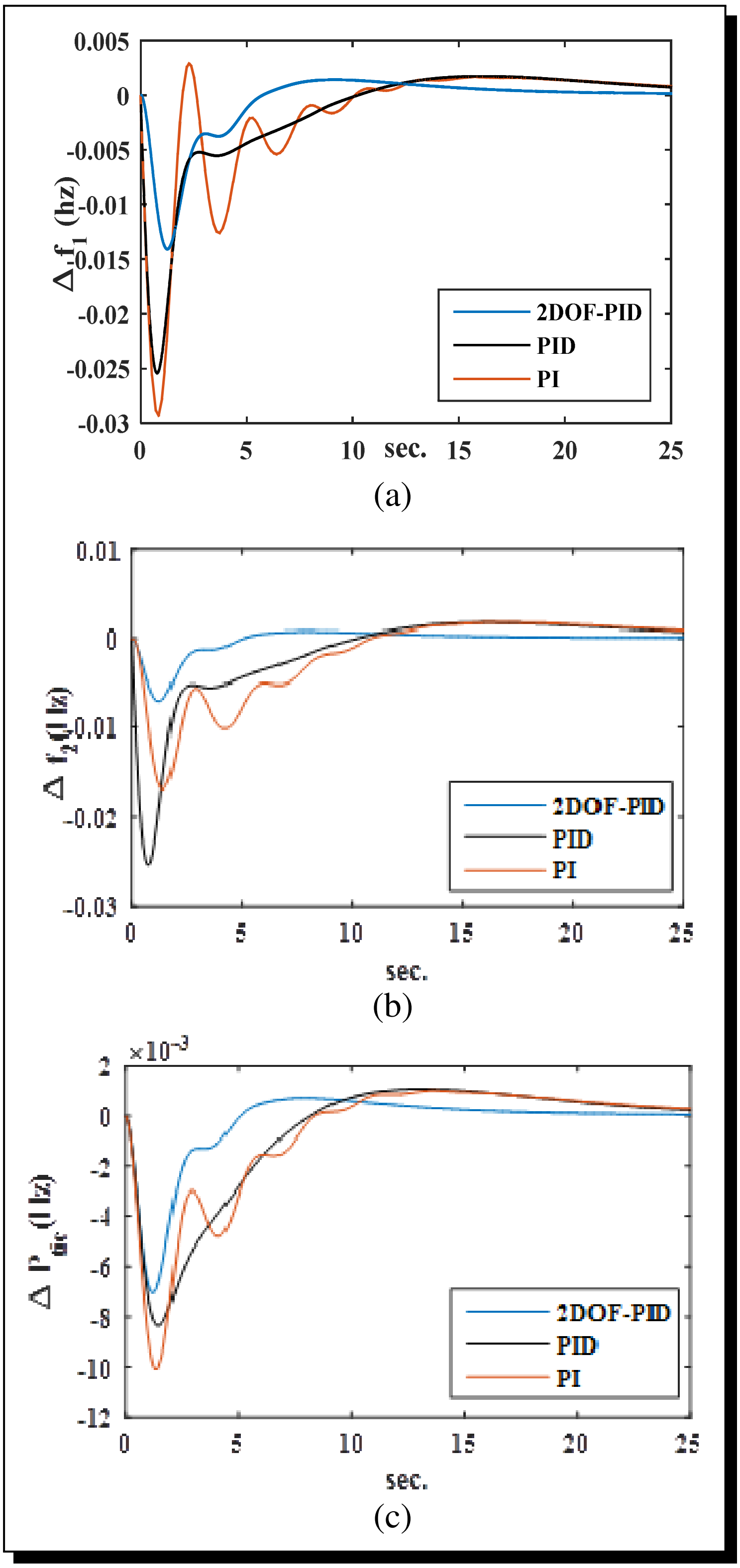

Figure 4. Response of (a) frequency deviation in area-1 (b) frequency deviation in area-2 (c) tie line power for SLP of 1% in both area

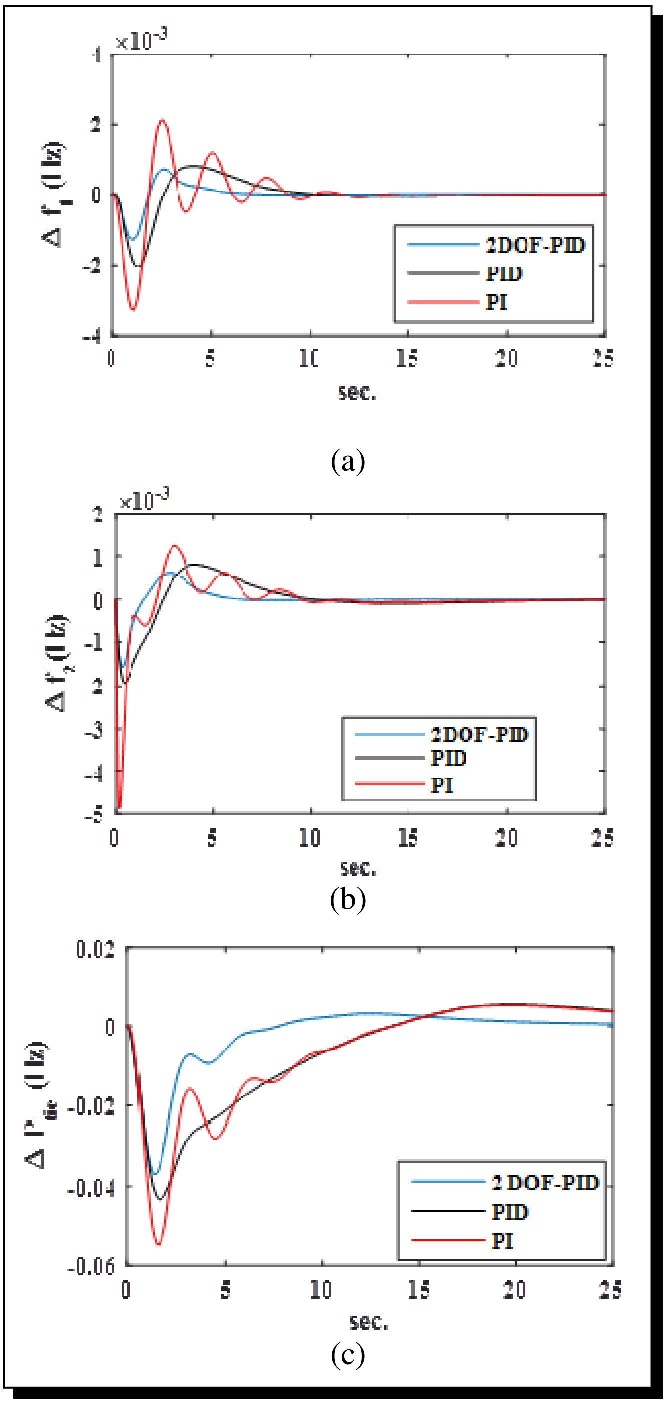

Figure 5. Response of (a) frequency deviation in area-1 (b) frequency deviation in area-2 (c) tie line power for SLP of 5% in both area

From the figure it can be explored that, the DE based proposed controller offer simproved response regarding settling time, peak overshot and undershoot are equated with normal PI controller and optimized PID controller. Moreover, the dynamic response is settled well before than the cut off limit. Also, it is evident that there is hardly any deviation in the performance of the suggested controller under the varying loading condition.

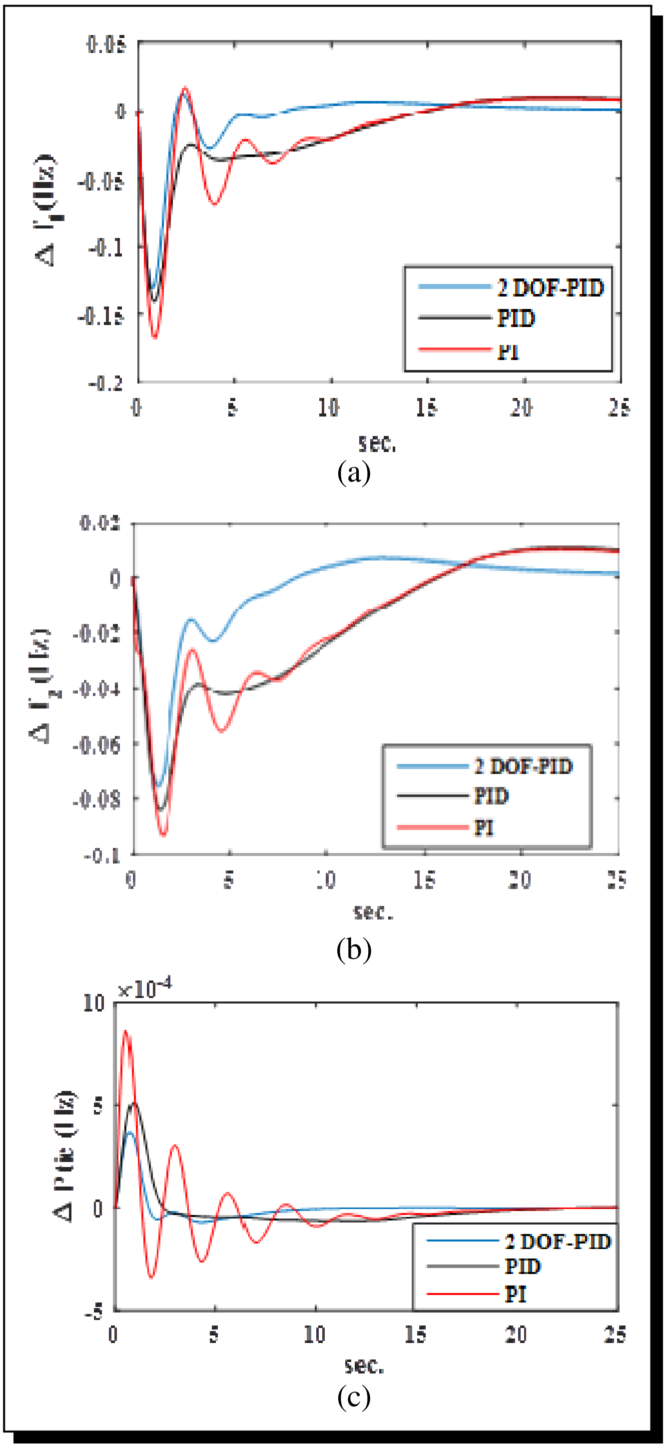

Figure 6. Response of (a) frequency deviation in area-1 (b) frequency deviation in area-2 (c) tie line power for SLP of 5% in both area

Under varying load condition, the robust controller often provides satisfactory performance. The response appears to be almost invariant to the diverse loading implementation. The deviation of frequency in both area and tie line is within the safe zone. The overshoot and undershoot imbalances are limited through the optimum controller.

6. Conclusion

The proposed study presents extensive analysis of 2 area interrelated power network controlled by DE based 2DOF-PID controller for frequency regulation in both area. For better analysis, ITAE is selected as cost function and through this controller parameters are optimized. The results obtained from the MAT LAB simulation software shows better dynamic performance of 2DOF-PID controller over PID controller and simple PI controller. The superiority of performance is achieved through application of DE algorithm. Moreover, robustness of the system is carried out through wide range of loading condition in which the presented controller scheme shows the enhanced performance.

Appendix

$P_R = 2000$ MW, $P_L = 1000$ MW; $F = 60$ Hz, B_1,$B_2 = 0.045$ p.u./Hz; $R_1 = R_2 = 2.4$ Hz/p.u.; $T_{G1} = T_{G2} = 0.08$ S; $T_{T1} = T_{T2} = 0.3$ S; $K_{PS1} = K_{PS2} = 120$; $T_{PS1} = T_{PS2} = 20$ S; $T_{12} = 0.545$ p.u.; $A_{12} = -1$.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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