BACTERIAL FORAGING OPTIMIZATION ALGORITHM BASED PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER FOR LOAD FREQUENCY CONTROL UNDER DEREGULATED ENVIRONMENT

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ABSTRACT

This paper deals, a Bacteria Foraging Optimization Algorithm (BFOA) based Proportional Integral Derivative (PID) controller for Automatic Generation Control (AGC) of multi source hybrid power system. A two area four unit reheat thermal power system under deregulated environment is considered with non linearities such as Time Delay (TD) and Generation Rate Constraint (GRC) for analysis purpose. Initially, PID controllers are placed as secondary controllers at each generating unit and the final values of PID controllers are obtained by optimizing with BFOA technique and using Integral Time multiplied Absolute Error (ITAE) criterion. Further, Redox Flow Battery (RFB) is inserted at area-1 to improve the dynamic performance of the system. From the simulation results it will be observed that, the performance of the system with RFB are better compared to without RFB.

Keywords: Automatic Generation Control, Bacteria Foraging Optimization Algorithm (BFOA); Deregulation; Proportional Integral Derivative controller (PID); Redox Flow Battery (RFB).

I. INTRODUCTION

Electrical Technology discovered by Faraday states that changing magnetic flux creates an electrical field which was the largest and most complex engineering achievement of man and the electric power system. While the basic features of the electrical power system have remained practically unchanged in the past century, there are some significant milestones in the evolution of electrical power system. In modern power system the main concern was about the control of power system even though there are some significant milestones in the evolution of the electric power which is due to demand increases day by day. The main objective of power system control is to maintain continuous supply of power with an acceptable quality, to all the consumers in the system. The system will be in equilibrium, when there is a balance between the power demand and the power generated. As AC form of power has real and reactive components: the balance of real power as well as the reactive power balance is to be achieved. There are two basic control mechanisms used to achieve reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). The former is called the automatic voltage regulator (AVR) and the latter is called the automatic load frequency control (ALFC) or automatic generation control (AGC) among which LFC is very important [1]. In an interconnected power system a sudden load change in any area causes the deviation of frequency of all the areas and also of the tie-line powers which has to be corrected to ensure generation and distribution of electric power with good quality and is achieved by load frequency control (LFC). The main objective of LFC is to maintain the steady frequency, control the tie-line flows, to control the frequency deviation by maintaining the real power balance in the system and distribute the load among the participating generating units [2-3].

Most of the previous work in the area of LFC pertains to an interconnected system and relatively lesser attention has been devoted to LFC of an interconnected multi-area multi source system. However few attempts have been made to propose the impacts of coordinated controllers Redox flow batteries (RFB) and superconducting magnetic energy storage (SMES) on load frequency control problem. Also little work has been done by considering the physical constraints such as time delay reheat turbine, Generation Rate Constraint (GRC) and Governor Dead Band (GDB) nonlinearity. Some authors have proposed the two-area thermal reheat power system taking into consideration bilateral contracts. The main goal of this paper is to investigate the load frequency control and inter-area tie-line power control problem for a two-area thermal reheat power system taking into consideration bilateral contracts and the non-linearities like TD and GRC. To make the change in frequency and change in tie-line power as steady i.e. zero in an interconnected power system very quickly, the conventional controllers may no longer be able to attenuate the large and sudden changes in frequency oscillations due to the slow response of the governor and Independent power producers (IPPs) that do not possess sufficient frequency control capabilities. The stabilization of frequency oscillations becomes challenging and highly expected in the future competitive environment [4-8].

II. CONTROL DESIGN OF TWO AREA REHEAT THERMAL POWER SYSTEM

The electric power system has over the years been dominated by large utilities that had an overall activities in generation, transmission and distribution of power, its domain of operation is known as "Vertically Integrated Utility (VIU). With emerge of deregulation environment the electric power industry is changing from a structure of regulated local vertically integrated organizations to one which competitive companies or Independent Power Producers (IPPs) generates electricity while the utilities maintain transmission and distribution networks. Thus, in deregulated environment generation, transmission and distribution is treated as individual sections. As there are several GENCOs and DISCOs in the deregulated environment, there can be various contracts between GENCOs and DISCOs. If DISCOs having contract with GENCOs of the same control area then it is known as "Pool based transaction. If DISCOs having contact with GENCOs of the another area then it is known as "Bilateral based transaction. If DISCOs violate the contact by demanding more than specified in the contract then it is known as "Contract violation based transaction". To know the contracts between GENCOs and DISCOs the concept of DISCO participation matrix (DPM) is introduced [4-8]. DPM is a matrix having no. of

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rows as no. of GENCOs and no. of columns as no. of DISCOs. The elements of DPM are indicated with cpf_{ij} which corresponds to fraction of total load contracted by a DISCO towards a GENCO. The sum of all the entries in a column in DPM is unity i.e. $\sum_{i}^{n} cpf_{ij} = 1$. In this paper, each area has two GENCOs and two DISCOs. Consider that GENCO1, GENCO2, DISCO1, DISCO2 are in area1 and GENCO3, GENCO4, DISCO3, DISCO4 are in area2. Then the corresponding DPM is written as

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (1)$$

where $'cpf'$ represents "contract participation factor" i.e. p.u. MW load of a corresponding DISCO. $'cpf'$ is like a signal which carries information are to which GENCO has to follow a load demanded by which DISCO.

The scheduled steady state power flow on the tie-line is given as

$\Delta P_{tie1,2}^{scheduled} =$ (Demand of DISCOs in area 1 to GENCOs in area2) - (Demand of DISCOs in area 2 to GENCOs in area1) (2)

The actual tie-line power is given as

$$\Delta P_{tie1,2}^{actual} = \frac{2\pi T_{12}}{s}(\Delta f_1 - \Delta f_2) \quad (3)$$

At any time, the tie-line power error is given by

$$\Delta P_{tie1,2}^{error} = \Delta P_{tie1,2}^{actual} - \Delta P_{tie1,2}^{scheduled} \quad (4)$$

$\Delta P_{tie1,2}^{error}$ vanishes in the steady as the actual tie-line power flow reaches the scheduled power flow. This error signal is used to generate the respective Area control error (ACE) signals as in the traditional scenario.

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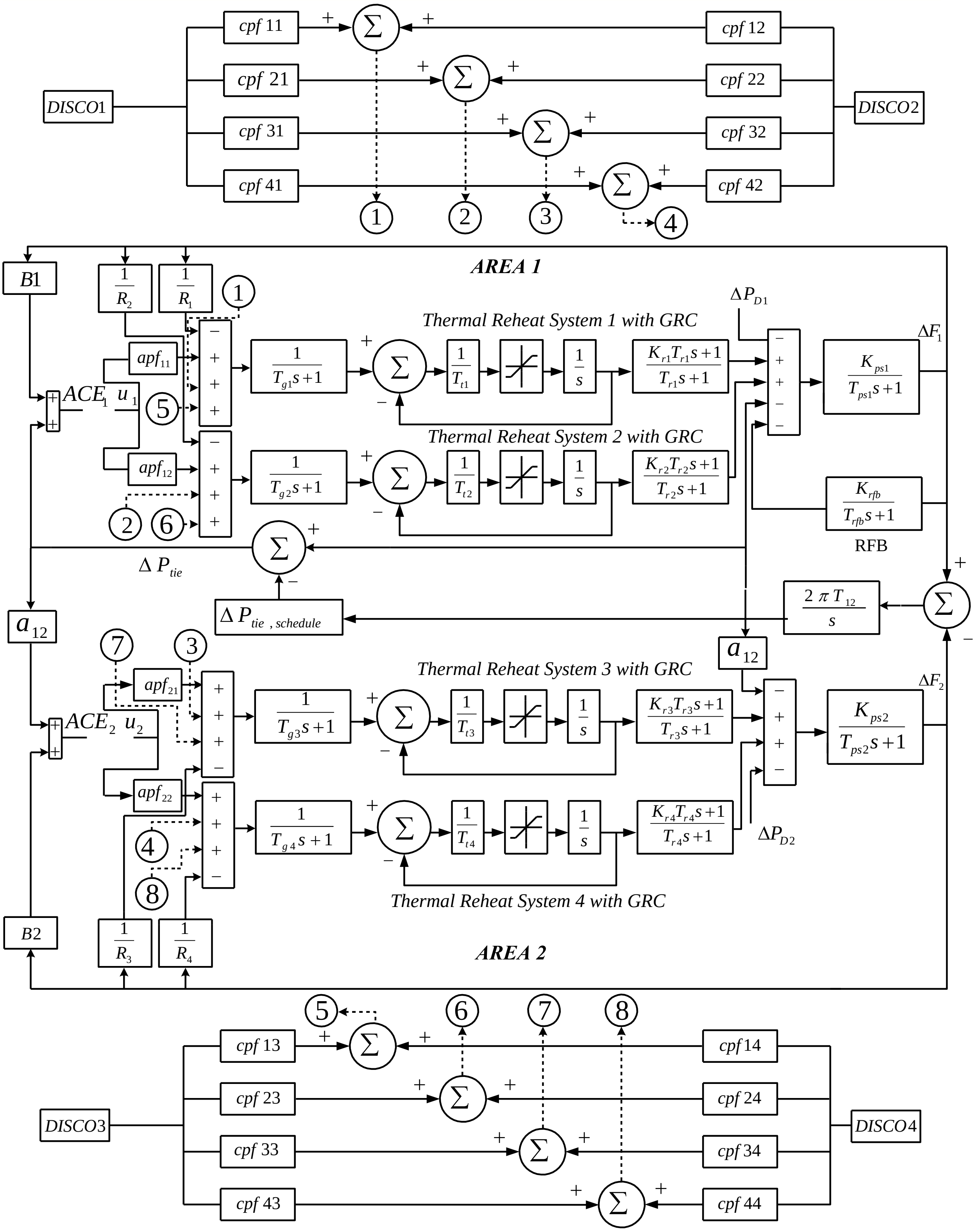

Fig. 1: Mathematical model of two area reheat thermal power system with RFB

$$ACE_1 = \beta_1 \ \Delta f_1 + \Delta P_{tie1,2}^{error}$$

(5)

$$ACE_2 = \beta_2 \Delta f_1 + a_{12} \Delta P_{tie2,1}^{error}$$

(6)

As there are two GENCOs in each area, ACE signal has to be distributed among them in proportion to their participation in the LFC. Coefficients that distribute ACE to GENCOs are termed as "ACE participation factors (apfs)". In a given control area, the sum of participation factors is equal to 1. Hence, apf_{11}, apf_{12} are considered as ACE participation factor in area 1. apf_{21}, apf_{22} are in area 2.

Generally, a large scale power system consists of a number of interconnected control areas, which are connected by the tie-line power. The modelling differential equations are given in eq.7 and eq.8. There are different complicated non-linear models for the large scale power systems. The block diagram of the two-area reheat thermal power system with IPFC and RFB is shown in the Fig. 1. In this block diagram, Time delay (TD) and Generation rate constraint (GRC) are considered. The model of GRC is shown in the Fig. 2. It can prevents the generation rate for the thermal plants [4]. The generate rate in the reheat turbine is considered as 3% i.e. limiters as $\pm$ 0.03. The time delay is considered as 5%. Redox flow battery (RFB) which behaves as a active source connected in area1 enhances the stability and its modelling equation is shown in eq.10.

$$\Delta f_1 = \frac{K_{P1}}{1 + sT_{P1}} \left[\Delta P_{g1} + \Delta P_{g2} - \Delta P_{RFB} - \Delta P_{IPFC} - \Delta P_{tie,12} - \Delta P_{d1} \right]$$

(7)

$$\Delta f_2 = \frac{K_{P2}}{1 + sT_{P2}} \left[\Delta P_{g3} + \Delta P_{g4} + \Delta P_{IPFC} - \Delta P_{tie,12} - \Delta P_{d2} \right]$$

(8)

$$\Delta P_{IPFC} = \frac{1}{1 + sT_{IPFC}} \left[k_1 \Delta f_1 + k_2 \Delta P_{tie1,2} \right]$$

(9)

$$\Delta P_{RFB} = \frac{K_{RFB}}{1 + sT_{RFB}} \left[\Delta f_1 \right]$$

(10)

III. CONTROLLER DESIGN AND OBJECTIVE FUNCTION

In process industries the proportional integral derivative (PID) controller is the most popular feedback controller. It is a robust, easily understood controller that can provide excellent control performance despite the varied dynamic characteristics of process plant. A proportional controller has the property of reducing the rise time, but never reduces the steady-state error. An integral controller has the property of reducing the steady-state error, but it may make the transient response poorer. A derivative control has the property of increasing the stability of the system, reducing the overshoot, and improving the transient response. Proportional integral (PI) controllers are the most often type used today in industry. A control without derivative (D) mode is used when

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fast response of the system is not required, large disturbances and noises are present during operation of the process and there are large time delays in the system. PID controllers are used when stability and fast response are required. Derivative mode improves stability of the system and enables increase in proportional gain and decrease in integral gain which in turn increases speed of the controller response. The design of PID controller requires determination of the three main parameters, Proportional gain constant (K_P), Integral time constant (K_I) and Derivative time constant (K_D) and its structure is shown in Fig. 2. The use of PID controller improves the stability of the system and helps to achieve better settling time compared to other controllers [9, 10]. The s-domain transfer function of PID is given by

$$TF_{PID} = K_P + \frac{K_I}{s} + K_D s \tag{11}$$

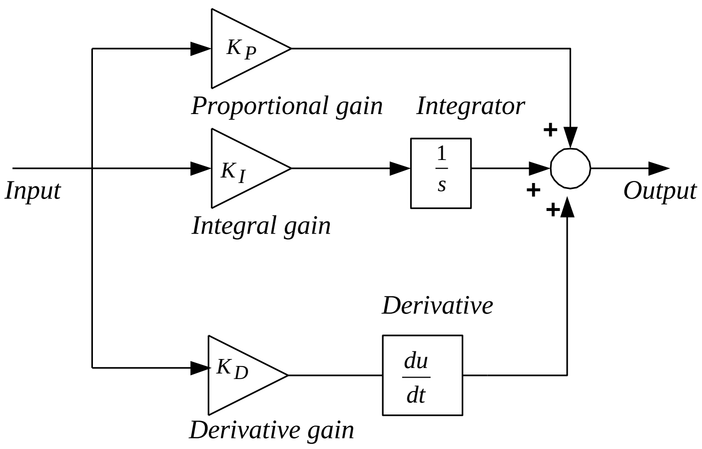

Fig. 2 Structure of PID controller

The error inputs to the controllers are the respective area control errors (ACE) given by:

$$e_1(t) = ACE_1 = B_1 \Delta F_1 + \Delta P_{Tie} \tag{12}$$

$$e_2(t) = ACE_2 = B_2 \Delta F_2 + a_{12} \Delta P_{Tie} \tag{13}$$

Proportional integral derivative controller use ACE1 as input in area 1 and ACE2 in area 2. The outputs of the PID controllers u_1 and u_2 are the control inputs of the two areas respectively. Initially, the objective function to be defined based on the desired constraints and specifications for the design of a modern heuristic optimization technique based controller. Performance criteria usually considered in the control design are the Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied Squared Error (ITSE) and Integral of Absolute Error (IAE). ITAE criterion reduces the settling time which cannot be achieved with IAE or ISE based tuning. ITAE criterion also reduces the peak overshoot. ITSE based tuning provides large controller output for a sudden change in set point which is not advantageous from controller design point of view. It has been reported that ITAE is a better objective function in LFC studies [11]. Therefore

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in this paper ITAE is used as objective function to optimize the proportional, integral and derivative gains of PID controller. Expression for the ITAE objective function is depicted in equation (14).

$$J = ITAE = \int_0^{t_{sim}} \left(|\Delta F_1| + |\Delta F_2| + |\Delta P_{Tie}| \right) \cdot t \cdot dt \quad (14)$$

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 PID controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem.

Minimize J (15)

Subject to $K_{P\min} \le K_P \le K_{P\max}$, $K_{I\min} \le K_I \le K_{I\max}$, $K_{D\min} \le K_D \le K_{D\max}$ (16)

The minimum and maximum gain values of controller parameters are chosen as -2 and 2 respectively.

IV. RESULT ANALYSIS

The block diagram of two-area reheat thermal power system with RFB shown in the Fig. 1, PID controllers considered for each area. The gains of PID controller are optimized by BFOA algorithm and technique of BFOA is explained clearly by the author in ref. [12] The range of gains of PID controller are taken as [-2, 2]. For the efficient performance of BFOA, these parameters should be selected carefully. In the present study, N= 10, N_C=3, N_S=5, N_{re}=10, N_{ed}=5, P_b=0.25, d_{at} =0.01, w_{at} =0.005, h_{re}=0.01, w_{re}=10 are chosen. Simulations were conducted on an Intel, Core i-5 CPU of 2.50GHz, 8GB, 64-bit processor computer in the MATLAB 9.1.0.441655 (R2016b) version. For system is simulated for two cases i.e. poolco based transaction and bilateral based transaction case and it is simulated for the following DPM values.

$$\therefore DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \text{ and}$$

$$DPM = \begin{bmatrix} 0.4 & 0.25 & 0.75 & 0.3 \\ 0.3 & 0.2 & 0 & 0.25 \\ 0.2 & 0.2 & 0.25 & 0.25 \\ 0.1 & 0.35 & 0 & 0.2 \end{bmatrix}$$

Table 1: Optimal controller parameters under different cases

Controller Parameters		**Poolco based transaction**		**Bilateral based transaction**	
		PID controller	**PID controller with RFB**	**PID controller**	**PID controller with RFB**
ITAE		**0.1295**	**0.1107**	**2.2368**	**1.6143**
Area 1	K_{P1}	0.3297	1.0719	-1.9760	-1.6556
	K_{I1}	-1.6317	-1.8268	-1.0010	-1.4880

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	K_{D1}	-0.0354	0.8733	-1.5502	-1.1117
Area 2	K_{P2}	-0.3160	-1.1726	-1.6497	0.0934
	K_{I2}	-1.9039	-1.3857	-0.9535	-1.8078
	K_{D2}	-0.8869	-1.4854	-0.0209	-1.1409

Initially, a step load disturbance of 1% is considered in the poolco based transaction and 0.5% of step load disturbance is considered in DISCO1 and DISCO2. PID controllers are placed in each area as a secondary controller and optimized by using BFOA technique with above mentioned parameters. The optimal controller parameters are shown in Table 1. After that, RFB is placed in area-1 for fast and improved dynamic responses of the system. The corresponding dynamic responses under poolco based transaction are shown in Figs. 3-5. Similarly, bilateral transaction case studied by considered 0.5% load disturbance in all the DISCOs and as result there will be 1% load disturbance in both the areas. The corresponding dynamic responses under bilateral based transaction are shown in Figs. 6-8.

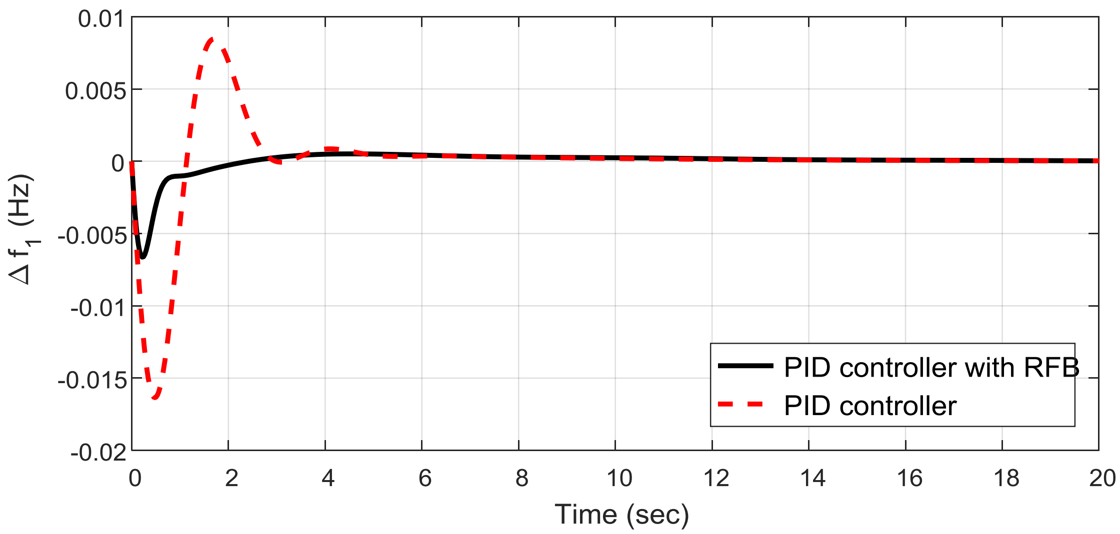

Fig. 3. Frequency deviation in area 1 under poolco based transaction

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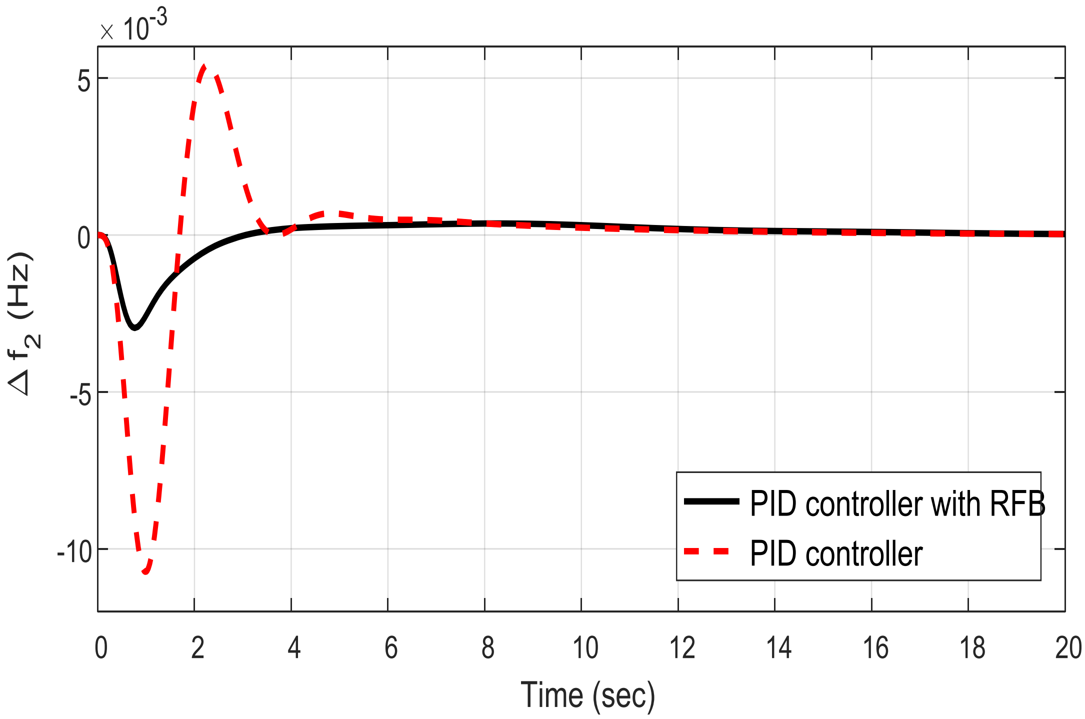

Fig. 4. Frequency deviation in area 2 under poolco based transaction

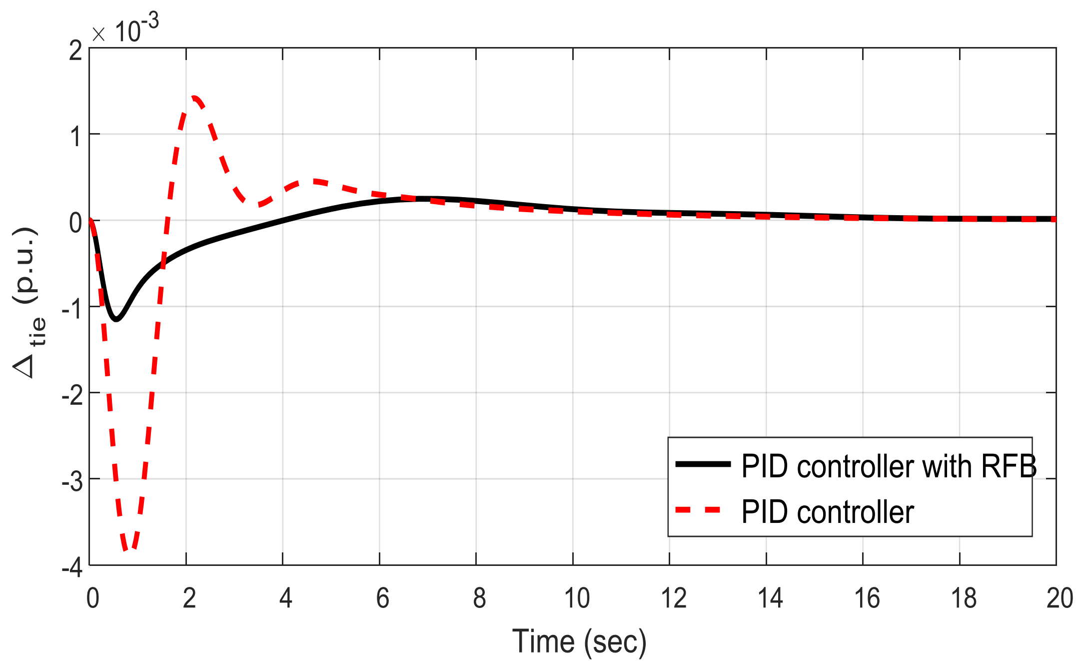

Fig. 5. Tie-line power deviation under poolco based transaction

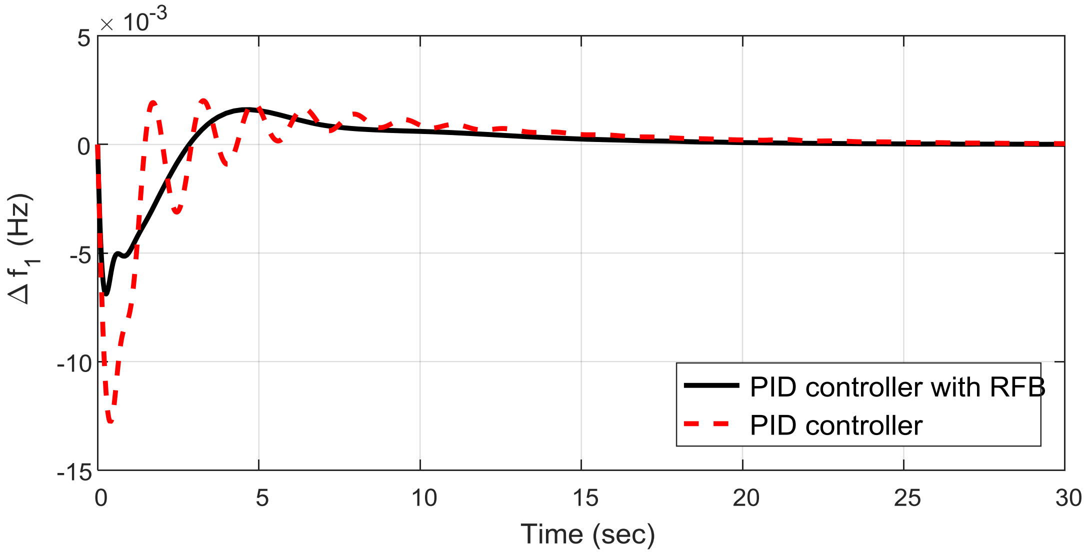

Fig. 6. Frequency deviation in area 1 under bilateral based transaction

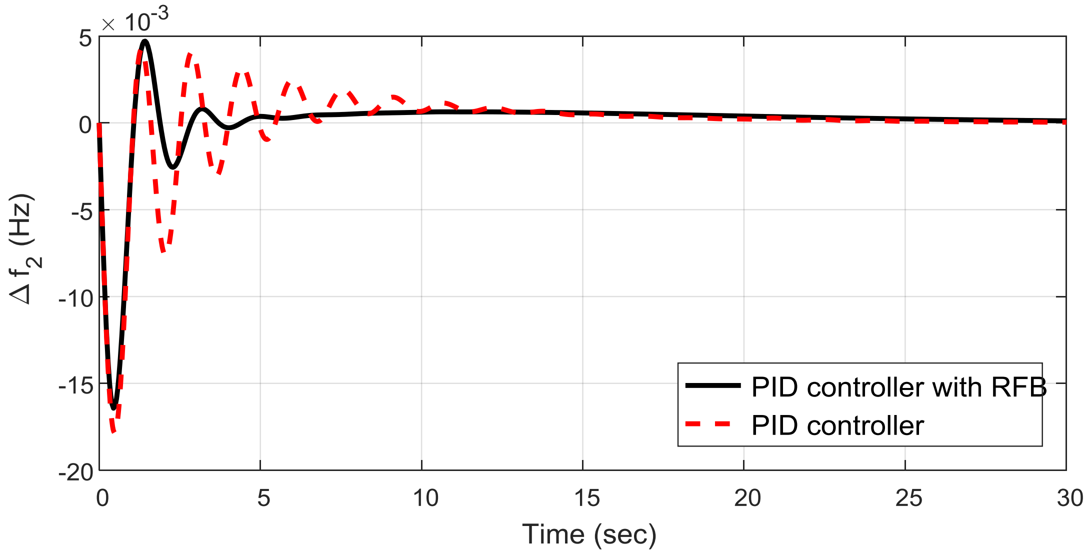

Fig. 7. Frequency deviation in area 2 under bilateral based transaction

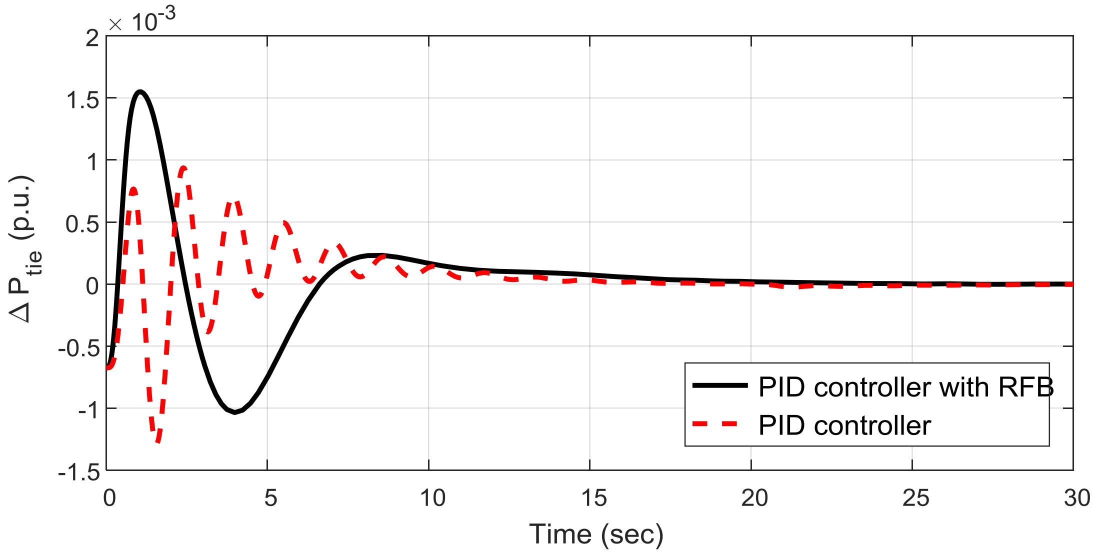

Fig. 8. Tie-line power deviation under bilateral based transaction

V. CONCLUSION

In this paper, BFOA technique is proposed to tune Proportional-Integral-Derivative controller (PID) for Automatic Generation Control (AGC) problem. A two area four unit reheat thermal power system under deregulated environment is considered to demonstrate the proposed method and the physical constraints such as, Time Delay (TD), Governor Dead Band (GDB) and Generation Rate Constraint (GRC) are considered to show the ability of the proposed approach to handle nonlinearity in the system model. Further, Redox Flow Battery (RFB) is placed in area-1 for better performance of the system. It is observed from the simulation results that, the transient response of the system with RFB is better in both the transaction cases.

APPENDIX

Data for Reheat-Thermal power system [4]

Rated frequency = 60Hz, Rating of each area = 2000 MW, Base power = 2000 MVA, $R_1 = R_2 = R_3 = R_4$ =2.4 Hz/p.u.MW, $B_1 = B_2$ = 0.425 p.u.MW/Hz, $T_{g1} = T_{g2} = T_{g3} = T_{g4}$ = 0.08sec, $T_{r1} = T_{r2} = T_{r3} = T_{r4}$ = 10sec, T_t = 0.3sec, $K_{p1} = K_{p2}$ = 120 Hz/p.u. MW, $T_{p1} = T_{p2}$ = 20sec, $K_{r1} = K_{r2} = K_{r3} = K_{r4}$ =0.5; a_{12} = -1, $2\pi T_{12}$ = 0.545 p.u.MW/Hz, K_{RFB}=0.6787

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