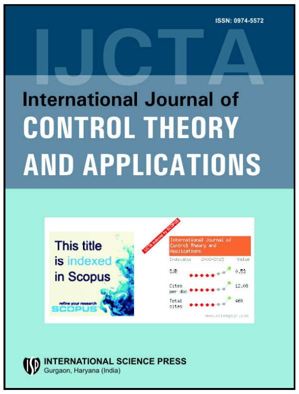


International Journal of Control Theory and Applications

ISSN : 0974-5572

© International Science Press

Volume 10 • Number 6 • 2017

H„ PID cum RFB Controller for Load Frequency Control of a Deregulated Power System considering the effect of nonlinearities

Arlene Davidson R.[1] and S. Ushakumari[2]

1 Department of Electrical Engineering College of Engineering Trivandrum, Thiruvananthapuram, Kerala, India,
Email: arlene@cet.ac.in
2 Department of Electrical Engineering College of Engineering Trivandrum, Thiruvananthapuram, Kerala, India,
Email: ushalal2002@gmail.com

Abstract: A deregulated power system is a complex nonlinear system characterized by bilateral transactions. Consideration of nonlinearities makes the development of controller for load frequency control in such systems difficult. Yet it is inevitable that nonlinearities are taken care of in the design of controller from a practical viewpoint. Robust H„controllers are said to be robust against parameter uncertainty and nonlinearities. Still they are insufficient in the face of uncertainties like generation rate constraint or governor deadband. But in conjunction with Redox Flow Batteries (RFB) in each area of a two area power system, the objectives of secondary control in Automatic Generation Controlare met. This idea is different from previous works in that a nonlinear system is usually handled by nonlinear controllers or PID controller tuning through optimization techniques only. This paper deals with the combined application of H„controller and RFB for a two area deregulated non-reheat thermal power system. Modelling of the hard nonlinearities is done using describing function method and a rate limiter has been includedin each area to prevent excessive control action.

Keywords: Nonlinearities, Deregulated, Robust, Load frequency control

1. INTRODUCTION

Interconnected power systems in general depend on primary control and secondary control for reducing frequency deviation and deviation in tie-line power exchange from their nominal values. Primary control is done with the help of governors and secondary control is usually done using integral controllers which help to bring the steady state error in frequency and tie-line power exchange to zero [1]. A deregulated power system is marked by a distributed control environment comprising of Generation Companies (GENCOs), Transmission Companies (TRANSCOs) and Distribution Companies (DISCOs) with an independent entity called as Independent Service Operator (ISO) to regulate and coordinate the overall operation. DISCOs contract with GENCOs in any control area for purchase of power [3]. This is referred to as 'bilateral transactions'. Several physical constraints are present in a deregulated power system. These include uncertainty of system parameters as well as nonlinearities. The nonlinearities include generation rate constraint and governor deadband. In view of these constraints, load frequency control (LFC) in power systemsbecomes challenging. Previous works in LFC of deregulated power systems with the consideration of nonlinearities are very less. Chandrasekhar et al have done LFC considering the nonlinearities using firefly algorithm optimization of fuzzy PID controller [6]. Other works done in LFC of deregulated power systems without consideration of nonlinearities are found in [3], [7-8]. The works are generally based on tuning of controller parameters using optimization techniques. Redox Flow Batteries (RFB) are known for their excellent performance in the areas of load levelling and short time overload output response. This paper deals with the application of robust PID controller and RFB for load frequency control of a two area deregulated power system consisting of non-reheat thermal turbines.

The rest of the paper is organized as follows. A brief description of the system is given in Section II. The design of robust controller and action of RFB is explained in section III. Simulation results are presented in section IV. Concluding remarks are given in section V.

2. SYSTEM DESCRIPTION

The basic block diagram of the system considered is given in Figure 1. It comprises of two GENCOs and two DISCOs in each control area. $GENCO_i$ in the figure refers to the combination of governor and turbine transfer functions for the ith GENCO. $DISCO_i$ refers to the load demand of the ith DISCO. All the GENCOs considered here are non-reheat thermal turbines.The mathematical equations for modelling of the systemare given in [11].

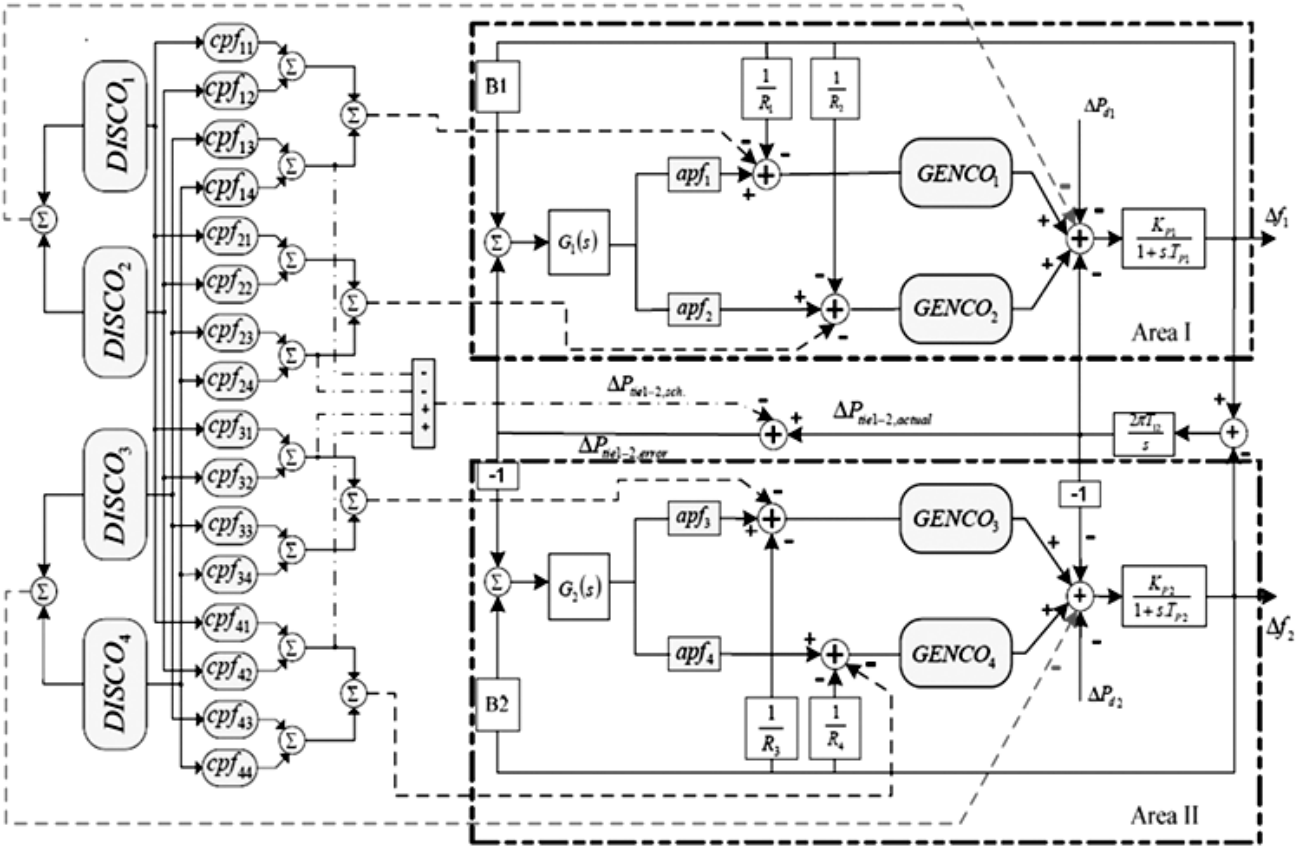


Figure 1: Block diagram model of a two area deregulated power system

$G_i(s)$ in Figure 1 shows the controller transfer function to be designed. Fig. 2 shows the model of a GENCO excluding nonlinearities.

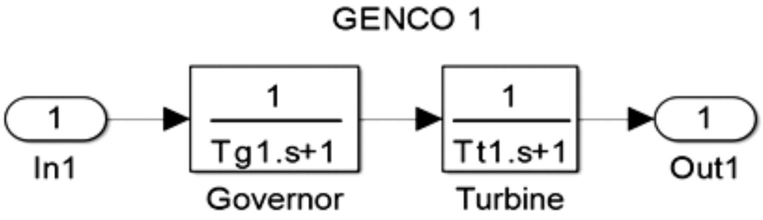


Figure 2: Model of a typical GENCO

2.1. Generation rate constraint (GRC)

Power generation in thermal and hydro plants takes place only at a specific rate due to thermodynamic and mechanical constraints. It is 10% per minute in the case of non-reheat thermal power plants. It is modelled as in Fig. 3. 'K' has the value '$1/T_t$' where T_t is the turbine time constant.

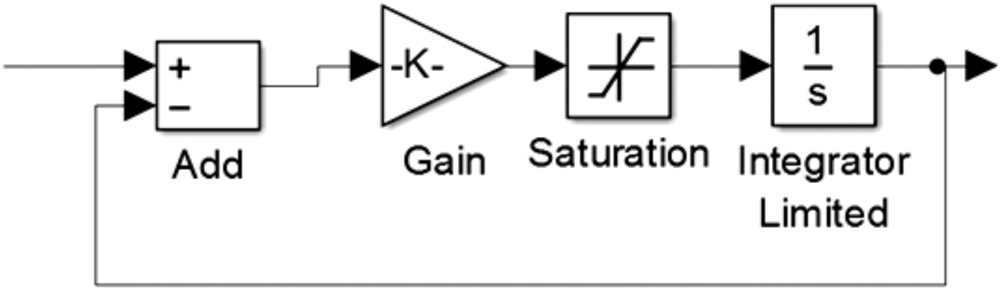


Figure 3: Modelling of Generation Rate Constraint

2.2. Governor Deadband

Test results from different types of governors show that inherent deadband is very small (<0.005 Hz) and could be neglected. But manufacturers intentionally create deadband in governors and is of the order of 0.05 Hz which may affect the performance of the system. Intentional deadband helps to reduce excessive controller action in the course of normal power system frequency variations. Due to governor deadband, there is a delay in the response of valves though a change in speed occurs. This nonlinearity may be defined as

$$y = q(x, \dot{x}) \tag{1}$$

where x stands for sinusoidal oscillation due to deadband and y can be written as a Fourier series given below.

$$y = y_0 + k_1 x + \frac{k_2}{2\pi f_0}\frac{dx}{dt} \tag{2}$$

where f_0 is the frequency of sustained oscillations due to deadband. y_0 is zero as the nonlinearity is symmetrical about the origin. Assuming a backlash of 0.5%, $k_1 = 0.8$ and $k_2 = -0.2$. Hence the transfer function of governor is obtained as $\dfrac{0.8-\left(\dfrac{0.2s}{\pi}\right)}{(1+s\ Tg\ 1)}$.

Appendix A gives the state space equations of the system considering the two nonlinearities.

2.3. Redox Flow Battery (RFB)

Redox Flow Batteries are electrochemical devices, which are primarily known for their excellent load levelling and fast response against frequency deviations. They effectively suppress the peak value of frequency deviations quickly against sudden load change, subsequently the input to the governor system is updated with the required input for the compensation of the steady state error of frequency deviations [10]. Fig. 4 shows the model of RFB.

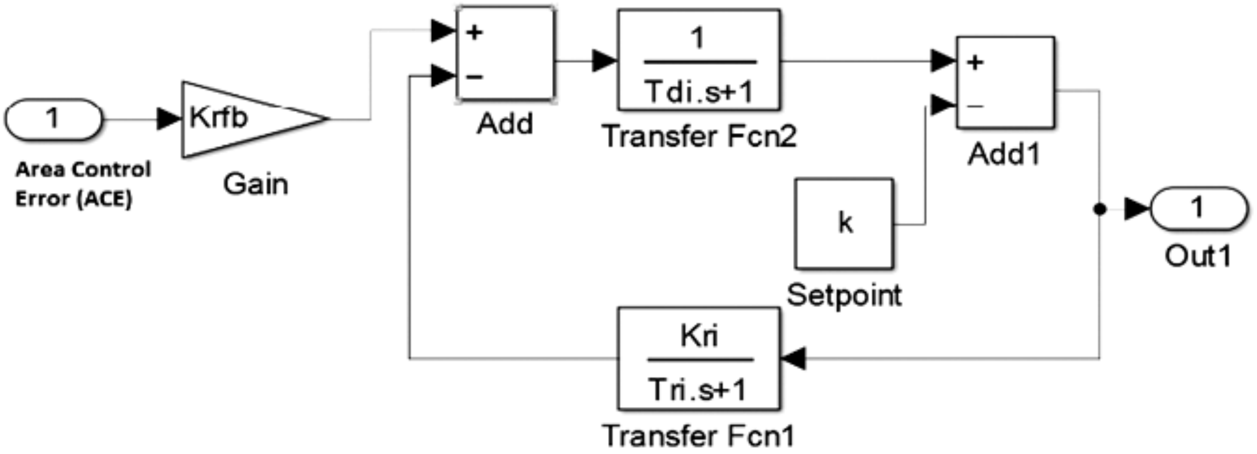


Figure 4: Modelling of Redox Flow Battery

$$ACE_i x K_{rfb} - \left(\frac{K_{ri}}{1+sT_{ri}}\right)\left(\frac{1}{1+sT_{di}}\right) - \text{SetValue} = \Delta \text{P}_{rfb} \tag{3}$$

Due to the delayed response of ACE (Area Control Error) as well as governor, oscillations occur during sudden load perturbations and RFB helps in quick supply of stored energy to the power system. So the RFBs play a great role in damping of oscillations during load perturbations.

2.4. Rate limiter

Rate limiter is perceived as a nonlinear filter and is included in the controller output so that the filtered output is fed to the plant. Here the rate limit is set at the value of the generation rate applicable to the GENCOs of that area. This ensures that the output of rate limiter follows the input if the rate of change of input is smaller than the rate limit of the GENCOs in that area. Thus a realistic picture of the system is obtained in the simulation as well.

3. CONTROLLER DESIGN

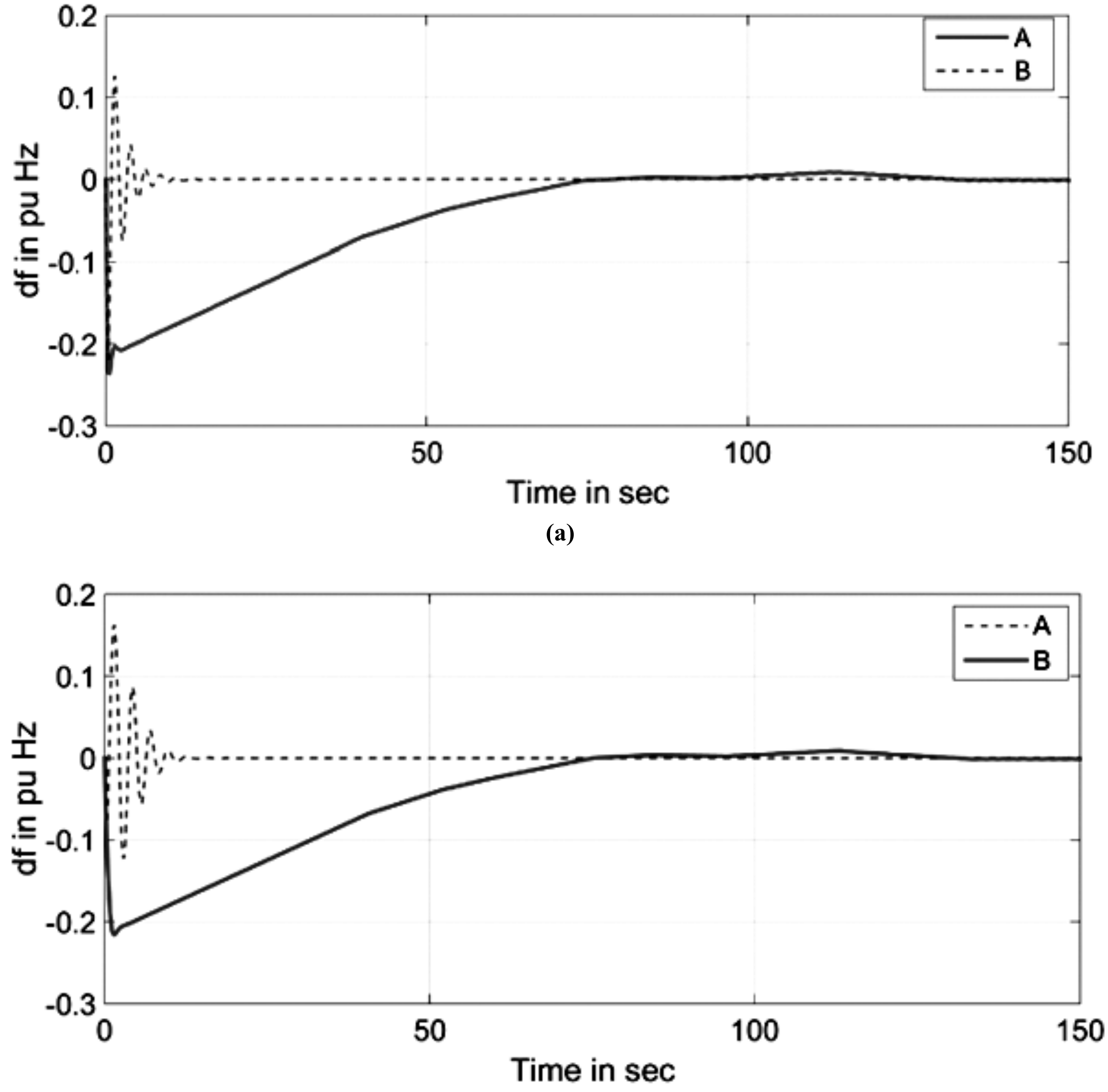
Robust controllers are said to be robust against parameter uncertainty and nonlinearities to some extent. Hence H„ PID controller was designed for the system model given in Appendix A. An elaborate description of this controller design may be found in [4]. In the tuning of controller parameters, a trade-off between good set point tracking and fast disturbance rejection occurs. For a fixed bandwidth, the loop gain within the bandwidth is to be large for faster disturbance rejection but this is achievable only by increasing the slope near crossover frequency. Since a larger slope signifies a smaller phase margin, this is achieved by tolerating more overshoot in the response to set point changes.

$$G_i(s) = K_p + \frac{K_i}{s} + \frac{sK_d}{1+sT_f} \tag{4}$$

The design is done using Robust Control Toolbox of Matlab [9]. But this controller alone was not sufficient to achieve the objectives of LFC viz., to bring the frequency deviation and change in tie-line power error to zero. Hence RFBs, one in each area is included, which are also capable of damping out oscillations.

4. SIMULATION RESULTS

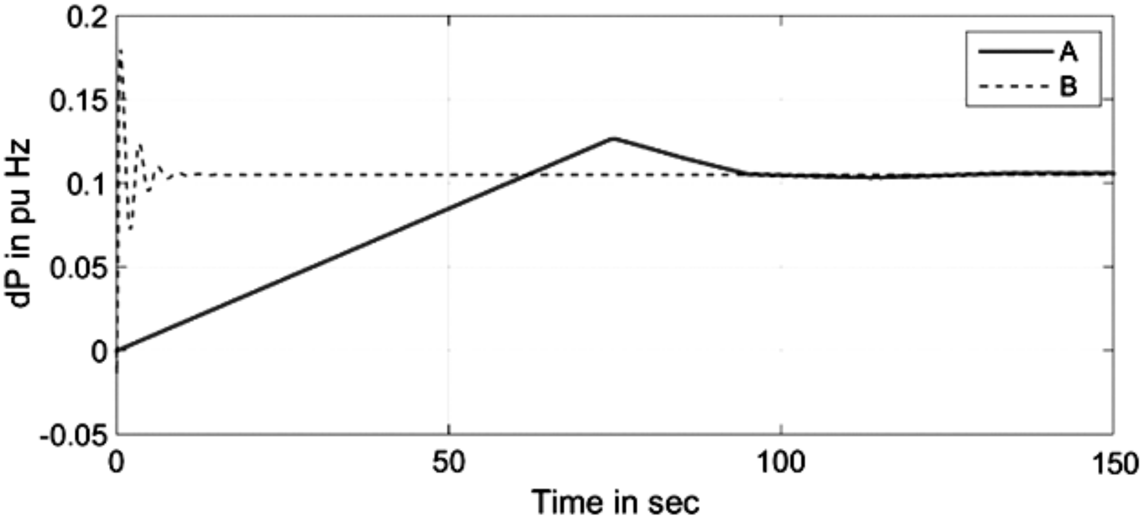
First, the H_∞ PID controller is designed for the system excluding nonlinearities ('A' in figures). The change in frequency deviation in each area and change in tie-line power error are analysed using the simulations done on Simulink in Matlab. These plots are then compared for the system including nonlinearities ('B' in figures) in which H_∞ PID controller in conjunction with RFB is used in each area. Fig. 5 (a) and 5(b) show the change in frequency deviation in Area 1and Area 2 respectively. Fig. 7 shows the change in tie-lie power error, which is the difference in change in scheduled tie-line power and the change in actual tie-line power. Fig. 6(a), 6(b), 6(c), 6(d) show the change in power generation of GENCO 1, GENCO 2, GENCO 3 and GENCO 4 respectively.



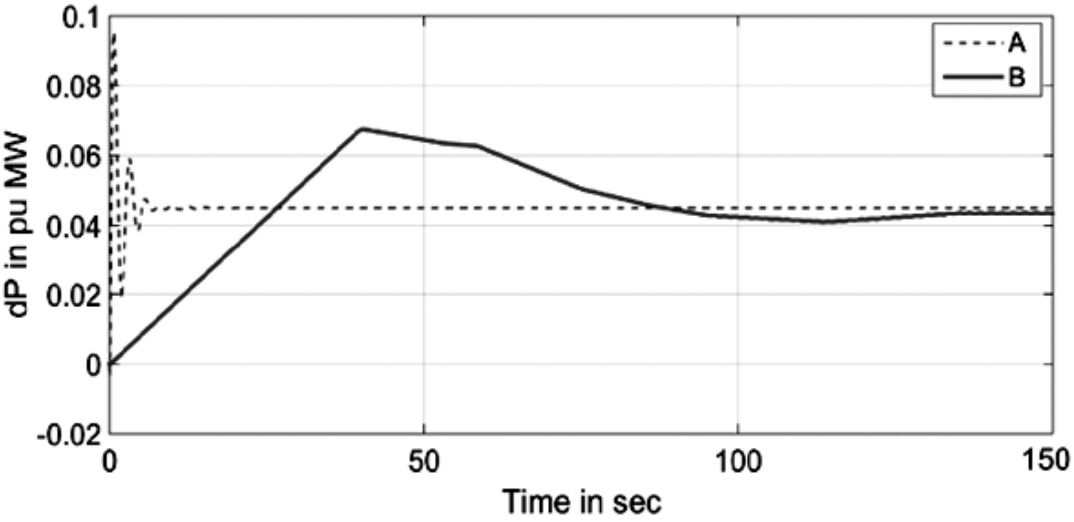
(a)

(b)

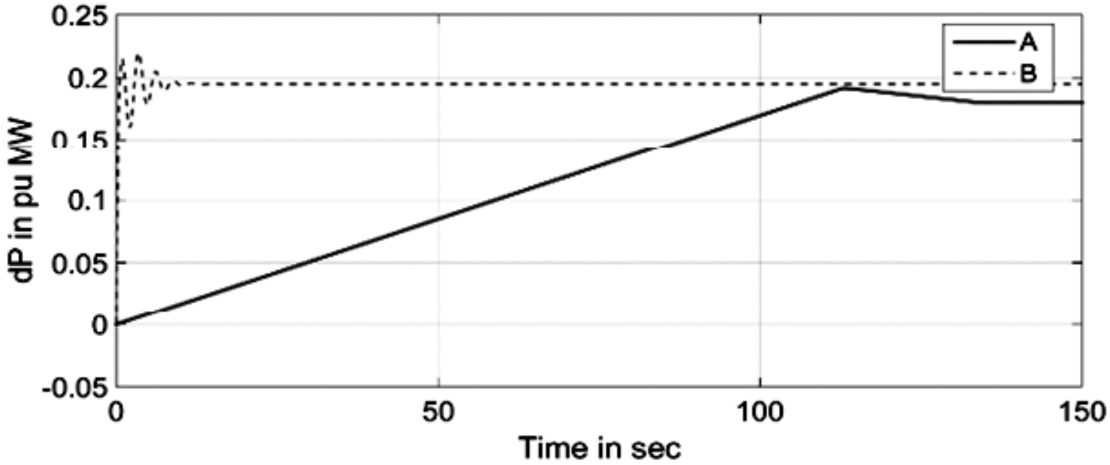
Figure 5: (a) Change in frequency deviation of Area 1 (b)Change in frequency deviation of Area 2


0.2
0.15
0.1
0.05
0
-0.05
dP in pu Hz
0
50
100
150
Time in sec
A
B

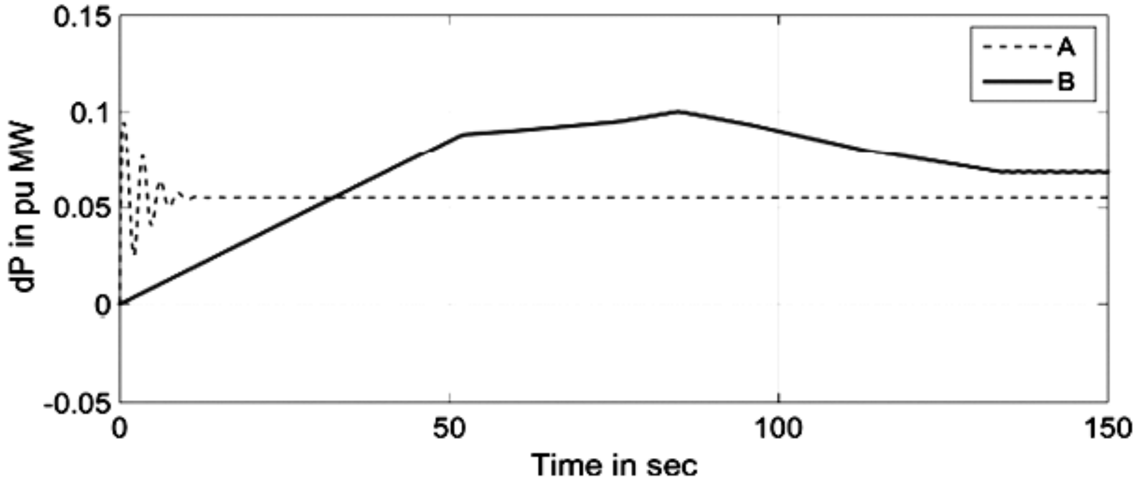
(a)


0.1
0.08
0.06
0.04
0.02
0
-0.02
dP in pu MW
0
50
100
150
Time in sec
A
B

(b)


0.25
0.2
0.15
0.1
0.05
0
-0.05
dP in pu MW
0
50
100
150
Time in sec
A
B

(c)



(d)

Figure 6: Change in power generation of GENCOs : (a)GENCO 1 (b) GENCO 2 (c) GENCO 3 (d) GENCO 4

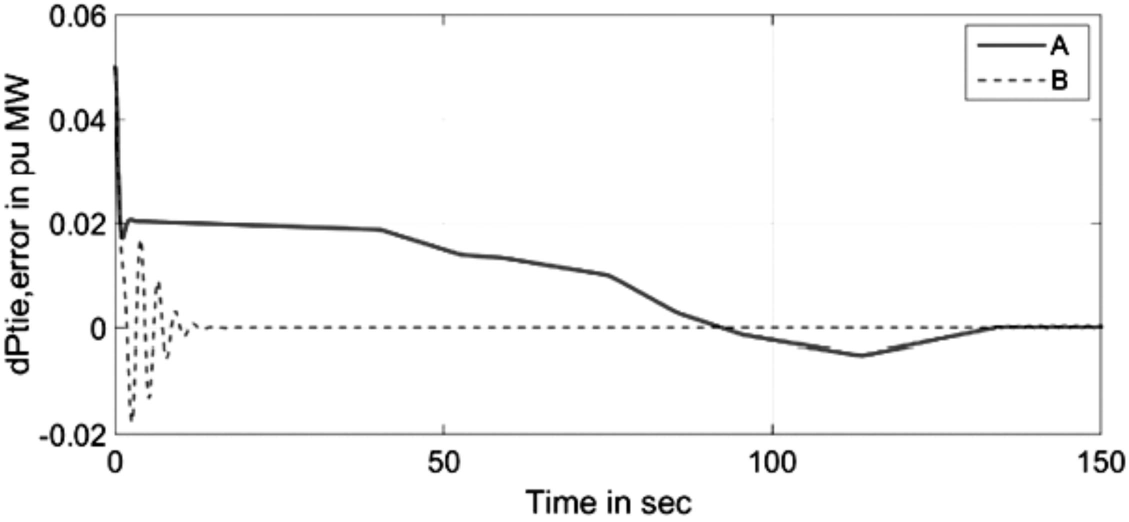


Figure 7: Change in tie-line power error

Table 1 shows the performance comparison for the system without nonlinearities (controlled by robust PID controller) and the system considering nonlinearities (controlled by robust PID controller in conjunction with RFB). It may be noted that the settling time permitted for AGC is in the range of a few seconds to about fifteen minutes.

5. CONCLUSION

The simulations have been done from a practical viewpoint considering possible nonlinearities and a rate limiter which is essentially close to the practical situation. It is evident from the frequency deviation response and the tie-line power response curves that load frequency control is achieved despite the consideration of nonlinearities.

The use of RFB helps to stabilize an otherwise unstable response resulting from the effect of nonlinearities. The settling time is increased with the consideration of nonlinearities in the system but the time range of AGC being a few seconds to about fifteen minutes is permissible for the system.

Table 1
Performance parameters of system without nonlinearities (With Robust Controller) and system with nonlinearities (With Robust Controller and RFB)

		Peak Overshoot (%)	*Settling time (s)*	*Area I*			*Area II*		
				IAE	*ISE*	*ITAE*	*IAE*	*ISE*	*ITAE*
System without nonlinearities (With Robust PID Controller)	df1	12.5	5	0.2145	0.0091	0.6206	0.2512	0.0111	0.8063
	df2	16	8						
	dP1	71.43	6						
	dP2	120.93	5						
	dP3	12.82	7.8						
	dP4	72.72	8						
	dPtie, error	5	2						
System with nonlinearities (With Robust PID Controller and RFB)	df1	0.85	65	2.608	0.1481	58.71	4.864	0.3734	145.2
	df2	0.85	63						
	dP1	17.9	61						
	dP2	54.54	88						
	dP3	6.11	103						
	dP4	47.35	130						
	dPtie, error	5	10						

In addition, the peak overshoot is reduced much due to the presence of RFB in comparison with the action of robust PID controller in the absence of nonlinearities. Since a lower ISE value implies lower overshoot and thus a better transient response, this is substantiated. Similarly, a lower IAE value indicates a better steady state response. Hence it can be seen that the steady state values are affected by the presence of nonlinearities, though RFB in association with robust PID controller helps to achieve the objectives of LFC problem.

REFERENCES

[1] P. Kundur, "Power System Stability and Control", McGrawHill Inc., *2003.*

[2] Zhou K, J. C. Doyle, "Essentials of Robust Control", NY: Prentice Hall, *1998.*

[3] Vaibhav Donde, M. A. Pai, Ian Hiskens, "Simulation and Optimization in AGC Systems after deregulation," IEEE Transactions on Power Systems, Vol.16, No.3, August 2001.

[4] P. Apkarian and D. Noll, "Non-smooth Hinfinity Synthesis," IEEE Transactions on Automatic Control, vol. 51,No.1, pp. 71-86, 2006.

[5] Ravi Shankar et al, "Impact of Energy storage system on load frequency control for diverse sources of interconnected power system in deregulated power environment", International Journal of Electrical Power and Energy Systems 79 (2016) 11-26.

[6] G. T. Chandrasekhar et al, "Load frequency control of power system under deregulated power environment using optimal firefly algorithm", International Journal of Electrical Power and Energy Systems 79 (2016) 11-26.

[7] P. K. Hota, Banaja Mohanti, "Automatic Generation Control of multi source power generation under deregulated environment", International Journal of Electrical Power and Energy Systems 80(2016) 205-214.

[8] Chandan Kumar Shiva, V. Mukherjee, "Design and analysis of multi source multi area deregulated power system for automatic generation control using quasi oppositional harmony search algorithm", International Journal of Electrical Power and Energy Systems 79 (2016) 382-395.

[9] Robust Control Toolbox, Matlab 2014b.

[10] I. A. Chidambaram, B. Paramasivam , "Optimized load frequency simulation in restructured power system with Redox Flow Batteries and Interline Power Flow Controller", International Journal of Electrical Power and Energy Systems 50 (2013) 9-24.

[11] Arlene Davidson R, S. Ushakumari, "Optimal Load Frequency Controller for a Deregulated Non-Reheat Thermal Power System," In Proceedings of the IEEE International Conference on Control Communication and Computing (ICCC 2015)

[12] Arlene Davidson R, S. Ushakumari, "H Infinity Loop Shaping Controller for load frequency control of an Uncertain Deregulated Power System," In Proceedings of the IEEE International Conference on Electrical Electronics and Optimization Techniques (ICEEOT 2016)