Robust Load Frequency Controller Design Via Genetic Algorithm and H∞

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Abstract

Three robust load frequency controllers are proposed in this paper. The first is based on H∞ control design in order to obtain robustness against uncertainties. The second controller is a reduced model to the H∞ controller because the first one is very complex for practical implementation. Genetic algorithm (GA) is used in the third controller to optimize proportional integral differential (PID) controller parameters. The proposed controllers are tested on two area power system model. The robustness of these controllers is investigated through parameter variations and changing the magnitude of load disturbances. A comparative study results is made between all controllers to demonstrate the effectiveness and robustness of these controllers.

Key Words: Load Frequency Control (LFC), Genetic Algorithm (GA), H∞ Control.

1. Introduction

In power system the active power has to be generated as the same time it is consumed. Any mismatch between the demanded and the generated power leads to power imbalance causes the system frequency and the tie line power to deviate from their nominal and scheduled values. The basic role of LFC is to maintain the megawatt output of a generator in balance with the demand and therefore control the interconnection frequency [1]. This goal is achieved by automatic control of the steam valves or water gates of speed governors to adjust the amount of the steam or water flowing through the turbine. As a result of this control, the mechanical power and then the generated electrical power is adjusted. Many controllers have been presented for power system LFC problems in order to achieve a better dynamic performance, where the most employed one is the conventional fixed gain controller like a proportional integral (PI) controller or a PID controller as in [2]. Fixed gain controllers are designed at nominal operating points by try and error and may no longer be suitable in all operating conditions. For this reason adaptive gain scheduling approaches have been proposed for LFC [3, 4, 5, 6, 7, 8, and 9].

Three parameters that represent system operating conditions are monitored and used as inputs to fuzzy system whose output is the adaptive gain of the integral or PI controller [3]. A fuzzy gain scheduling of the PI controller is proposed in [4, 5]. The inputs to the fuzzy system are area control error and its change. Genetic fuzzy system for automatic fuzzy rules design by GA has been developed in [6]. Generation rate constraints (GRC) are considered in many fuzzy logic based approaches [7, 8]. Modified dynamic neural network controller was designed to LFC for generation electricity with good quality [9]. Other technical approaches are used for tuning the parameters of PI or PID controllers for LFC such as tabu search [10] and with maximum peak resonance specifications that is graphically supported by nicholas chart [11]. The decentralized LFC controller design problem can be translated into an equivalent problem of decentralized controller design for multi-input multi-output (MIMO) controller using many approaches such as structured singular values (SSV) [12].
This paper is organized as follows: section 1, introduction. Section 2, the mathematical model for the two area power system is presented. A brief description for the principles of the H∞ controller and the reduced H∞ controller is described in section 3. In section 4, results obtained from the application of these controllers are presented. Sections 5, Principles of GA are discussed. Section 6, Results obtained from application of GA to PID controller and comparative study between controllers is presented. Section 7, conclusion.

2. LFC System Model

The block diagram for LFC of a two area power system is shown in appendix (3). A state space model for the system of this figure can be constructed as:

$$\dot{X} = AX(t) + Bu(t) + Fd(t) \quad (1)$$

Where X is the state vector, u is the control vector, d is the disturbance vector.

$$X(t) = [\Delta f1, \Delta P_{t1}, \Delta P_{v1}, \Delta E1, \Delta P_{tie}, \Delta f2, \Delta P_{t2}, \Delta P_{v2}, \Delta E2]$$

$$u(t) = \begin{bmatrix} u1(t) \\ u2(t) \end{bmatrix}, d(t) = \begin{bmatrix} d1(t) \\ d2(t) \end{bmatrix}$$

$$A=\begin{bmatrix} \frac{-1}{T_P} & \frac{K_{P1}}{T_{P1}} & 0 & 0 & \frac{-K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1T_{g1}} & 0 & \frac{-1}{T_{g1}} & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 \\ K_1B_1 & 0 & 0 & 0 & K_1 & 0 & 0 & 0 & 0 \\ T_{12} & 0 & 0 & 0 & 0 & -T_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{K_{P2}}{T_{P2}} & \frac{-1}{T_{P2}} & \frac{K_{P2}}{T_{P2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{T2}} & \frac{1}{T_{T2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{-1}{R_2T_{g2}} & 0 & \frac{-1}{T_{g2}} & \frac{-1}{T_{g2}} \\ 0 & 0 & 0 & 0 & -K_2 & K_2B_2 & 0 & 0 & 0 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 & \frac{1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{g2}} & 0 \end{bmatrix}^T$$

$$F^T(t)=\begin{bmatrix} \frac{-K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-K_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$(2)\ y(t)=\begin{bmatrix} \Delta f1(t) \\ \Delta f2(t) \\ \Delta Ptie \\ \Delta E1(t) \\ \Delta E2(t) \end{bmatrix}=CX(t)$$

Where,
C = the output matrix.
Δ = incremental change.
f(t) = frequency of the area(HZ).
Ptie = tie line power (pu MW).
T12 =synchronizing coefficient.
E(t) = integral control signal(load reference set-point)(pu MW).
d(t) = load disturbance(pu MW).
Tp = the plant model time constant.
Tt = the turbine time constant.
Tg = the governor time constant.
Kp = the plant gain.
K = the integral control gain,
R = the speed regulation due to governor reaction.
B = frequency bias constant.
u(t) = the supplementary control input signal. [12]

3. H∞ controller

The H∞ norm of a system is the peak value for the magnitude of the transfer function over the whole frequency range.
Given a state space form of a generalized plant P(s) (as shown in Fig 1)

$$P(s)=\begin{bmatrix} A & B1 & B2 \\ C1 & D11 & D12 \\ C2 & D21 & D22 \end{bmatrix} \tag{3}$$

Find a stabilizing feed back control law

$$u2(s)=F(s)\ y2(s) \tag{4}$$

Which maintains system response and error signals within prespecified tolerances despite the effects of uncertainty on the system.

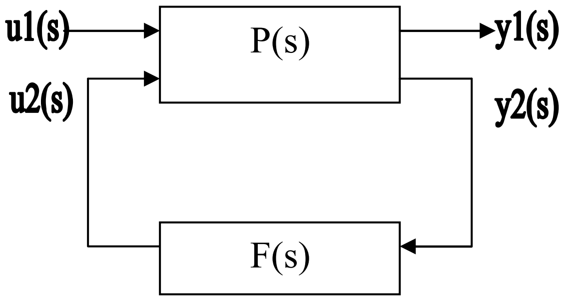

Fig. (1) Generalized block diagram of H∞

u1(s) would contain disturbances, y1(s) would contain the performance variables one wishes to keep small in the presence of the disturbances contained in u1(s) that would tend to drive y1(s) away from zero. On other words one want to minimize the effect of u1(s) (disturbance) on y1(s). Hence, the disturbance rejection performance would depend on the "size" (infinity norm) of the closed loop transfer function from u1(s) to y1(s), which one shall denote as $\|T_{y1u1}\|_\infty$.

3.1 The proposed algorithm

The proposed algorithm will be the H∞ control using γ iteration. This algorithm will use the loop shifting two Riccati formula of H∞ control. The output of this algorithm is the stabilizing feedback law F(s) ,the closed loop transfer function Ty1u1(s) and the optimal value of γ for which the cost function Ty1u1(s)can achieve under a present tolerance.

$$\left\| \begin{bmatrix} \gamma Ty1u1 \\ Ty1u1 \end{bmatrix} \right\|_\infty \le 1 \tag{5}$$

The search of optimal γ stops whenever the γ relative error between two adjacent stable solutions is less than the tolerance specified. For most practical purposes, the tolerance can be set at 0.01 or 0.001.

3.2 Reduced H∞ controller

In the design of controllers for complicated systems, model reduction arises in several places:

1) In using certain design methods (including the H∞ method), fictitious unobservable/uncontrollable states are generated by the algorithms which must be stripped away by a reliable model reduction algorithm.

2) H∞ procedure controllers of order at least equal to that of the plant. This control law may be too complex with regards to practical implementation. A good model reduction algorithm applied to the control law can sometimes significantly reduce control law complexity with very little change in control system performance.

One of the most robust reduction algorithms is hankel minimum degree approximation procedure which computes a k^{th} order reduced model

$$G_r(s) = C_r(Is + A_r)^{-1} B_r + D_r$$

Of a possibly non-minimal and not necessarily stable, n^{th} order system.

$$G(s) = C(Is + A)^{-1} B + D$$

So,

$$\| G(j\omega) - G_r(j\omega) \|_\infty \leq totband$$

Where,
totband= specified tolerance(0.01 or 0.001).

4. Results Obtained from H∞ controller

In order to investigate the robustness of the proposed controllers through parameter variations and changing the magnitude of load disturbances two different operation conditions are considered. In each one, the proposed controllers are applied to two area power system model described earlier.

Case 1: Figure (2) gives the plots of the frequency and tie power deviations for the two area interconnected power system for 0.1 p.u step load increase in area1 (d1=0.1 p.u, d2=0 p.u) . It is observed that, the proposed H∞ controller damps all oscillations, minimizes the overshoot and reaches zero after few seconds for frequency and tie power deviations. Whereas, the conventional integral controller fails to damp oscillations. Also, it is observed that there is no significant difference between the performances of the H∞ controller and the reduced controller.

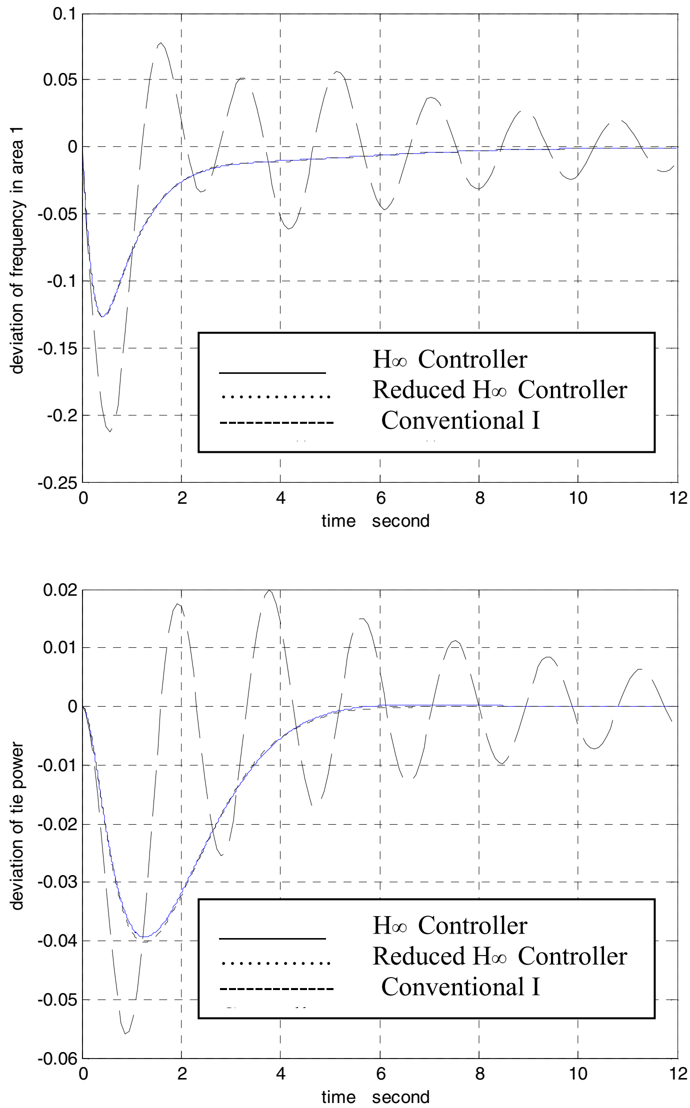

Fig. (2) Responses of $\Delta f1$ and $\Delta Ptie$ due to 0.1 p.u step load increase in area1.

Case 2: To demonstrate the robustness of the proposed controller, figure (3) gives the plots of the frequency and tie power deviations for the two area interconnected power system for 0.15 p.u step load decrease in area2 (d1=0 p.u, d2=-0.15 p.u) and 25% increase in the turbine time constant. Simulation results shows that frequency and tie power responses under the proposed H∞ controller have much lower overshoot, rise time and settling time than the conventional integral controller. It is also observed that, there is no significant difference between the performances of the H∞ controller and the reduced controller.

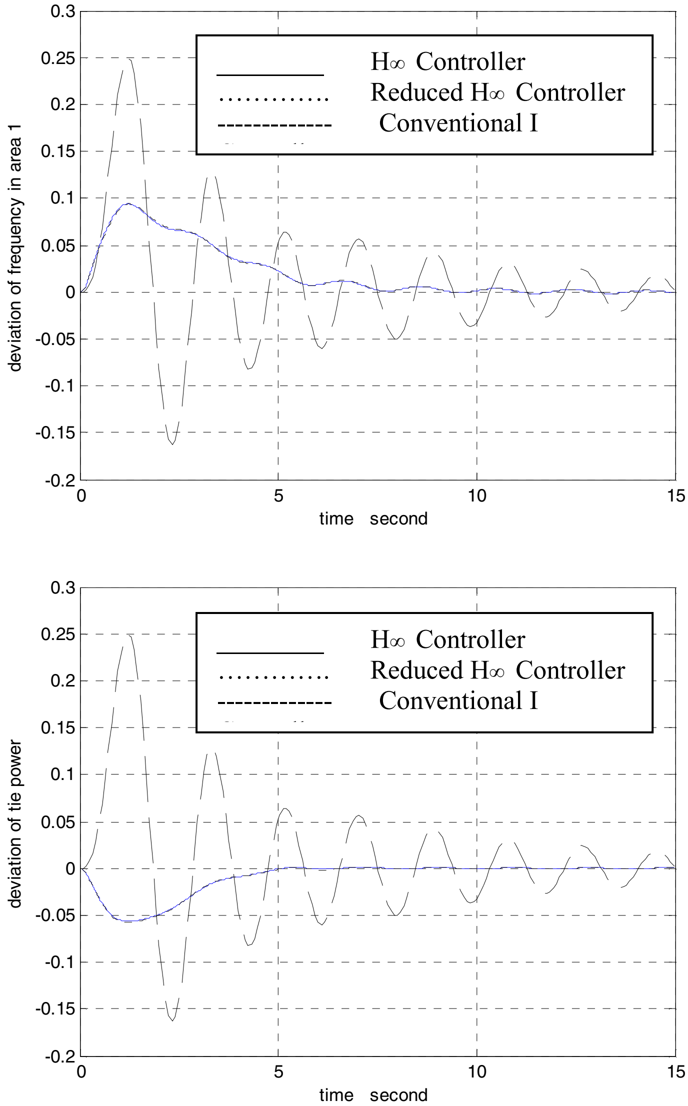

Fig. (3) Responses of Δf1 and ΔPtie due to 0.15 p.u step load decrease in area2 and 25% increase in the turbine time constant.

5. Principles of GA

GA is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. A key step in GA applications is the definition of the objective (fitness) function which is the function you want to optimize. Here, the fitness functions is taken to minimize the sum squared error of frequency of area1, area2 and tie power.

$$\text{Fitnessfunction} = \min\left[\sum_{k=0}^{\infty}(\Delta f_1^2(k)+\Delta f_2^2(k)+\Delta P_{tie}^2)\right] \quad (6)$$

GA repeatedly modifies a population of individual solutions. At each step, GA uses the current population to create the children that make up the next generation. The algorithm selects a group of individuals in the current population, called parents, who contribute their genes (the entries of their vectors) to their children. The algorithm usually selects individuals that have better fitness values as parents. GA creates three types of children for the next generation:

• Elite children are the individuals in the current generation with the best fitness values. These individuals automatically survive to the next generation.
• Crossover children are created by combining the vectors of a pair of parents.
• Mutation children are created by introducing random changes, or mutations, to a single parent.

Over successive generations, the population "evolves" toward an optimal solution. One can apply GA to solve a variety of optimization problems that are not well suited for standard optimization algorithms.

6. Results for GA based PID controller

In this section, the conventional integral controller is replaced by a PID controller in the two area interconnected power system. GA is used in this paper to optimize the parameters of this controller. To demonstrate the effectiveness of this controller, the same two cases previously used, are taken in consideration here. Figure (4) shows the GA convergence performance corresponding to the mean value of the fitness function for each generation. One can notice the fast convergence rate at the initial iterations and a flat convergence rate at the final stages. This curve shape is very common for GA applications.

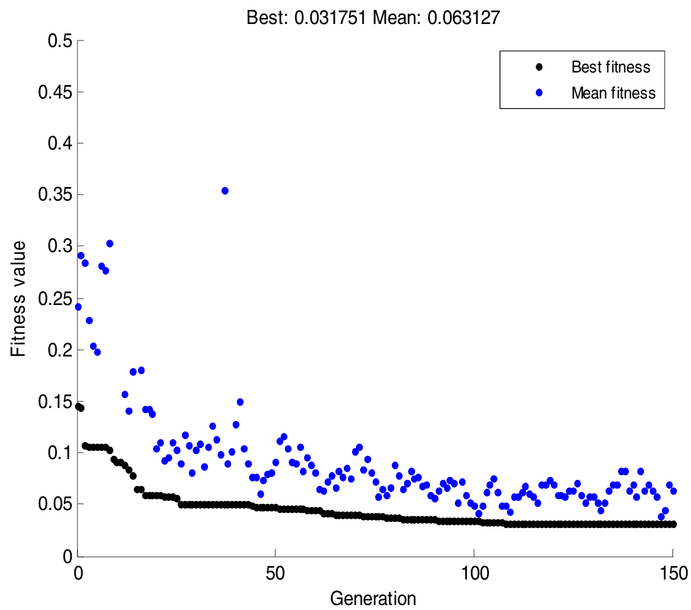

Fig. (4) GA convergence performance

Case 1: Figure (5) gives the plots of the frequency and tie power deviations for the two area power system for 0.1 p.u step load increase in area1 (d1=0.1 p.u, d2=0 p.u). It is observed that, the PID controller has a better performance than the H∞ controller in damping all oscillations, minimizing the overshoot by a great amount and reaching zero in 5 seconds.

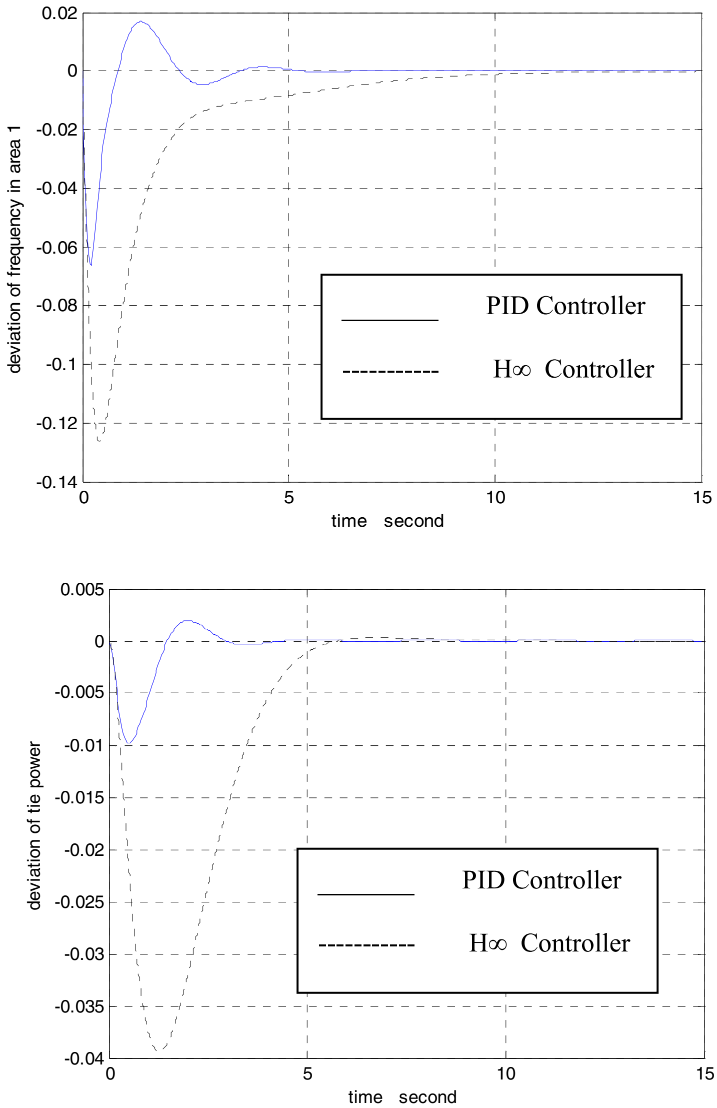

Fig. (5) Responses of Δf1 and ΔPtie due to 0.1p.u step load increase in area1.

Case 2: To demonstrate the robustness of the proposed controllers, figure (6) gives the plots of the frequency and tie power deviations for the two area interconnected power system for 0.15 p.u step load decrease in area2(d1=0 p.u, d2=-0.15 p.u) and 25% increase in the turbine time constant. It is observed that, the proposed PID controller has an excellent performance for damping oscillations, minimizing overshoot and reaching zero in 5 seconds.

Table (1) shows a detailed comparison between H∞ controller and GA controller for the previous two cases in settling time, overshoot and time in which overshoot occurs which prove the excellent performance of GA controller..

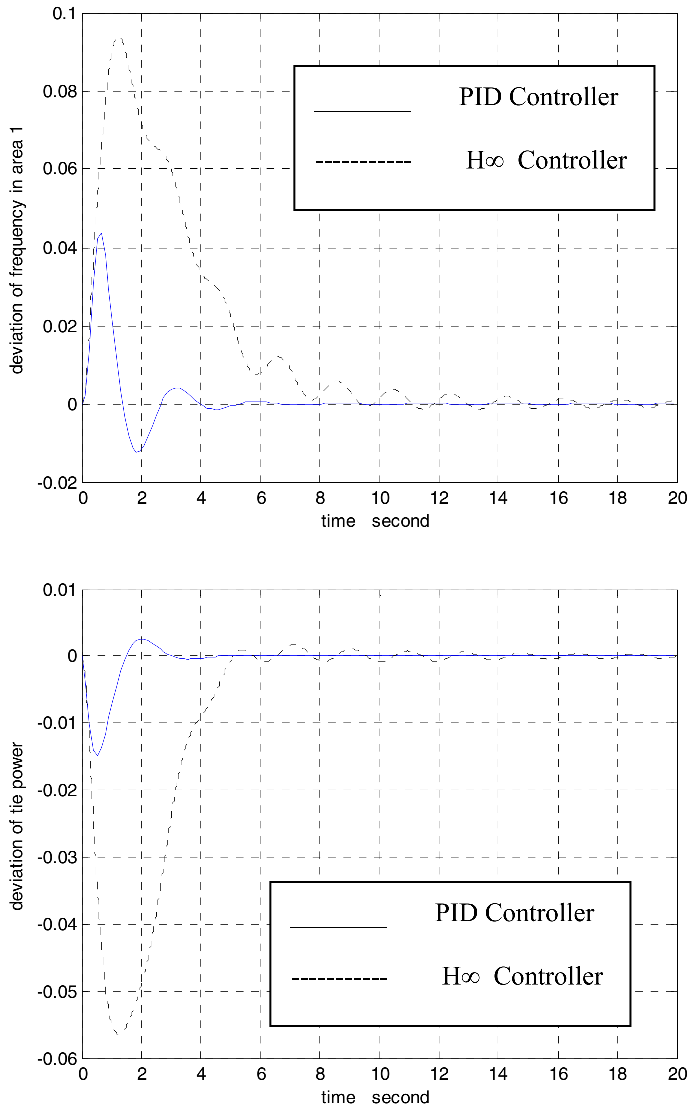

Fig. (6) Responses of Δf1and ΔPtie due to 0.15 p.u step load decrease in area2 and 25% increase in the turbine time constant.

Table(1) a detailed comparison between H∞ and GA controllers.

		Settling time		Overshoot		Time at which overshoot occurs	
		H∞	GA	H∞	GA	H∞	GA
Case(1)	Δf1	8.220	4.4205	0.1264	0.066	0.41	0.21
	ΔPtie	5.176	3.986	0.0394	0.009	1.27	0.51
Case(2)		H∞	GA	H∞	GA	H∞	GA
	Δf1	12.66	4.9273	0.094	0.043	1.23	0.65
	ΔPtie	7.474	4.0098	0.0564	0.014	1.24	0.52

7. Conclusion

Three robust load frequency controllers are proposed in this paper. The first is based on optimal H∞ control design in order to obtain robustness against load disturbances and parameters changes. Reduced H∞ controller is presented for practical applications. The results show that there is no significant difference between the performances of the exact and the reduced one. GA is used to optimize the parameters of PID controllers. Results show that the PID controller has the best performance in damping oscillations, minimizing overshoot by a great amount and reaching zero value in about 5 seconds.

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Appendix 1

The nominal values of the two area power system model parameters are:

T12 =0.545 puMw.	Tp1= Tp2=20seconds.
Tt1=Tt2=0.3seconds.	Tg1= Tg2=0.08seconds.
Kp1= Kp2=120 Hz/puMW.	K1=K2=1.
R1=R2=2.4 HZ/pu MW.	B1=B2=0.425puMW/Hz [12].

Appendix 2

Genetic parameters are:

Population size	:	20	Initial range	:	[0.5; 1]
Elite count	:	2	Crossover	:	0.8

Appendix 3

Block diagram for the load frequency control of a two area power system