Design of Controller for The Single Area Load Frequency Control in Interval Model

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Abstract:In this paper presents a design of PI controller for the single area load frequency control in the interval model. In the rapid development in the world, there was a ineluctable demand of power with maintaining good quality. In order to maintain demand of power with good quality power system has an effective controller for the load frequency control. The uncertainty of the parameters and external disturbances rejections continue to retain the stability are the major issues while design of load frequency control for the engineers. In this paper a PI control is designed for the single area load frequency control in the interval model. The interval analysis of plant is carried out by using Kharitonov theorem and the complexity of the system can be reduced by using model order reduction (MOR). For this MOR the Routh approximation is used in this paper and the analysis and results are carried for the reduced model. From the results it is observed that the controller gives good performance to stabilize the system for the wide range of variations in the system parameters

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IndexTerms - Kharitonov Theorem, Interval model, Model order reduction, Routh approximation, Load frequency control (LFC).

I. INTRODUCTION

Power system is used for the conversion of natural energy to electric energy. For the optimization of electrical equipment, it is necessary to ensure the electric power quality. It is known three phase AC is used for transportation of electricity. During the transportation, both the active and reactive power balance must be maintained between the generation and utilization AC power. When either frequency or voltage changes equilibrium point will shift. Good quality of electrical power system means both the voltage and frequency to be fixed at desired values irrespective of change in loads that occurs randomly. It is in fact impossible to maintain both active and reactive power without control which would result in variation of voltage and frequency levels. To cancel the effect of load variation and to keep frequency and voltage level constant a control system is required. Though the active and reactive powers have a combined effect on the frequency and voltage, the control problem of the frequency and voltage can be separated. Frequency is mostly dependent on the active power and voltage is mostly dependent on the reactive power. Thus the issue of controlling power systems can be separated into two independent problems. The active power and frequency control is called as load frequency control (LFC). The most important task of LFC is to maintain the frequency constant against the varying active power loads, which is also referred as un- known external disturbance. Power exchange error is an important task of LFC.

Generally a power system is composed of several generating units. To improve the fault tolerance of the whole power system, these generating units are connected through tie-lines. This use of tie-line power creates a new error in the control problem, which is the tie-line power exchange error. When sudden change in active power load occurs to an area, the area will get its energy through tie-lines from other areas. Eventually the area that is subject to the change in load should balance it without external support Or else there will be economic conflicts between the areas. This is why each area requires separate load frequency controller to regulate the tie line power exchange error so that all the areas in an interconnected system can set their set points differently. In short, the LFC has two major duties, which are to maintain the desired value of frequency and also to keep the tie line power exchange under schedule in the presence of any load changes. Also, the LFC has to be unaffected by unknown external disturbances and system model and parameter variation [11]. The most generally used electrical energy sources of now days are thermal energy and hydel energy etc. here in the generation of electrical energy we use prime movers and synchronous generators, where prime movers converts thermal or hydel into mechanical energy and synchronous generators converts these mechanical energy into electrical energy. These prime movers and governor mechanism provided with a efficacy method of controlling both electrical energy and frequency by LFC (load frequency control) or automatic generation control (AGC) [1].In general the generating stations are far away from the load centers these are connected with the help of transmission system. In this system due to fluctuation of the load or any disturbances or faults in the transmission line will leads disturbances in the system power or frequency. In order to maintain the synchronization and stability of the system with the help of Load frequency control. The LFC is designed in both single area and multi area power system. In the design power system the LFC design is play important role [12].

In this present paper the single area isolated power system load frequency control is taken into consideration. In the real life there is no exact values for the system, there will be a range of values for the system i.e. lower and upper limits for the fixed value. These range of values called as interval model. For this type of system the analysis was difficult. In order analysis this system there was method namely called Kharitonov theorem [4] which is proposed by Kharitonov in the 1978. It is stated that by using these theorem only four polynomials are required to generate from the interval model and stability can be analyzed by Routh stability criteria [7].In general the real life system has higher order degree. The mathematical analysis and design of such a systems is very complex and difficult. In order to avoid those complexities in this paper present order reduction using Routh approximation [12]. The higher order interval plant can be reduced by using Routh approximation. In this paper the controller values i.e. proportional gain (k_p) and integral gain (k_i) are tuned by using interior-point method with predefined objective function and constraints. By using these controller gains the system will bring back to stable region.

II. INTERVAL ANALYSIS

The interval model can be defined by the set of values($x \in$ Real) such that $p \leq x \leq q$, for p=q the interval model becomes [p, p] which is a regenerated interval. The arithmetic operations of intervals [7-8] are given as follows:

1. $[p,q]+[r,s]=[p+r, q+s]$

2. [p,q]-[r,s]=[p-s, q-r]
3. [p,q]×[r,s]=[min(pr,ps,qr,qs), max(pr,ps,qr,qs)]
4. [p,q]÷[r,s]=[p,q]×$[\frac{1}{s},\frac{1}{r}]$,where [r,s]∉ 0 (1)

In other way the interval number x^I can be expressed as

$$x^I=[\,p,\,q]=\{x\in R\,,\,p\leq x\leq q\}=[x_0-\Delta x, x_0-\Delta x] \quad (2)$$

Where $x_0=(p+q)/2$ and $\Delta x = (q-p)/2$

III. INTERVAL MODEL OF LOAD FREQUENCY CONTROL

The entire power system is a large scale system having very complexity and non linear dynamics. So for the case of LFC, the system taken into consideration is subjected to small change in the load, therefore it can be suitably represented as a linear model, linearized around the operating model. This LFC model consists of governer, turbine, load, machine and droop characteristics. The droop characteristics are a type of feedback gain used to improve the damping properties of the power system. Here the single area is considered where the load is supplied by a single generator. The linear model of single area system is shown in fig 1, and the nomenclature is given in table 1.

Table.1. Nomenclature of power system parameters.

ΔP_D	Load disturbance (p.u. M.W)
ΔP_G	Incremental change in generator output (p.u. M.W)
ΔX_G	Incremental change in governor value position
Δf	Incremental frequency deviation (Hz)
K_p	Electric system gain
T_p	Electric system time constant (s)
T_T	Turbine time constant (s)
T_G	Governor time constant (s)
T_R	Constant of reheat turbine
R	Speed regulation due to governor action (Hz/p.u. M.W)
c	Percentage of power generated in the reheated portion

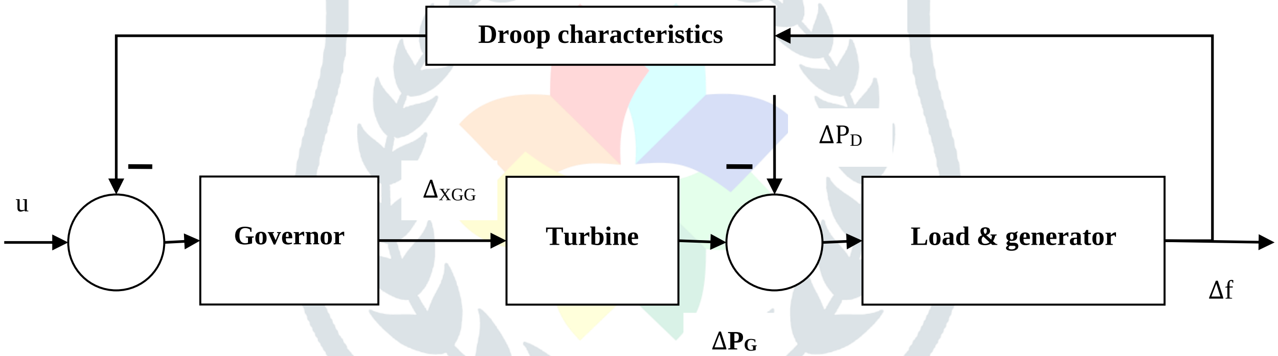


Fig.1. Isolated single area load frequency control.

In mathematical model the system the transfer function of isolated single area load frequency control can be represented as [1]

$$G(s) = \frac{G_P(s)G_G(s)G_T(s)}{1+\frac{G_P(s)G_G(s)G_T(s)}{R}} \quad (3)$$

Where $G_P(s)$ represents the power system dynamics (load and machine)

$$G_P(s) = \frac{K_P}{T_P S+1} \quad (4)$$

$G_T(s)$ represents the turbine dynamics

i. In case of non-reheated turbine[3]

$$G_T(s) = \frac{1}{T_T S+1} \quad (5)$$

ii. In case of reheated turbine

$$G_T(s) = \frac{cT_R S+1}{(T_R S+1)(T_T S+1)} \quad (6)$$

$G_G(s)$ represents the governor dynamics

$$G_G(s) = \frac{1}{T_G S+1} \quad (7)$$

$\frac{1}{R}$ is the droop characteristics

In this paper reheated turbine is considered. In this type of turbine, the steam coming from the high pressure section is passed through a re-heater and sent to the intermediate pressure section. The parameter values for the reheated turbine are [1]. The transfer function of the single area load frequency control is given by (4)(5)(6)&(7)

$$\frac{K_P R(cT_R S+1)}{R[(T_G S+1)(T_T S+1)(T_P S+1)(T_R S+1)]+K_P(cT_R S+1)} \quad (8)$$

This transfer function has higher order system. The analysis of higher order system is difficult. In order to reduce these complexities of the system the model order reduction is presented in this paper. Model order reduction (MOR) is a technique for reducing the computational complexity of mathematical models in numerical simulations.

The main reasons for obtaining lower order model can be stated as follows:

1. To have lower order models so as to simplify the understanding of the system.
2. To decrease the computational efforts and so make the design of the controller more efficient.
3. To speed up the simulation process in the design validation stage.
4. To obtain simpler control laws.

The MOR is classified into two categories.

I. frequency domain analysis
II. time domain analysis

In frequency domain analysis the following are the some of MOR methods

1. Padé Approximation Method
2. Pole Placement Method
3. Routh Approximation Method
4. Energy based methods
5. Mixed approximation methods etc.

In this paper Routh approximation is used to Model order reduction.

The combination of Routh stability criterion and ISE (integral square error) criterion is implemented for the linear model reduction of higher order dynamic system.

Computation of the Routh approximation entails four steps [6].

Step1: apply the reciprocal transformation from G(s) to obtain G′(s).

Step2: compute the alpha-beta expansion of G′(s).

Step3: compute the k^{th} routh convergent K(s) from the alpha and beta coefficients of G′(s).

Step4: apply the reciprocal transformation to R(s) is the K^{th} order reduced model.

IV. DESIGN OF PI CONTROLLER

The power system consists of continuously operating dynamic machines. The main aim of the development of a control model for controlling such systems using control action in an optimum manner with maintaining the stability.

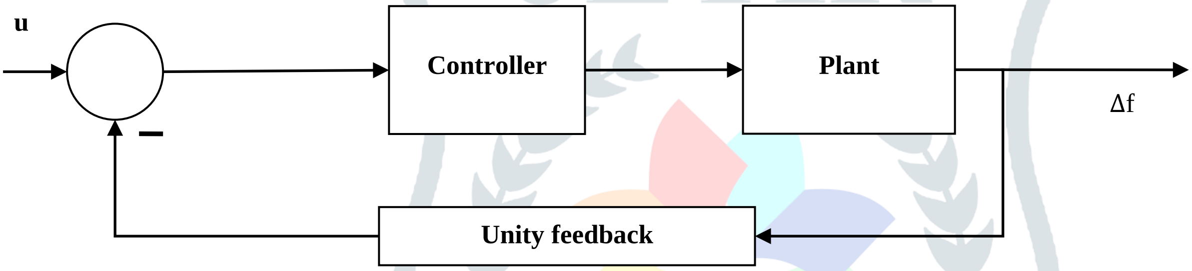


Fig.2. Plant with PI controller.

In this interval plant is in the form

$$G(s) = \frac{N(s)}{D(s)} \quad (9)$$

Where the numerator polynomial are in the form

$N(s) = p_0+p_1s+p_2s^2+p_3s^3+$…………… (10)

$D(s) = q_0+q_1s+q_2s^2+q_3s^3+$…………… (11)

Where vectors p and q lie in values of P and Q respectively

$p \in P = \{p: p_i^- \leq p_i \leq p_i^+ \ \text{ for } i = 0,1,2,\ldots\ldots\}$ and (12)

$q \in Q = \{q: q_i^- \leq q_i \leq q_i^+ \ \text{ for } i = 0,1,2,\ldots\ldots\}$ (13)

In this section an efficient and systematic approach has been presented for designing robust stabilizing controller for interval plants. To stabilize the interval plant family we consider the proper first order compensator of the form

$$C(s) = K_1+\frac{K_2}{s} \quad (14)$$

We say that this compensator robustly stabilize the interval plant family, resulting the closed loop polynomial

$$G_c(s) = N_c(s)N(s)+D_c(s)D(s) \quad (15)$$

Have all its roots in the strict left half of plane. i.e. $G_c(s)$ is Hurwitz

The necessary and sufficient conditions for the stability of the system is given by

1. Necessary condition
   $\sum_0^n a_i > 0$ Where i=0,1,2,3…. (16)
2. Sufficient condition
   $a_1^2 > 3b_0b_2$ (17)

V. NUMERICAL EXAMPLE

Consider the problem [1].

K_P=120, T_P=20, T_T=0.3, T_G=0.08, R=2.4, T_R=4.2, and c=0.35

The values of these parameters are taken in the interval model as:

$K_P \in$[60, 180], $T_P\in$[10, 30], $T_T\in$ [0.15, 0.45], $T_G\in$[0.04, 0.12], R∈ [1.2, 3.6], $T_R\in$[2.1, 6.3], c ∈ [0.175, 0.525].

In this case the intervals are formed by taking 50% lower and upper bound uncertainties. Solving the model in the transfer function model, from equation (8)

$$G_R(s) = \frac{N_R(s)}{D_R(s)} = \frac{P_1s+P_0}{Q_4s^4+Q_3s^3+Q_2s^2+Q_1s+Q_0} \quad (18)$$

Where $P_1 = RK_pcT_r \in [26.46, 2143.26]$,
$P_0 = RK_P \in [72, 648]$,
$Q_4 = RT_PT_GT_RT_T \in [[0.1512, 36.7416]$,
$Q_3 = R\,[T_GT_RT_T+T_PT_RT_T+T_PT_GT_T+T_PT_GT_R] \in [4.87512, 527.15448]$,
$Q_2 = R\,[T_RT_T+T_GT_T+T_PT_T+T_GT_R+T_PT_R+T_PT_G] \in 27.966, 755.082]$,
$Q_1 = R\,[T_T+T_P+T_G+T_R]+cK_PT_R \in [36.798, 728.082]$,
$Q_0 = K_P+R \in [61.2, 183.6]$.

The overall transfer function in the interval model is given by

$$G_R(S) = \frac{[26.46, 2143.26]S + [72, 648]}{[0.1512, 36.7416]s^4 + [4.87512, 527.15448]s^3 + [27.966, 755.082]s^2 + [36.798, 728.082]s + [61.2, 183.6]}$$

According to the Kharitonov theorem [14] from the 4 kharitonov polynomials are

$$G_1(s) = \frac{26.46s + 72}{0.1512s^4 + 527.15448s^3 + 755.082s^2 + 36.798s + 61.2}$$

$$G_2(s) = \frac{2143.26s + 648}{36.7416s^4 + 4.87512s^3 + 27.966s^2 + 728.08s + 183.6}$$

$$G_3(s) = \frac{26.46s + 648}{36.7416s^4 + 527.15448s^3 + 27.966s^2 + 36.798s + 183.6}$$

$$G_4(s) = \frac{2143.26s + 72}{0.1512s^4 + 4.87512s^3 + 755.082s^2 + 728.082s + 61.2} \quad (19)$$

From the procedure of the routh approximation [6] the reduced models for the 4 kharitonov polynomials are

$$G_1(s) = \frac{26.46s+72}{0.1512s^4+527.15448s^3+755.082s^2+36.798s+61.2},\ R_1(s)=\frac{0.2175s+0.592}{s^2-0.3025s+0.50215}$$

$$G_2(s) = \frac{2143.26s+648}{36.7416s^4+4.87512s^3+27.966s^2+728.08s+183.6},\ R_2(s)=\frac{80.612s+22.548}{s^2+27.2316s+6.867}$$

$$G_3(s) = \frac{26.46s+648}{36.7416s^4+527.15448s^3+27.966s^2+36.798s+183.6},\ R_3(s)=\frac{17.61s-0.249}{s^2-0.01414s-0.07}$$

$$G_4(s) = \frac{2143.26s+72}{0.1512s^4+4.87512s^3+755.082s^2+728.082s+61.2},\ R_4(s)=\frac{2.83999s+0.0955}{s^2+0.9648s+0.096}$$

The second order interval plant from the reduced model is

$$G(s) = \frac{[0.2175, 80.162]s+[0.0955, 22.548]}{[1,1]s^2+[-0.01414, 27.2316]s+[-0.07, 6.867]} \quad (20)$$

In order to design robust stabilizing feedback controller for this unstable interval plant, we perform the nominal controller design of the form [5]

$$C(s) = K_1+\frac{K_2}{s}$$

To robustly stabilizing the interval plants the C(s) will stabilize the given interval plant if the closed loop interval polynomial is stable The characteristic equation of interval model for the reduced model is given by

$[1,1]s^3 + [0.2175K_1 - 0.01414,\ 80.162K_1 + 27.2316]s^2 + [0.0955K_1 + 0.2175K_2 - 0.07, 22.548K_1 + 80.162K_2 + 6.867]s + [0.0955K_2, 22.548K_2]$ (21)

The optimal characteristic equation that minimizes the IATE performance for step input is given by [10] is

$$s^3+1.75\omega_n s^2+2.15\omega_n^2 s + \omega_n^3=0. \quad (22)$$

By comparing (21) and (22) we get the nominal pi controller parameter as K_1^0=23.37 and K_2^0=56.27.

For finding the controller parameters, K_I and K_D such that the objective function

$$J = (K_1 - K_1^0)^2 + (K_2 - K_2^0)^2 \quad (23)$$

Where K_1^0 and K_2^0 are the pre defined values and K_1 and K_2 are tuned by using interior point method.

From the necessary and sufficient conditions the constraints for the reduced interval model are

$-0.2175K_1+0.01414 > 0$

$-0.0955K_1 -0.2175K_2+0.007 > 0$

$-0.0955K_2 > 0$

-(0.0955K_1+0.2175K_2-0.07)^2+3*(22.548K_2)*(80.162K_1 +27.2316) > 0

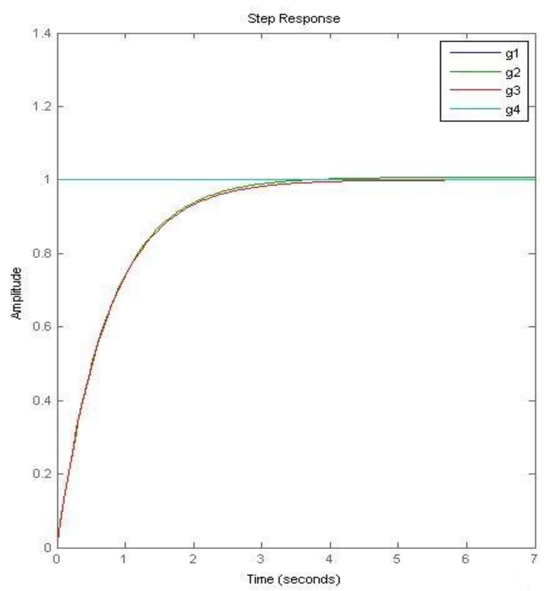
In the design of PI-controller based on the objective function and optimized constrains the tuned vales of controller is obtained by using interior point method.

Table 6: PI controller for the interval plant

Controller set	∈Value	K_P	K_I
1	0.01	6.1918	0.1097
2	0.02	3.4629	0.2194
3	0.03	1.8677	0.2487
4	0.04	2.4806	0.3291
5	0.05	31.046	1.2202
6	0.06	37.274	3.5461

VI. RESULTS

The simulation results obtained by the implementation of the controller designed in the previous section and the response of the controller for the reheated turbine are presented for different values of K_p and K_i corresponding values of∈.



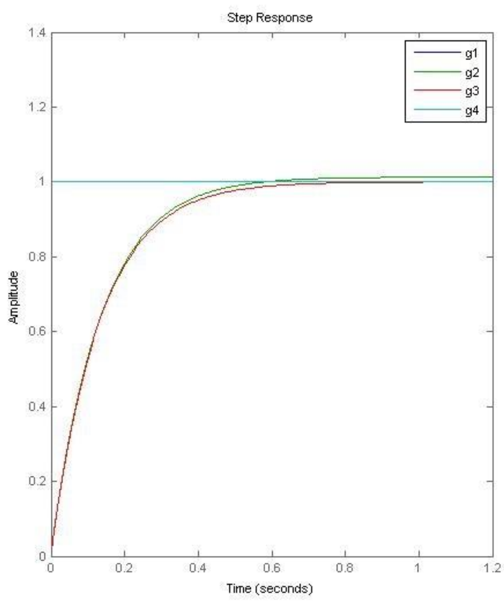
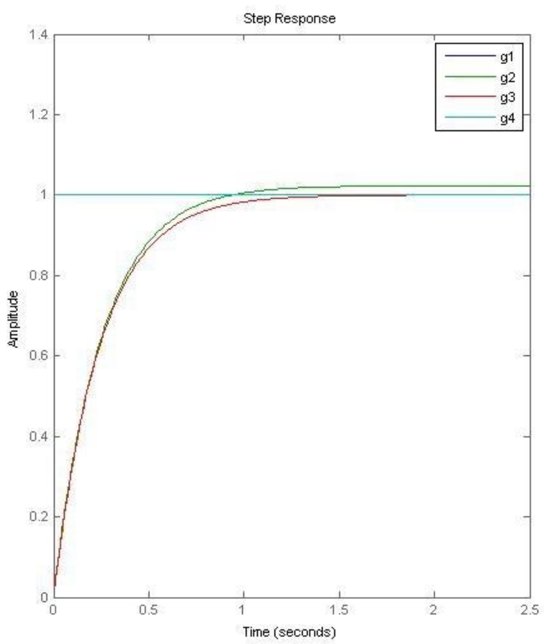


Fig (a). Step response for ∈=0.01 **Fig (b). Step response for** ∈=0.02



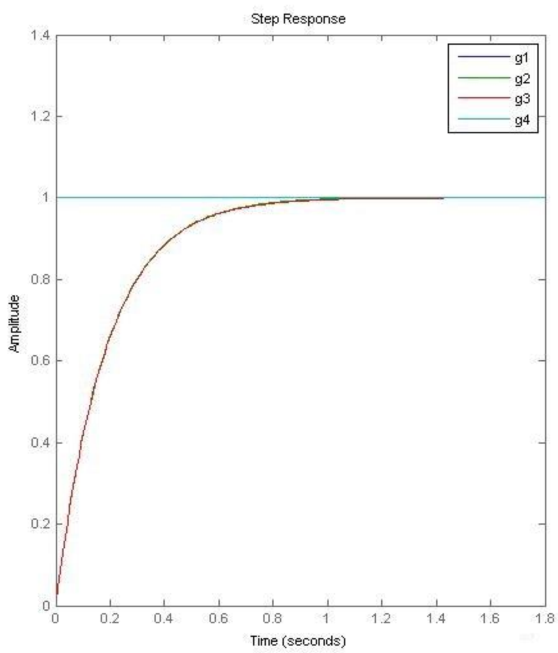


Fig (c). Step response for ∈=0.03 **Fig (d). Step response for** ∈=0.04

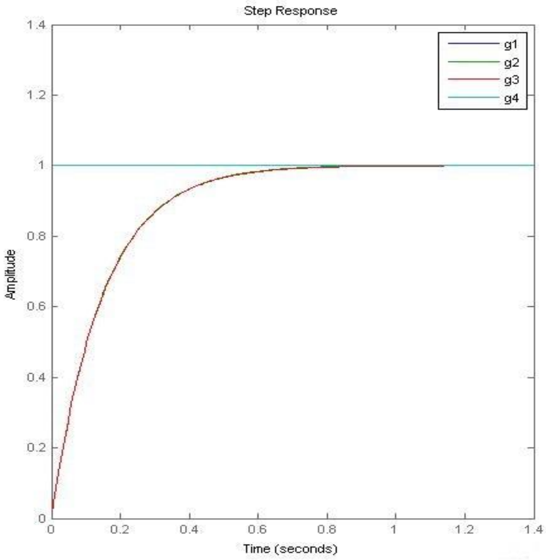


Fig (e). **Step response for** ∈=0.05

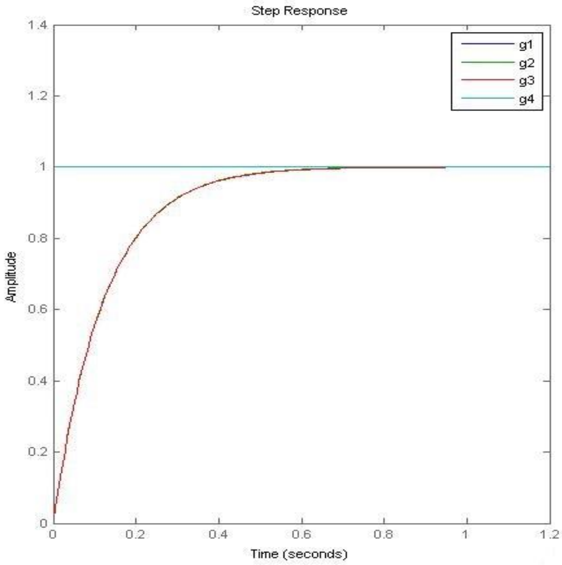


Fig (f). **Step response for** ∈=0.06

VII. CONCLUSION

The rapid development in the world of today is continuously posing the huge demand of the electrical energy. Therefore very important to have an effective LFC system which has a good disturbance rejection capability while working under uncertain environment. In this paper the PI controller is designed based on the necessary and sufficient conditions for the reheated turbine. By using this controller we can maintain the stability of the system under the parameter uncertainties.

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