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Controller Design for Single Area Load Frequency Control with Time Delays Using Genetic Algorithm

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Abstract

The load frequency control (LFC) plays an important role in regulating the frequency variations that occur in power system due to the mismatch between load and generation. This paper proposes a new method to design controllers for a time delayed single area LFC system using genetic algorithm. The proposed method offers high accuracy and less computation time compared to previous time delay control methods. The controller parameters are selected so as to attain maximum delay margin with less deterioration in damping performance of the system. The effectiveness of the controller in retaining the stability of the system is validated using MATLAB/SIMULINK.

Keywords: Delay margin, Delay Sweeping method, Genetic Algorithm, Load Frequency Control, Time delay, Power system stability

INTRODUCTION

With the extensive growth in electric power industry, the power system network has become large and more complex. The large scale power system is subjected to degradation in the dynamic performance due to various uncertainties. One of the most important uncertainties is the time delay arising during transmission of control signals in LFC structure. In traditional LFC structure, these time delays are nominal and hence it is neglected. In deregulated environment, the control signals are transmitted via open communication channels. In such a case, time delays have become more significant. These time delays are more certain to affect the stability of the power system [1] [2].

Generally the stability of LFC system with time delay is analyzed by frequency domain approach (direct method) and time domain approach (indirect method). The method of tracing critical eigen value [3] and cluster treatment of characteristics roots [4]-[6] is a direct method of finding delay margin. Another method is the indirect method of determining delay margin based on Lyapunov stability theory and LMI [7]-[9]. X. Yu et.al[10] presented an approach for stability analysis of LFC system with communication delays based on LMI technique. Hassan Bevarani et.al[11] proposed a robust decentralized PI controller based on H_2/H_∞ control technique for three area interconnected power system with communication delay. L.Jiang et.al [12] investigated the stability of multi area LFC scheme with PI controllers using Lyapunov-theory based delay dependent criterion and LMI techniques. Dey R,Ghosh S et.al[13] designed the delay dependent / independent H_∞ controller for two area LFC system. Chuan-ke Zhang et.al[14] presented the delay dependent stability analysis of multi area LFC system by finding the delay margin using LMI technique and the relationship between delay margin and controller parameter is investigated. Chuan-ke Zhang et.al [15] proposed a method to design PID controller for delay dependent robust load frequency control . J. Chen et.al [16] proposed a method to compute the delay margin of a linear time delay system by determining generalized eigen values of certain constant matrices. Wim Michiels et.al[17] examined a new method for the determination of controller parameters in a broad class of linear control systems affected by time-delays. Sahin Sonmez et.al [18] applied frequency domain approach for computing time delay margin using Routh's stability criterion. Saffet Ayasun et.al [19] suggested a new method to compute delay margin of time delayed generator excitation control system with stabilizing transformers. In all the above mentioned literature works, the delay dependent stability analysis of LFC system was investigated and delay margin was determined for fixed values of the controller parameters by trial and error method. It was investigated that the controller parameters play an important role in improving the dynamic performance of the system. Thus, if the controller is tuned properly using appropriate optimization technique, the stability of the LFC system can be enhanced. In this outlook, the research on enhancing the stability delay margin of time delayed LFC system using genetic algorithm gains prominence.

This paper introduces an algorithm to design output feedback controllers for a time delayed LFC system. The genetic algorithm is used to search for possible solutions in order to attain the optimal trade-off between dynamic performance and delay margin. The main objective of the research is to find the controller parameters which give maximum delay margin ensuring the stability of the system.

DYNAMIC MODEL OF LFC WITH DELAY

This section explains the linear dynamic model of single area LFC scheme with time delay. A time delay is introduced into the control loop of the conventional LFC model [20]. The block diagram of single area LFC system is shown in Fig.1. The time delay is denoted by an exponential term $e^{-s\tau_k}$.

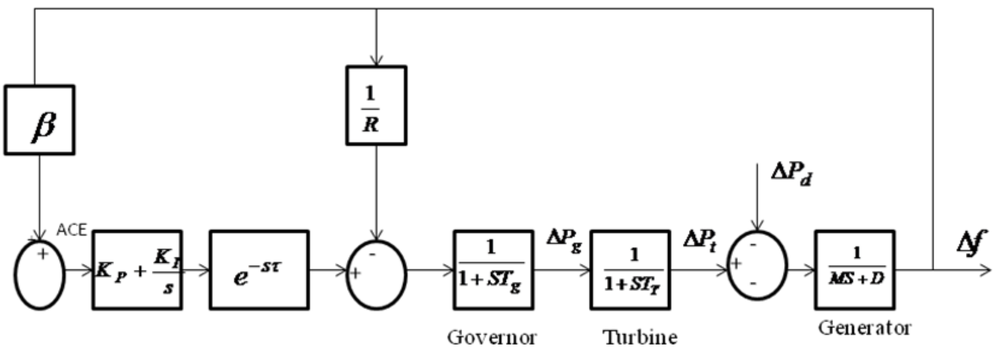


Figure 1. Dynamic model of single area LFC scheme.

The model of single area LFC can be expressed in state space form as:

$$\dot{x}(t) = Ax(t) + Bu(t-\tau) + Fw(t) \quad (1)$$

$$y(t) = Cx(t) \quad (2)$$

where

$$A = \begin{bmatrix} \frac{-D}{M} & \frac{1}{M} & 0 & 0 \\ 0 & \frac{-1}{T_t} & \frac{1}{T_t} & 0 \\ \frac{-1}{RT_g} & 0 & \frac{-1}{T_g} & 0 \\ \beta & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & \frac{1}{T_g} & 0 \end{bmatrix}$$

$$F = \begin{bmatrix} \frac{-1}{M} & 0 & 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} \beta & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

w(t) is disturbance vector and the disturbance variable is ΔP_d. x(t) is state vector and the state variables are $\Delta f, \Delta P_t, \Delta P_g$ and $\int ACE$. y(t) is output vector and the output variables are ACE and $\int ACE$. τ is a fixed delay. $\Delta f, \Delta P_t$ and ΔP_g are the deviation in frequency, the turbine power output and governor output respectively. ΔP_d is the change in load. β is frequency bias factor. T_g, T_t, M, D and R are governor time constant, turbine time constant, Moment of inertia, Damping co-efficient and speed droop respectively.

The tie-line power exchange is zero for a single area system. Therefore, the area control error (ACE) can be written as:

$$ACE = \beta\Delta f \quad (3)$$

The PI type load frequency controller is designed as:

$$u(t) = [K_P ACE + K_I \int ACE] \quad (4)$$

To get the closed loop model of the system in the state space form, the PI control problem is altered in to state output feedback control (SOF) problem. The closed loop model of single area LFC system can be expressed as:

$$\dot{x}(t) = Ax(t) + A_d x(t-\tau) + Fw(t) \quad (5)$$

$$y(t) = Cx(t) \quad (6)$$

where

$$A_d = [B * K * C]$$

$$K = [K_P \quad K_I]$$

The characteristic equation of the system (5) is required to be determined to analyze the stability of the system. This can be attained from the following equation:

$$\Delta_h(s) = \det(sI - A - A_d e^{-s\tau}) \quad (7)$$

The equation (7) can be written as:

$$P(s) + Q(s)e^{-s\tau} = 0 \quad (8)$$

where

$$P(s) = P_4 s^4 + P_3 s^3 + P_2 s^2 + P_1 s$$

$$Q(s) = q_1 s + q_0$$

P(s) and Q(s) are polynomials of s having real coefficients .The coefficients of these polynomials are given in Appendix-I.

DELAY DEPENDENT STABILITY ANALYSIS

The stability of time delayed LFC system can be analyzed by locating the roots of characteristic equation (8).The necessary and sufficient condition for the asymptotic stability of the system is that all the roots of the characteristic equation should lie in left half of the complex plane.

Stability Analysis

The asymptotic stability of the system is classified as delay independent stability and delay dependent stability.

- **Delay independent stability:** The system is stable independent of delay if the stability exists for all possible nonnegative time delays.
- **Delay dependent stability:** The system is stable dependent of the delay if the stability persists only for a subset of nonnegative delays.

In delay dependent stability, the roots of the characteristic equation depend on time delay τ. The roots of the characteristic equation move as τ varies. Initially when $\tau = 0$, the system is stable. As τ increases, the roots start moving from LHP to RHP. Fig.2. illustrates the movement of roots as time delay τ varies. The time delay (τ_d) at which the roots cross imaginary axis by moving from LHP to RHP is defined as the time delay margin.

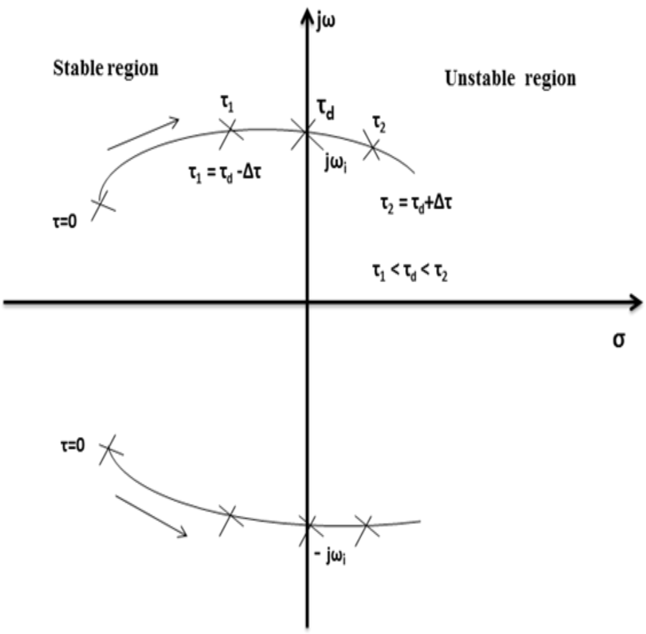


Figure 2. Illustration of movement of the roots of characteristic equation with respect to time delay.

Computation of Delay Margin

The stability delay margin of a system is defined as the maximum tolerable value of time delay until which the system is stable. Delay sweeping method [21] [22] is used to determine the delay margin. It provides less computation time and high accuracy.

Consider a system with time delay given by:

$$\dot{x}(t) = Ax(t) + A_d x(t-\tau) + Fw(t) \tag{9}$$

that satisfies $0 < \tau < \tau_d$

where τ is a constant time delay and τ_d is time delay margin.

The quasi polynomial (characteristic) equation of the above system can be written as:

$$\Delta_h(s) = P(s) + Q(s)e^{-s\tau} \tag{10}$$

with

$$P(s) = p_n s^n + p_{n-1}s^{n-1} + ... + p_1 s + p_0 \tag{11}$$

$$Q(s) = q_m s^m + q_{m-1}s^{m-1} + ... + q_1 s + q_0 \tag{12}$$

where P(s) and Q(s) are polynomials of s satisfying the following assumptions

- $m \le n$, if m=n then $|q_m|<1$
- P(s) and Q(s) have no common roots
- $p_0 + q_0 \neq 0$

If the above mentioned assumptions are not satisfied then $\Delta_h(s)$ is unstable for all $\tau > 0$.

Substituting $s = j\omega$ in (10), the characteristic equation $\Delta_h(s)$ can be written as:

$$\Delta_h(j\omega) = P(j\omega) + Q(j\omega)e^{-j\omega\tau} = 0 \tag{13}$$

$$e^{j\omega\tau} = \frac{Q(j\omega)}{-P(j\omega)} \tag{14}$$

This in turn is equivalent to:

1) $\left|e^{j\omega\tau}\right| = 1 = \left|\frac{Q(j\omega)}{-P(j\omega)}\right|$ (Magnitude relation) (15)

2) $\omega\tau = \arg\left[\frac{Q(j\omega)}{-P(j\omega)}\right]$ (Phase relation) (16)

The magnitude relation helps in finding the existence of roots crossing $j\omega$ axis.

The magnitude relation (15) can be rewritten as:

$$|Q(j\omega)| = |P(j\omega)| \tag{17}$$

The solution of the above equation can be obtained as:

$$\varphi(\omega) = P(j\omega)P(-j\omega) - Q(j\omega)Q(-j\omega) = 0 \tag{18}$$

The positive real solution of $\varphi(\omega)$ gives the frequency ω_i at which the roots of characteristic equation cross the jω axis. For the crossing frequency ω_i, the corresponding delay margin is obtained using phase relation.

The direction in which the roots cross jω axis is determined from:

$$\sigma(\omega) = \operatorname{sgn}\frac{d\varphi(\omega)}{dt} \tag{19}$$

If $\sigma(\omega_i)>0$, the roots migrate from LHP to RHP at crossing frequency ω_i(switch). If $\sigma(\omega_i)<0$, the roots migrate from RHP to LHP at crossing frequency ω_i (reversal). If $\sigma(\omega_i)=0$, the roots migration depends on higher derivatives. The delay at which the roots cross jω axis is obtained from phase relation (16):

$$\tau = \frac{\arg\left[\dfrac{Q(j\omega)}{-P(j\omega)}\right]}{\omega} + \frac{2\Pi k}{\omega} \tag{20}$$

For each crossing frequency ω_i , the equation (20) yields sequence of delays:

$$\tau_{i,k} = \tau_{i,0} + \frac{2\Pi k}{\omega_i} \quad k=(0, 1, 2.....) \tag{21}$$

where $\tau_{i,0} = \frac{\arg\left[\frac{Q(j\omega_i)}{-P(j\omega_i)}\right]}{\omega_i}$ is the smallest solution of equation(20). The stability analysis requires sorting of all $\tau_{i,k}$ in increasing order. There always exists a delay τ_d(delay margin) at which the roots cross jω axis from LHP to RHP after which the system goes unstable.

In the next section, one of the most effective optimization techniques is introduced to tune the controller parameters so as to optimize delay margin.

GENETIC ALGORITHM

This section presents a methodology for accomplishing the delay dependent stability analysis of single area LFC system in genetic algorithm. The Genetic algorithm is a global search optimization technique based on the operation of natural genetics and Darwin survival of the fittest. A main step in genetic algorithm is to define the objective (fitness) function which is the function to be optimized.

Problem Formulation

The problem is formulated to optimize the objective function involving PI controller parameters:

$$\text{Maximize } \tau_d \text{ subject to (18) – (21)} \tag{22}$$

GA starts with the random generation of initial population and then the selection, crossover and mutation operations are carried out until best population is obtained.GA repeatedly changes the population of individuals in each generation. At each step, GA uses the current population to create the children that make up the next generation. Finally, the algorithm selects individuals that have better fitness values.

Outline of the Algorithm

1. Initial solutions to N_j individuals of controller parameters K are generated randomly using a random number between [0, 1] and its values changes thereafter with in the evolution procedure according to the objective.
2. For every K_j, the delay margin τ is calculated such that with a delay τ and K_j, the equation (18) - (21) is feasible. Take every delay τ as the objective value corresponding to the controller value K and associate every K_j with a fitness value according to rank based fitness approach. If for a K_j, there is no feasible delay margin such that there is no solution for jω crossing, then the objective value should be assigned a large value to reduce its opportunity to be survived in the next generation.
3. Tournament selection approach is used to choose the offspring.
4. Uniform crossover with probability p_c is performed to produce new offspring.
5. The bits for individuals in the population are mutated with a small mutation probability p_m.
6. The best chromosome in the population is retained using elitist reinsertion method.
7. Step 2-6 corresponds to one generation. The process is repeated for N_g generations or being ended when the search process converges with a given accuracy.

SIMULATION RESULTS

Simulation studies are carried out for time delayed single area LFC endowed with PI controller. The system parameters are tabulated in Appendix-II. The stability of the system is analyzed and the maximum value of time delay at which the roots of characteristic equation cross jω axis is computed with the help of Delay Sweeping method. The results of the delay margin calculated for different sets of controller parameters are tabulated in Table 1.

Table 1. Delay margin obtained by the proposed method for fixed PI controller parameters (without GA)

τ_d (secs)	K_I						
K_P	0.05	0.1	0.15	0.2	0.4	0.6	1.00
0	30.85	15.18	9.95	7.327	3.377	2.039	0.920
0.05	31.854	15.664	10.269	7.569	3.496	2.585	0.968
0.1	32.72	16.091	10.556	7.784	3.605	2.191	1.010
0.2	34.176	16.823	11.051	8.152	3.782	2.306	1.753
0.6	34.885	17.173	11.259	8.297	3.819	2.275	0.942
1	0.592	0.582	0.572	0.561	0.513	0.461	0.360

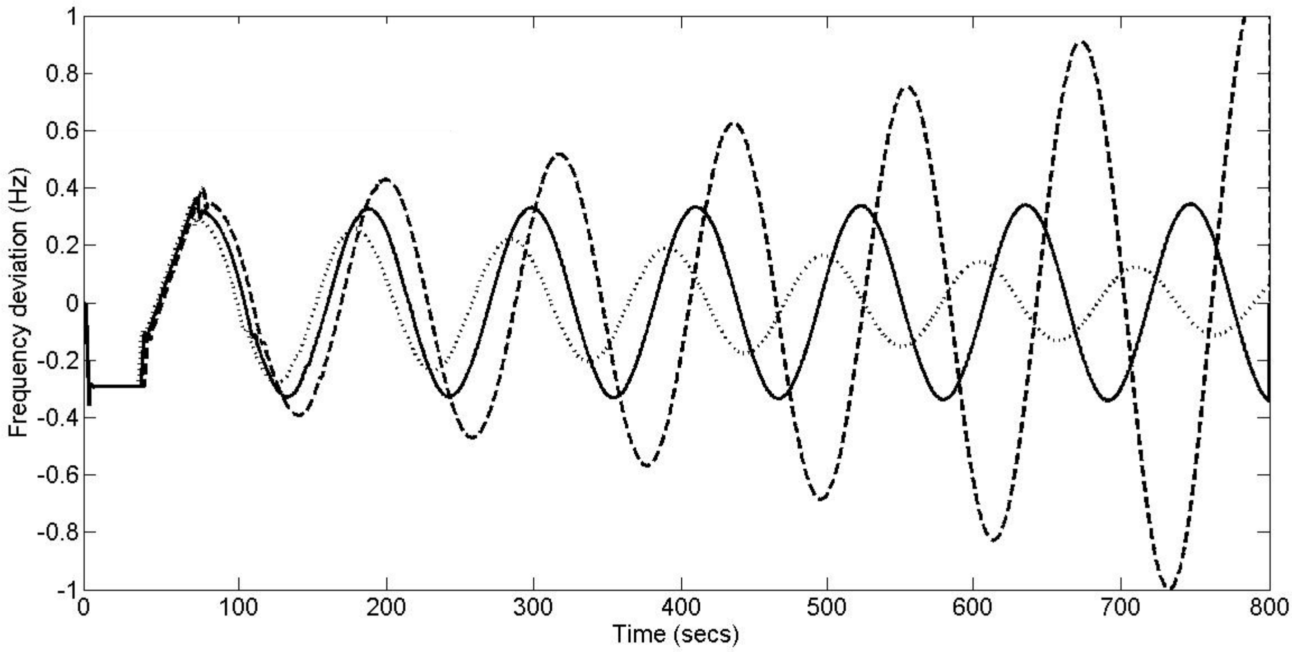
The comparison of delay margin obtained in the proposed method with the previous time delay control method is summarized in Table 2.

Table 2. Performance comparison of proposed method with previous time delay control method

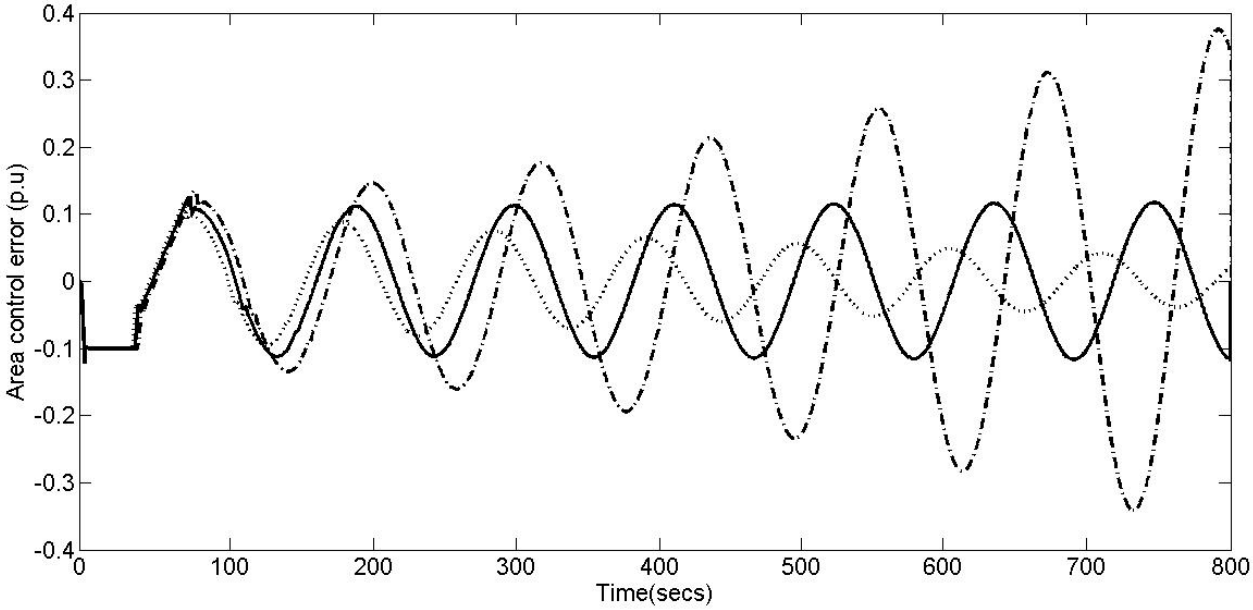
Methods	Maximum Delay Margin(s)	Controller Gain
Previous time delay control method[12]	27.927	[0,0.05]
Proposed method (without GA)	34.885	[0.6,0.05]
Proposed method (with GA)	35.827	[0.4523, 0.05023]

Evaluation of Theoretical Result through Simulation

Simulation is done to evaluate the accuracy of the delay margin calculated using proposed method. This is executed by increasing the time delay step by step from 0 secs in simulink model until the system goes unstable. The time response of the single area LFC system with GA based PI controller is shown in Fig.3.



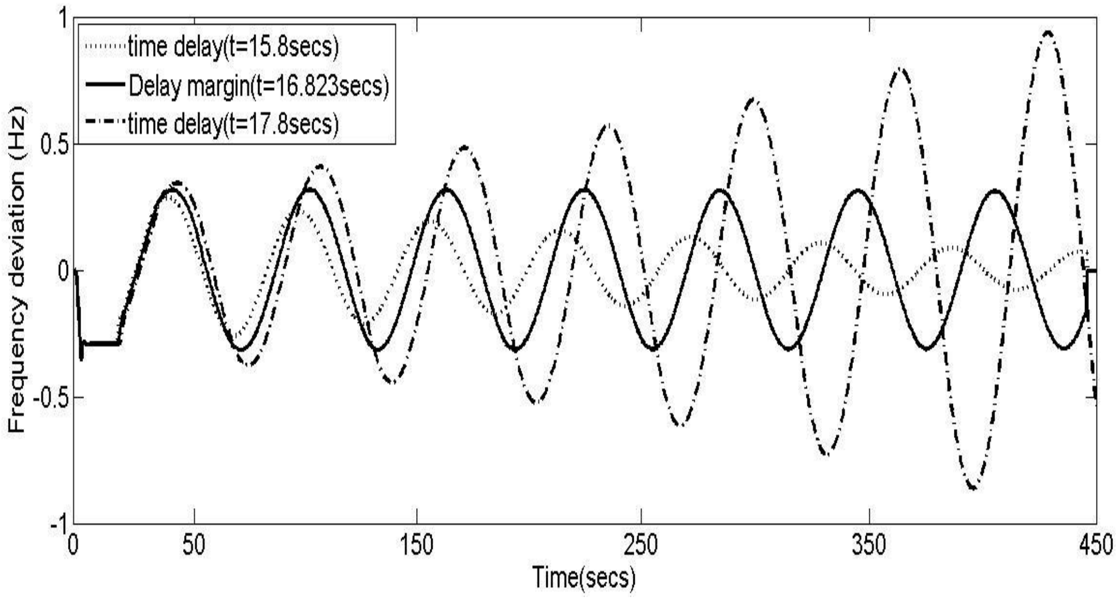
(a)



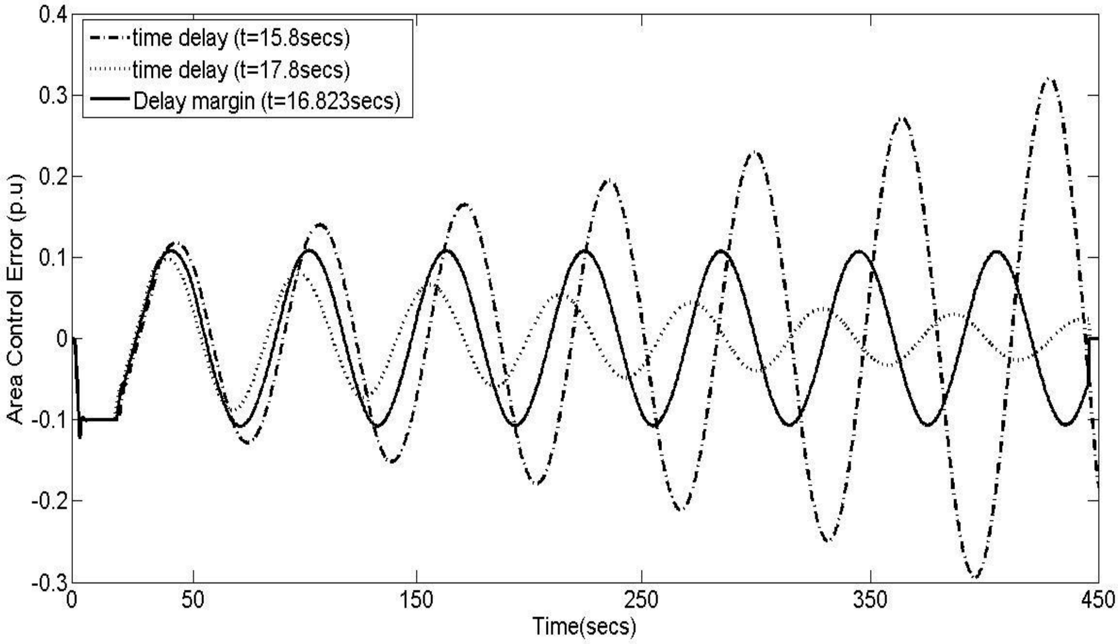
(b)

Figure 3. Time response of the single are LFC with PI controller tuned using GA (a) frequency variation, (b) ACE.

The dashed dotted line in Fig.3. shows the growing oscillations for time delay τ=38s. The dotted line in Fig.3. shows decreasing oscillations for time delay τ =34s .Thus the system loses its stability somewhere between 34 s and 38s and delay margin should lie within the range [34s, 38s]. The solid line in Fig.3. shows the sustained oscillations for delay margin τ_d =35.8s which indicates the system is marginally stable. This delay margin value is closer to the theoretically calculated delay margin (35.827s).It proves that the proposed method is highly accurate in finding delay margin compared to other frequency domain methods [18] and time domain methods [12] [14]. It also reveals that the system is stable for all time delays less than delay margin and it will go unstable when the time delay exceeds delay margin. The system response for PI controller gain (without GA) K_P= 0.2 and K_I=0.1 is shown in Fig.4.



(a)



(b)

Figure 4. Time response of the single are LFC with PI controller (without GA) (a) frequency variation, (b) ACE.

Discussion

The maximum value of delay margin obtained based on Lyapunov stability criteria [12] is only 27.927s. But in the proposed method, the controller is designed to obtain the maximum delay margin using GA. The delay margin obtained in the proposed method is 35.827s. Thus PI controller designed using proposed method is more effective in retaining the stability for longer time period. The bigger delay margin extends the on service time of LFC scheme in the event of any communication faults and the stability of the system is not disturbed even for longer period of time delay. The controller gain decides the delay margin and damping performance of the system. Its value can be selected in such a way to get larger delay margin and less deterioration in the damping performance of the system.

CONCLUSION

The Delay dependent stability of single area LFC scheme equipped with PI controller is analyzed and the delay margin is determined using Delay Sweeping Method. Genetic Algorithm is used to tune the controller parameters in order to obtain maximum delay margin. Simulation is done to prove that the proposed method is highly accurate and provides bigger stability region, less computation time. The results summarized in Table.2 reveal that the GA tuned controller is highly superior and robust as compared to conventional controller in maximizing the stability margin of LFC system with less degradation in system dynamic performance.

APPENDIX-I

The coefficients of polynomials P(s) and $Q(s)$ in (8) are given in terms of controller gains and time constants of the LFC system:

$$P(s) = p_4 s^4 + p_3 s^3 + p_2 s^2 + p_1 s$$

$$Q(s) = q_1 s + q_0$$

where

$$p_4 = RT_g T_t M$$

$$p_3 = RDT_g T_t M + RT_t M + RT_g M$$

$$p_2 = MR + RT_t D + RT_g D$$

$$p_1 = RD + 1$$

$$q_1 = \beta RK_P$$

$$q_0 = \beta RK_I$$

APPENDIX-II

Parameters of single area LFC scheme are:

β =21, D=1.0, M=10s, T_g =0.1s, T_t =0.3s, R=0.05

REFERENCES

[1] Gu.K, Khaitonov.V.L, Chen.J, *Stability of time delay systems,* (Birkhauser, 2003).

[2] Niculescu.S.I, *Delay effects on stability- A robust control approach* (New York: Springer-Verlag, 2001).

[3] Jia.H.J, X.D.Yu, A simple method for power system stability analysis with multiple time delays, *in proc. IEEE Power and Energy SO. General Meeting,* 2008, 20-24.

[4] Olgac.N, Sippahi.R, An exact method for stability analysis of time delayed linear time invariant systems, *IEEE Trans. Autom. Control, 47*(5),2002, 793-797.

[5] Sippahi.R, N.Olgac, Complete stability robustness of third order LTI multiple time-delay systems, *Automatica, 41* (8), 2005, 1413-1422.

[6] Liu.Z.Y, C.Z.Zhu & Q.Y.Jiang, Stability analysis of time delayed power system based on cluster treatment of characteristics roots method, *in Proc, IEEE Power and Energy Soc. General Meeting,* 2008,20-24.

[7] He.Y, O.G.Wang, L.H.Xie &C.Lin, Further improvement of free-weighting matrices technique for systems with time varying delay, *IEEE Trans. Autom. Control, 52*(2),2007, 293-299.

[8] Wu.M, Y.He, J.H.She & G.P.Liu, Delay dependent criterion for robust stability of time varying delay systems, *Automatica,40*(8),2004, 1435-1439.

[9] Xu.S.Y, J.Lam, On equivalence and efficiency of certain stability criteria for time delay systems, *IEEE Trans. Autom. Control, 52*(1), 2007, 95-101.

[10] Yu.X, K.Tomsovic, Application of linear matrix inequalities for load frequency control with communication delays, *IEEE Trans. Power Syst., 19*(3), 2004, 1508-1515.

[11] Hassa Bevarani, Takashi Hiyama, On Load-Frequency Regulation with Time Delays: Design and Real time Implementation, *IEEE Trans on Energy conversions, 24*, 2009, 292-300.

[12] Jian.L, W.Yao, Wu.Q.H, Wen.J.Y, Delay Dependent stability for load frequency control with constant and time varying delays, *IEEE Trans. Power Syst., 27*(2), 2012, 932-941.

[13] Dey.R, Ghosh.S, Ray.G, Rakshit.A, Load Frequency control of interconnected power systems with communication delays, *Electrical Power and Energy Systems, 42*, 2012, 672-684.

[14] Chuan-ke Zhang, Jiang.L, Further Results on Delay Dependent Stability of Multi Area Load Frequency Control, *IEEE Trans. Power Syst., 28*(4), 2013, 4465-4474.

[15] hang, Jiang.l, Delay dependent robust load frequency control for time delay power system, *IEEE Trans. Power Syst., 28*(3), 2013.

[16] Chen.J, Gu.G, Nett.C.N, A new method for computing delay margins stability of linear delay systems, *System and Control Letters, 26*(2), 1995,107-117.

[17] Wim Michiels, Tomas Vyhidal, Pavel Zitek, Control design for time-delay systems based on quasi-direct pole placement, *Journal of Process Control,20*, 2010, 337-343.

[18] Sahin Sonmez, Saffet Ayasun, Ulas Eminoglu, Computation of Time delay Margins for stability of a single area load frequency control system with communication delays, *Wseas Trans. On Power systems, 9*, 2014,67-74.

[19] Saffet Ayasun, Sahim Sonmez, Computation of Stability Delay Margin of Time-Delayed Generator Excitation Control System with a Stabilizing Transformer, *Mathematical problems in Engineering*,2014.

[20] Kundur.P, *Power System Stability and Control*, (McGraw-Hill Inc, 1994).

[21] Walton.K, Marshall.J.E, Direct method for TDS stability analysis, *IEEE Prooceedings:Control Theory and Applications,134*(2), 1987, 101-107.

[22] Saffet Ayasun, Sahim Sonmez, An Exact Method for Computing Delay Margin for Stability of Load Frequency Control Systems With Constant Communication Delays IEEE Transactions on Power Systems (Volume: 31, Issue: 1, Jan. 2016).