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LOAD FREQUENCY CONTROL USING MULTI VARIABLE CHARACTERISTIC LOCI METHOD IN POWER SYSTEMS

H.A. Shayanfar M. Ghazal M. Karami

Electrical Engineering Department, Iran University of Science and Technology
Tehran, Iran
hashayanfar@yahoo.com, milad_g64@yahoo.com, mahkaram@yahoo.com

Abstract- This paper describes a Multi Input Multi Output (MIMO) design method based on the Characteristic Loci (CL) to Load Frequency Control (LFC) of the power systems. The load frequency control problem has been a major subject in electrical power system design/operation and is becoming more significant recently with increasing size, changing structure and complexity in the interconnected power systems. In practice LFC systems use simple proportional integral controllers. However, since the PI control parameters are usually tuned based on the classical or trial-and-error approaches, they are incapable of obtaining good dynamic performance for a wide range of operation conditions and various load changes scenarios in multi-area power system. To solve this problem, in this paper the CL method is proposed. In addition for reducing compelxibility in computation, redefine input and output of system. The proposed method is tested on two area power system under various operating conditions .The simulation results show that the proposed CL design method controller achieves good performance even in the presence of Generation Rate Constraints (GRC) and is superior to the other controllers.

Keywords: Load Frequency Control, Power System Control, Multi Variable CL Method, Good Performance.

I. INTRODUCTION

The dynamic behavior of many industrial plants is heavily influenced by disturbances and, in particular, by changes in the operating point [1]. Load Frequency Control (LFC) is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. The main goal of the LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area power system [1].

The advantages of this operating philosophy are apparent in providing cost savings in data communications and in reducing the scope of the monitoring network. The mechanical input power to the generators is used to control the frequency of the output electrical power and to maintain the power exchange between the areas as scheduled. The main function of the power plant controller (governor) is to regulate the turbine speed, and hence frequency and active power [1].

The conventional strategy for the LFC system was the classical integral controller, but it have poor dynamic performance, especially in the presence of other destabilizing effects such as parameter variations and nonlinearities [2,3].

To improve the transient response, various control methods, such as linear feedback, optimal control and variable structure, have been proposed [4-7]. Although these methods had good transient response performance and robustness in the change parameter system but need some state of the system. The power system can be translated to state space model, then using modern control theory and MIMO design method can design controller for the power system.

In this paper, the controller with CL methods is designed and applies to the LFC problem of a two area power system. CL design methods is based on achieving the required diagonal dominance, so that each control loop can be designed independently, but this system have restriction to diagonal dominance. Although this specification fail, but simulation results show that the responses with this controller are robust to the parameter variation, even in the presence of system uncertainty, and have good transient performance [8].

II. SYSTEM MODEL

Generally change in the load is small in normal condition. Thus, a linear model can be used for the load frequency control. Figure 1 shows a block diagram of a two area power system without controller in each area. The state space model is [3]:

$$\dot{x} = Ax + Bu \qquad (1)$$

$$y = Cx$$

Where:

$$u = [\Delta P_{D1}, \Delta P_{D2}, u1, u2] \qquad (2)$$

$$y = [y_1, y_2] = [\Delta f_1, \Delta f_2, \Delta P_{tie}] \qquad (3)$$

$$x = [\Delta P_{G1}, \Delta P_{T1}, \Delta f_1, \Delta P_{tie}, \Delta P_{G2}, \Delta P_{T2}, \Delta f_2] \qquad (4)$$

$$A=\begin{bmatrix} \frac{-1}{T_{G_1}} & 0 & \frac{-1}{r_2T_{G_1}} & 0 & 0 & 0 & 0 \\ \frac{1}{T_{T_1}} & -\frac{1}{T_{T_1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 \\ 0 & 0 & T_{12} & 0 & 0 & 0 & -T_{12} \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{G_2}} & 0 & \frac{-1}{r_2T_{G_2}} \\ 0 & 0 & 0 & 0 & \frac{1}{T_{T_2}} & \frac{-1}{T_{T_2}} & 0 \\ 0 & 0 & 0 & \frac{1}{M_2} & 0 & \frac{1}{M_2} & \frac{-D}{M_2} \end{bmatrix} \quad B=\begin{bmatrix} 0 & 0 & \frac{1}{M_1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} \\ \frac{1}{T_{G_1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{T_{G_2}} & 0 & 0 \end{bmatrix} \tag{5}$$

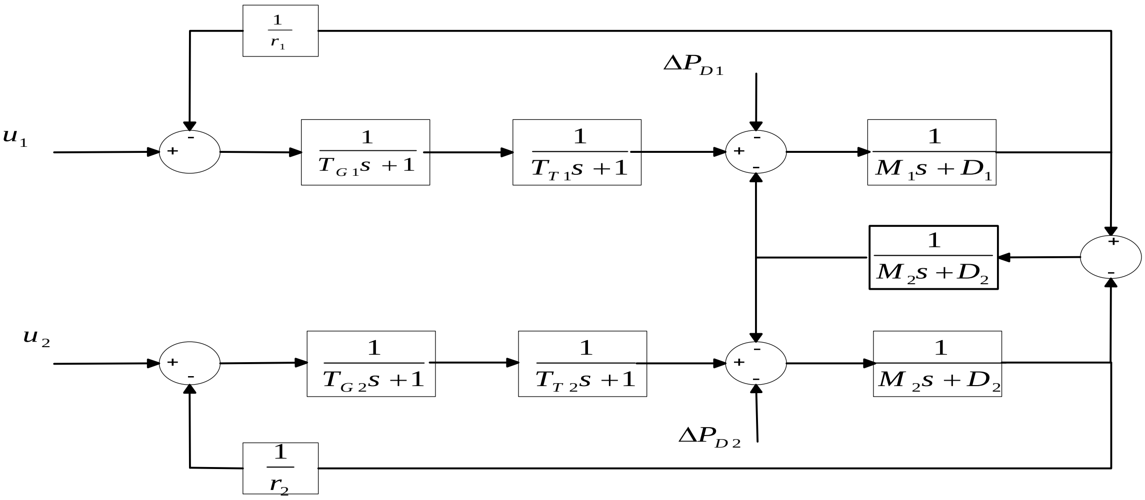


Figure 1. Block diagram of the two area power systems without controller

The typical values of the system parameter for the nominal condition are

$M=2H, T_{T1}=T_{T2}=0.03; T_{G1}=T_{G2}=0.08;$

$r_1=r_2=2.4; T_{12}=0.545$

The systems have high uncertainty in the parameter which causes difficulty to maintain good stability margins and performance properties for the closed-loop system. This paper, is prepared to demonstrate performance robustness of the proposed method, includes time response of frequency deviation for different uncertainty in parameters.

III. OVERVIEW OF CL DESIGN METHOD

The basic idea behind CL design method (MacFarlane and Kouvartakis, 1977) is first design of controller to achieve diagonal dominance at high frequency and then design commutative compensator to manipulate the characteristic locus as if they were ordinary Nyquist locus [9]. Briefly design method separated in three parts design controller that are series with plant according to Figure 2. The subscripts h, m and l denote high, medium and low frequency, respectively. controller is used to reduce interaction there at high frequency, if possible and commutative controller is used to improve the characteristic locus compensated plant at medium frequency, and finally controller is used for improving the steady state behavior. Design producer based on the CL methods can be described as follow [8]:

(1) Compute a real $K_h \approx -G^{-1}(j\omega_h)$, where ω_h is the high frequency.

(2) Design an approximation commutative controller K_m at frequency $\omega_m \le \omega_b$ for the compensated plant GK_h, such that $K_m \xrightarrow[\omega\to\infty]{} I$,but this is not realistic goal.

(3) Design a controller K_l at some frequency $\omega_l \le \omega_m$ for improving low-frequency behavior(typically because of excessive steady-state errors) for the compensated plant GK_hK_m, such that $K_l \xrightarrow[\omega\to\infty]{} I$. Usually, $K_l(s)$ is used for integral action.

(4) Realize the compensator as $K(s)=K_hK_m(s)K_l(s)$

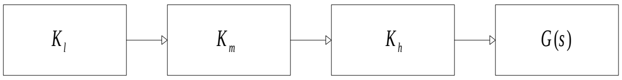


Figure 2. Three parts controller that are series with plant

IV. DESIGN OF CL CONTROLLER FOR TWO AREA POWER SYSTEM

Based on the procedure described in pervious section, a CL controller for two area power system whose model is mentioned in section 2 is designed. The objectives which must be met by closed- loop system are:

1) Band Width of about 3 rad/s is suitable and will result in a fast response for the closed- loop system.

2) Transient response; including overshoot and settling time of the step response are also important and should be remained in a sensible range.

3) Stability and performance of the closed- loop system should be robust with respect to the uncertainty of the plant and a turbine dynamics.

IV.A. Properties of the Plant

The time response of the plant for change in load in power station has steady-state error .the poles of the plant is:

-0.1081 + 0.7391i -12.1640
-0.1081 - 0.7391i -12.1628 -33.4571
-0.2174 -33.4571

Thus, the system is stable but not has a good performance and zero steady-state error. Figure 3 shows the two characteristic locus of the plant in Nyquist diagram. Since the range of the magnitudes is very large over the frequency range and close loop system is stable. Note that, to reduce the complexibility design and none equality of the input and output, new input and output redefined [3], Where:

Inputs:

u_{n1}: Control signal for the governor in the first area

u_{n2}: Control signal for the governor in the second area

Outputs:

y_1: For the first area is $y_1 = \Delta f_1 + T_{tie}$

y_2: For the second area is $y_2 = \Delta f_2 - T_{tie}$

Thus, we now see the system with two inputs and two outputs.

IV.B. Step I: Design Controller $K_h(s)$

The pre-compensator $K_l(s)$ is a constant controller for reducing the interaction between input and another output [8]. Figure 4 shows the miss alignment angles of the plant. Clearly, there isn’t any pre-compensation for reducing miss alignment angle (so reduce interaction). Therefore pre-compensator $K_h(s)$ is unit matrix.

$K_h = diag\{1,1\}$

where, $diag\{1,1\}$ is diagonal compensator.

IV.C. Step II: Design Controller K_m

Figure 5 shows the characteristic locus of $G(s)K_h$ in Nichols chart. To select medium frequency, by attention to Figure 5 and B.W, of the plant the medium frequency is selected 2 rad/sec (cross over frequency);a phase-lead can be designed for improvement in the system's stability and an increase in the response speed [10].

From the classical feedback control point view, such an increase means an improvement in the system robustness. By attention to figure 5, controller K_m design will be as follows (note that gain and phase margin have a little change). Thus, the controller is

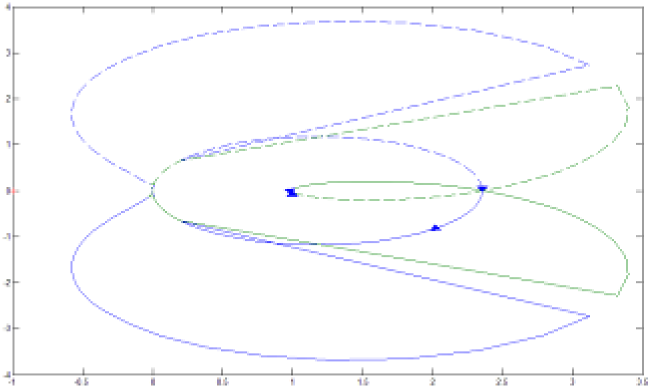


Figure 3. Characteristic locus of G(s) in Nyquist diagram

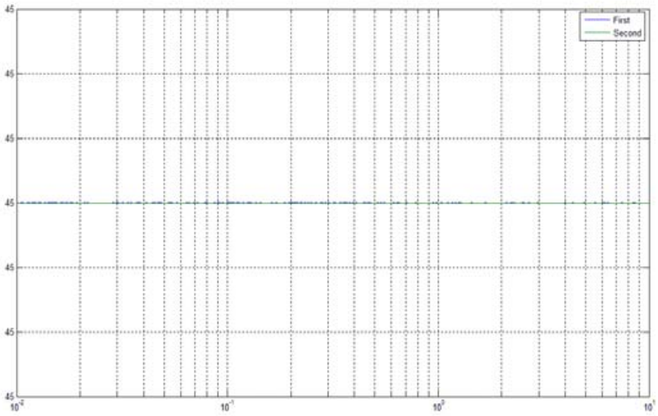


Figure 4. Miss alignment angle of G(s)

From the classical feedback control point view, such an increase means an improvement in the system robustness. By attention to Figure 5, controller K_m design will be as follows (note that gain and phase margin have a little change). Thus, the controller is

$$K_{mlead} = \frac{0.3443\ s + 1}{0.7023\ s + 1}$$

$$K_m = \begin{bmatrix} K_{mlead} & 0 \\ 0 & K_{mlead} \end{bmatrix}$$

Figure 6 shows the characteristic locus of the $G(s)K_hK_m(s)$ in Nichols chart. Clearly, gain margin and phase margin of the compensated system improved, but characteristic locus have small gain at low frequency.

IV.D. Step III: Design Controller $K_l(s)$

To improve gain at low frequency and improve behaviour of the $G(s)K_hK_m(s)$ controller $K_l(s)$ is designed. Figure 6 shows that the characteristic locus has low frequency gain smaller than 10 db. To increase characteristic locus at low frequency, it is clear to introduce integral action. So, we apply compensation of the form $(1+sT)/sT$ to each characteristic locus. To ensure that the controller $K_l(s)$ will not affected loci at frequencies greater than 2 rad/sec, we choose $T \geq 1/0.2$ [8]. Finally, we choosing T=5 and controller $K_l(s)$ is:

$$K_l = diag\{\frac{5s+1}{5s}, \frac{5s+1}{5s}\}$$

IV.E. Realize the Compensator

Finally complete compensator is $K(s)=K_h K_m(s) K_l(s)$. Figure 7 shows the characteristic locus of $G(s)K(s)$ in Nichols chart and figure 8 shows its principal gains in Bode form.

Clearly, open loop compensated plant have desired gain and phase margin and gain at low frequency. Note that to increase the effect frequency deviation toward tie line power; we multiply them by 10 at the feedback paths.

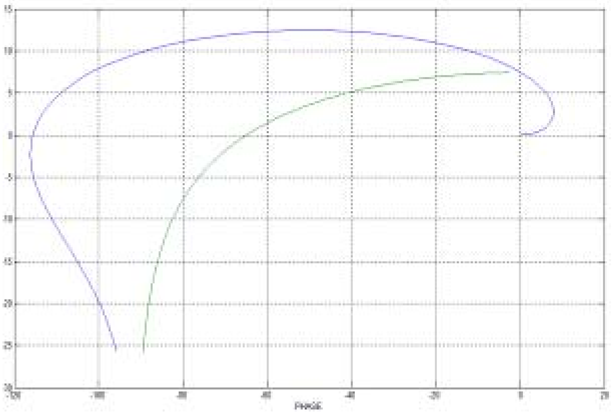


Figure 5. Characteristic locus of $G(s)K_h$ in Nichols chart

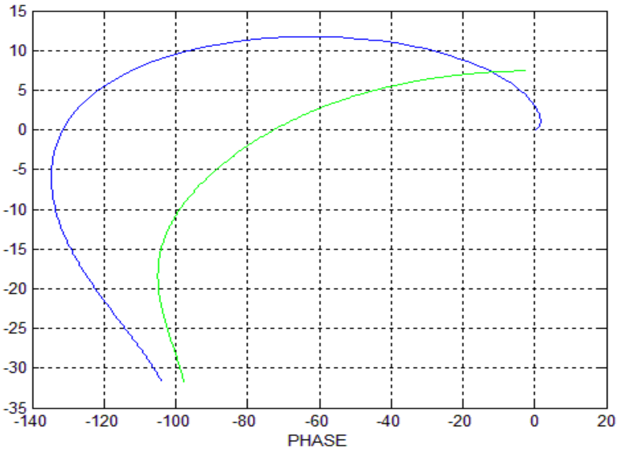


Figure 6. Characteristic locus of $G(s)K_h K_m(s)$ in Nichols chart

V. SIMULATION RESULT

In the simulation study, the linear model of the turbine is replaced by the nonlinear model of figure 7 (with ±0.1 limit). This is to take generation rate constrains into account, i.e. the practical limit on the rate of the change in the generating power of each generation companies.

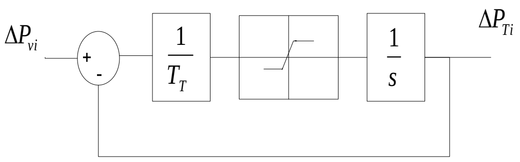


Figure 7. Nonlinear turbine model with generation rate constrains

The proposed controller is applied for each control area of the deregulated power system. Simulation has been done with 0.03 pu MW load changes in step form in the first area. The performance of the proposed controller is compared with QFT controller [3]. Figure 8a shows Δf_1, Δf_2 and ΔP_{tie} of the two area power system. Clearly, the frequency deviations of the two areas and the tie line power are quickly driven back to zero and have very small overshoots in the CL controller. For robustness evaluation, %25 change of system parameter is considered. For showing robustness, frequency deviation and tie line power of system has been shown in different uncertainty in the system parameters .Figure 8 and Figure 9 show the simulation result, for CL and QFT controllers with positive and negative uncertainty in the parameters, respectively. Clearly, uncertainty increase frequency deviation in two area and QFT controller is more sensitive and large uncertainty. The frequency deviation of the QFT controller cannot diverge.

To demonstrate the performance robustness of the proposed method, the Integral of the Time multiplied Absolute value of the Error (ITAE), the Integral of the Time multiplied Square of the Error (ITSE) based on frequency deviation are being used as [11]:

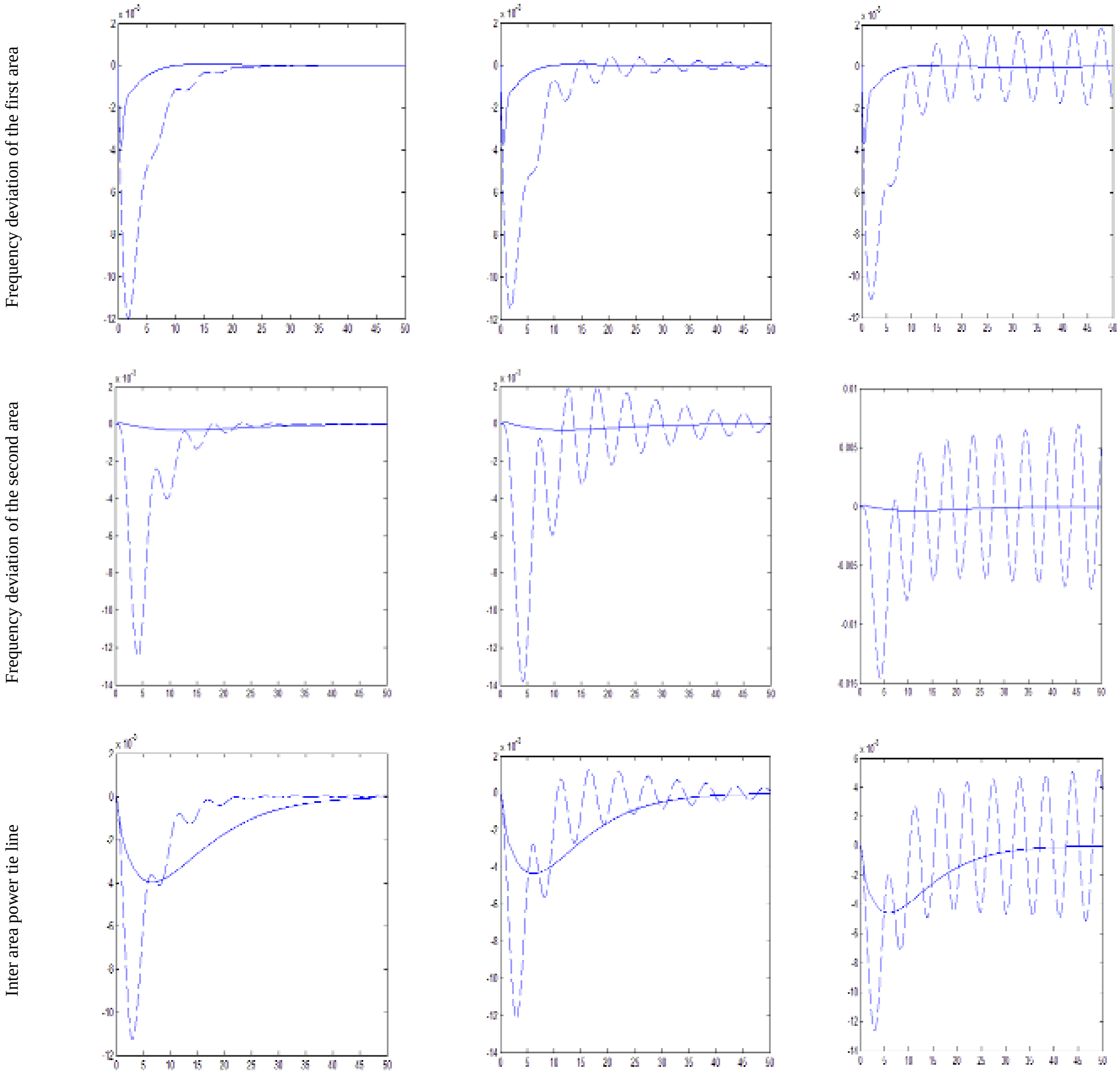
$$ITAE = 100\int_0^{50} t(|df_1| + |df_2|)dt \tag{6}$$

$$ITSE = 1000\int_0^{50} t(|df_1|^2 + |df_2|^2)dt \tag{7}$$

Numerical solution of the performance robustness for the above scenarios in the various operating conditions are listed in table1 and table 2.Clearly the performance of the proposed controller is better than those of the integral and QFT controller(clearly, QFT controller is better than integral controller [3]).

VI. CONCLUSION

In this paper, a decentralized controller based on CL method for two area power system is designed. Because of none equality of the input and output power system and also reducing the complexibility design, a new input and output are redefined in section fourth. Simulation result are comparing to frequency deviation and tie-line power of QFT controller. Simulation results show that the designed controller have a good performance compared with other QFT controller with or without uncertainty in the parameters. Finally, the simple decentralized controller designed in this paper can be used in practical applications.



a

B

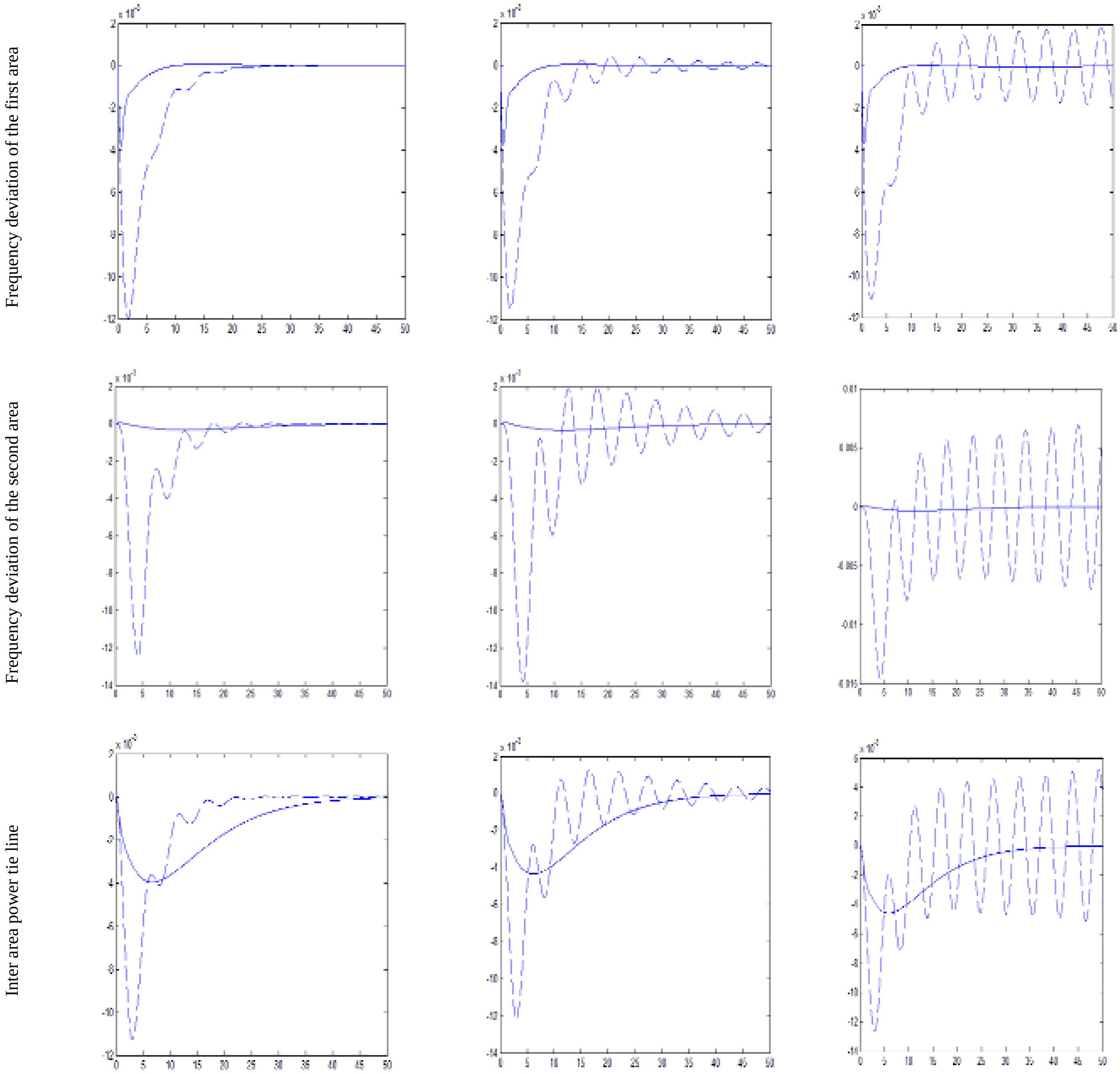
c

Figure 8. Dynamic response, following 0.03 change demand in first area (Solid line: CL controller, Dash line: QFT controller)

a) Dynamic response without uncertainty

b) Dynamic response with 15% uncertainty

c) Dynamic response with 25% uncertainty



a B c

Figure 9 Dynamic response, Following 0.03 change demand in first area (solid line: CL controller, dash line: QFT controller)

a) Dynamic response with -5% uncertainty

b) Dynamic response with -15% uncertainty

c) Dynamic response with -25% uncertainty

Table 1. Performance indices of ITAE

Test no.	Parameter change (%)	CL controller	QFT controller
0	0	17.18	72.77
1	+5	16.77	79.86
2	-5	17.68	72.68
3	+10	16.43	103.7
4	-10	18.31	73.45
5	+15	16.15	164
6	-15	19.07	74.3
7	+20	15.93	-
8	-20	19.76	75.25
9	+25	15.74	-
10	-25	20.69	76.42

Table 2. Performance indices of ITSE

Test no.	Parameter change (%)	CL controller	QFT controller
0	0	0.0408	3.493
1	+5	0.04561	3.678
2	-5	0.0485	3.376
3	+10	0.04525	4.39
4	-10	0.04702	3.28
5	+15	0.04492	5.02
6	-15	0.0476	3.218
7	+20	0.04464	-
8	-20	0.04823	3.157
9	+25	0.0444	-
10	-25	0.04892	3.103

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BIOGRAPHIES

Heidar Ali Shayanfar was born in Zabol, Iran, 1951. He received the B.Sc. and M.S.E. degrees in Electrical engineering in 1973 and 1979 and the Ph.D. degree in electrical engineering from Michigan State University, U.S.A., in 1981. Currently, he is a full professor at electrical engineering department of Iran University of Science & Technology University (IUST), Tehran, Iran. His research interests are in the application of artificial intelligence to power system control design, dynamic load modeling, power system observability studies and voltage collapse. He is a member of Iranian Association of Electrical and Electronic Engineers (IAEEE) and IEEE.

Milad Ghazal received his B.Sc. degrees in Electrical Engineering in 2007 from Shiraz University. Currently, he is pursuing his M.Sc. degree at Iran University of Science and Technology (IUST) in electrical engineering. His research interests include application of Robust Control, Artificial Intelligence to power system control design.

Mehdi Karami was born in Abadeh, Iran, 1979. He received his B.Sc. and M.Sc. degrees in Electrical Engineering in 2002 and 2004 from Tehran University and Iran University of Science and Technology (IUST), respectively. Currently, he is pursuing his Ph.D. degree at IUST in electrical engineering. His research interests include application of fuzzy logic and genetic algorithm to power system control, power system restructuring, power system economics and optimization. He is a member of Iranian Association of Electrical and Electronic Engineers (IAEEE).