Robust Controller Design for Load Frequency Control Based on Quantitative Feedback Theory

Asha Rani G.S
Department of Electrical
College of Engineering
Thiruvananthapuram, Kerala, India

Beena N.
Department of Electrical
College of Engineering
Thiruvananthapuram, Kerala, India

***Abstract*—Thelarge scale power systems are liable to performance deterioration due to the presence of sudden small load perturbations and parameter uncertainties. Due to this, modern control aspects are very important in Load Frequency Control (LFC). This paper presents a robust load frequency controller design based on Quantitative Feedback Theory (QFT). QFT is an engineering control design methodology that explicitly emphasizes the use of feedback to simultaneously and quantitatively reduce the effect of plant uncertainty and satisfy performance specifications. This new controller method not only handles the parametric uncertainty in power system, but also covers a wide range of load changes.**

Keywords-Load frequency control,Robust control,Quantitative Feedback Theory

I. INTRODUCTION

The successful operation of interconnected power systems require the matching of total generation with total load demand and associated system losses. Automatic generation control (AGC) is designed and implemented to automatically balance generated power and load demand in each control area. The primary objectives of AGC are to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values, by adjusting the output of selected generators. This function is commonly referred to as load frequency control (LFC)[1].

For Load Frequency Controller design the proportional-integral (PI) controller is widely used in power industry. Conventional PI controllers of fixed structure and constant parameters are usually tuned for one operating condition. Since the characteristics of the power system elements are non-linear, these controllers may not be capable of providing the desired performance for other operating conditions.The LFC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion. Zribi et al. has designed a decentralized adaptive control scheme [2]. However, this method requires either information of the system states or an efficient on-line identifier. A distributed Model predictive Control (MPC) structure was presented by Venkat et al. in [3]. For distributed MPC, the overall system is decomposed into interconnected subsystems each with its own MPC controller. But the effectiveness of MPC is dependent on a model of acceptable accuracy and the availability of sufficiently fast computational resources. In recent years, modern intelligent methods such as fuzzy logic, artificial neural networks (ANN), genetic algorithm (GA) and hybrid intelligent techniques have been proposed for load frequency control.The salient feature of these techniques is that they provide a model free description of control systems and do not require model identification. Since all of the developed intelligent techniques are usually dependent on knowledge extracted from environment and available data, knowledge management plays a vital role in the LFC synthesis procedures [4,5].

Since the important issue in the LFC design is robustness, the application of robust control theory to the LFC problem in multi area power system has been extensively studied during the last two decades. The main goals have been determined as holding the robust stability and robust performance against the system uncertainties and disturbances for a reasonable range of operating conditions. The robust controller based on Riccati equation approach is presented in [6]. Robust controller for load frequency control in a deregulated two area thermal power systems by using a µ-synthesis approach is presented by H.Bevrani in [7]. C. Balarko et al. has reported a decentralized H_∞ damping control design based on the mixed sensitivity formulation in the LMI framework [8].

A robust load frequency controller based on Quantitative Feedback Theory (QFT) is presented in this paper. In power systems the model uncertainties are typically large and most robust controller design methods that incorporate a conservative description of the uncertainty often fail to provide a solution even when one exists. Frequency domain techniques such as H_∞ optimization and µ-synthesis do not provide much control over the closed loop pole location and hence the transient response of the system[9]. QFT on the other hand, does not introduce any conservativeness in the uncertainty description and is therefore more likely to provide a solution with acceptable system performance[10].

II. SYSTEM MODEL

Many complicated nonlinear models have been presented for large power systems. But the linearized model has been usually used [1]. In Figure 1, a single-area power system has been shown. In this paper, this system has been studied and the errors of the linearization have been considered as parametric uncertainties.

Considering a non-reheat type steam turbine, the transfer function is

$$G_T(s) = \frac{1}{(1+sT_T)} \quad (1)$$

Load and machine transfer function is

$$\frac{1}{(2Hs+D)} \quad (2)$$

Most steam turbines now in service are equipped with turbine speed governors. The function of the speed governor is to monitor continuously the turbine-generator speed and to control the throttle valves which adjust steam flow into the steam turbines in response to changes in system speed or frequency.

Valve actuator's transfer function is

$$(3) \quad G_H(s) = \frac{1}{(1+sT_H)}$$

The T_T,T_H, D, and H are the turbine time constant,governor time constant, damping ratio and machine inertia, respectively. Droop characteristics of governor is 1/R.

In order to maintain the frequency at the scheduled value, the speed changer setting must be adjusted automatically by monitoring the frequency changes. For this purpose a PI controller is included as a secondary control. However this method cannot give good response especially when the parameters of the system changes. Therefore a new robust controller based on QFT is presented in the next section.

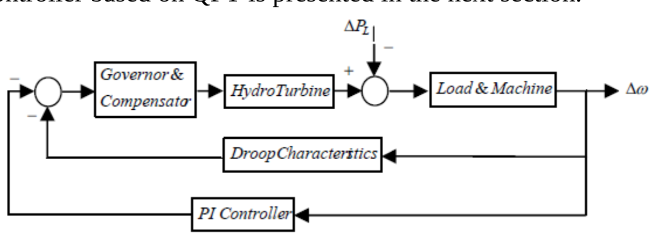

Fig.1Linear model of the single area LFC system

III. DESIGN OF QFT BASED LFC

Quantitative Feedback Theory (QFT) has been successfully applied to many engineering systems sinceit was developed by Horowitz [10,11]. The underlying principle of QFT is to transform plant uncertainties and closed-loop design specifications into robust stability and then open-loop performance bounds. This way a robust controller can be designed using simple loop shaping techniques with the nominal system. Figure 2 shows an overview of QFT control system design [12].

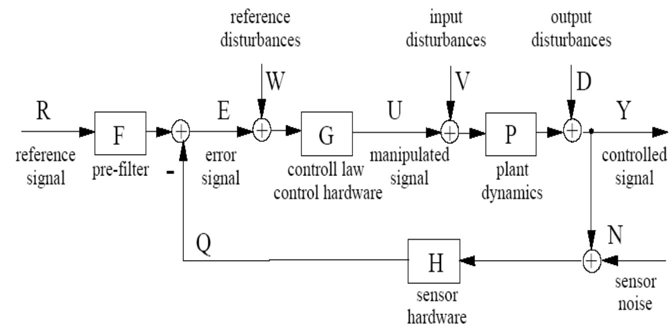

Fig.2.Two-DOF feedback system

QFT method is used to design a robust load frequency controller. The designed controller should guarantee the following performance specifications:

a. Power system stability within variations of operating point.

b. Acceptable dynamic response of step load changes

c. Frequency variations should be equal to zero in steady state.

Load and machine transfer function is assumed as the plant dynamics (P) and ΔP_Lwill be the input disturbance.

ΔP_{ref} is the reference signal. The effect of ΔP_{ref} in LFC is not considered. Therefore the design of the pre-filter is ignored. The poles and zeros of the controller are designed using QFT toolbox in MATLAB [12] with some modifications, so that the open-loop transfer function is reshaped.

The operating points of thepower system may randomly change during a daily cycle due to the inherent characteristics of load variationand system configuration. As a result, the parametric uncertainties of the power system should be considered.

A. QFT Design Procedure

A common QFT design procedure usually consists of the following steps, as outlined below[11,12].

1) Generating plant template and a nominal plant:

In QFT, uncertainties present in the plant are pictorially presented as an area on Nichols chart.A range of frequencies must be defined in the form of an array over which the performance of the system will be evaluated.The nonlinear plant is described by a set of j LTI plants which define the structured plant uncertainty. $P = \{P_i(s)\}$, (i=1, 2,…j)

j data points (log magnitude and phase angle), for each value of frequency, are plotted on the Nichols Chart. A contour is drawn through the data points, for each frequency, which describes the boundary of the region that contains all the j data points. This is called plant template.An arbitrary member in the plant set is chosen as the nominal case. Figure 3 shows the plant templates at the selected frequencies.

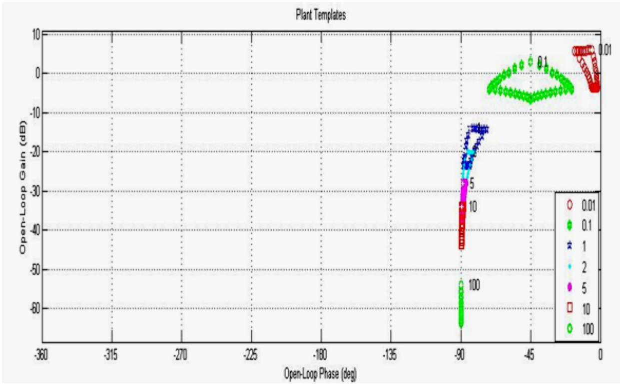

Fig.3.Plant templates

2) Design specifications

The controller G(s) is designed to satisfy the following performance specifications:

Robust stability margin: $\left|\dfrac{L(j\omega)}{1+L(j\omega)}\right| \le 1.2$, ω>0

L(jω)=P(jω) G(jω)H(jω) is the loop transfer function.

Robust input disturbance rejection: $\left|\dfrac{\Delta w}{\Delta P_L}\right| \le 0.01$, ω>0

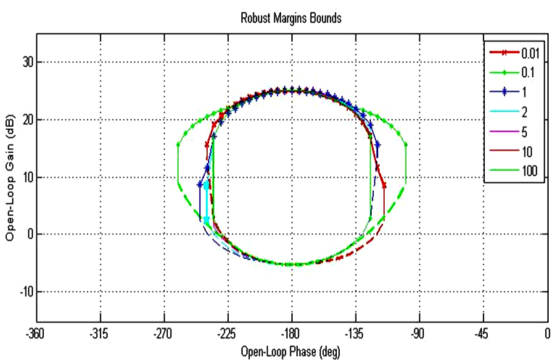

Fig. 4. Robust margin bounds

3)Formulation of Bounds

The design of the controller G(s) is accomplished in the Nichols chart, in terms of the nominal open loop transfer function.$L_0(s)=P_0(s)G(s)H(s)$ A discrete set of design frequencies is chosen. At each selected frequency point, combining the robust stability and robust performance specifications with plant templates yields stability margins and performance bounds in term of the nominal case. Intersection of all such bounds, i.e., the worst case bound, at the same frequency point yields a single QFT bound. Compute such QFT bounds for all frequency points. If there is no intersection between the bounds, the most restrictive bound is taken as the composite bound. However, if the bounds are intersecting, then the composite bound is formed by tracing the union of all bounds at that frequency. Hence the specifications of the closed-loop systems for all j LTI plantsare translated into that of the open loop nominal case.

Figure 4 shows the robust margin bounds and figure 5 shows the robust input disturbance rejection bounds. The intersection of all bounds is shown infigure 6.

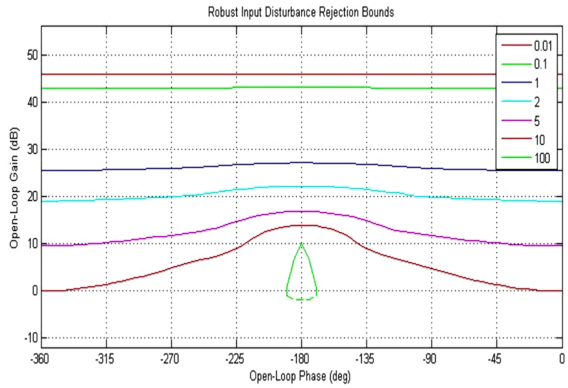

Fig.5. Robust input disturbance rejection bounds

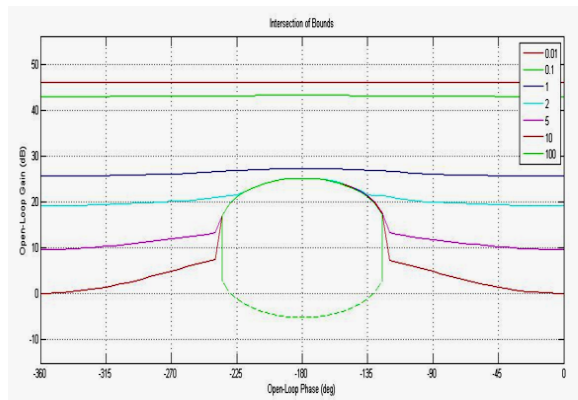

Fig.6.Intersection of all bounds

4) Loop-Shaping

Once the composite bounds are formulated, the next step is to design a controller such that loopgain satisfies these bounds. This process is called as loop-shaping and is done manually to ensure that the predefined stability and robustness features are achieved. The poles and zeros are placed arbitrarily, and designers have to look for various combinations of poles and zeros such that a satisfactory compensator is obtained. The loop shaping is performed using the QFT toolbox [12] in MATLAB. The resulting loop function is shown in figure 7.

IV. RESULTS AND DISCUSSION

Simulation is conducted by considering a typical single area power system[1], the parameters of which are as follows;

T_T=0.3,T_H=0.08, D= 1.5, H= 7, and R = 0.05

The controller obtained after loop shaping is

$$G(s) = 288.6\frac{s^2 + 2.944s + 3.435}{s(s+630)} \qquad (4)$$

The robust stability margin requirement is analyzed and the result obtained is shown in figure 8.The design specification is plotted as the dotted line and the worst closed loop response magnitude is shown as the solid line. It can be seen that the robust stability specification matches perfectly for the desired stability margin value.

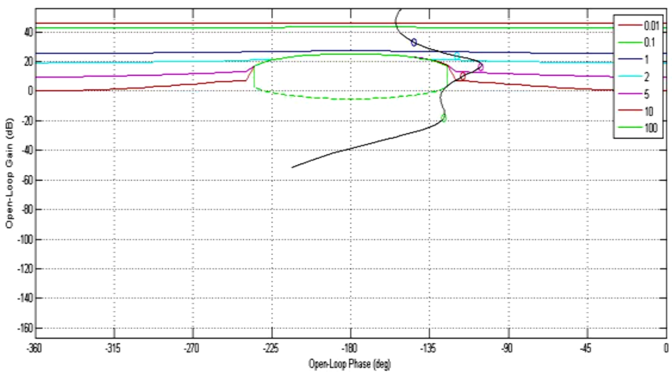

Fig. 7. Final loop shaping design

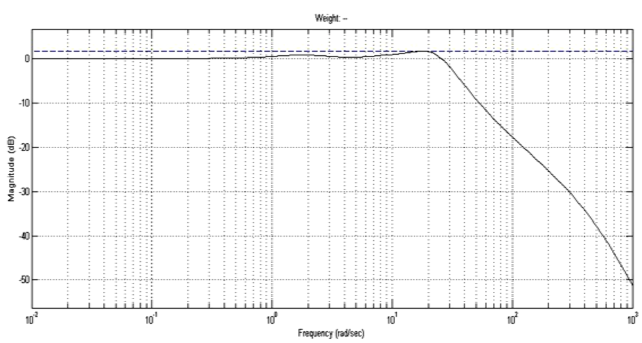

Fig. 8. Validation of closed loop robust stability

Figure 9 shows the change in frequency of the system for a small step change in load (ΔP_L= 0.02p.u)and from the results obtained it has been shown that the proposed controller is more accurate with less undershoot.

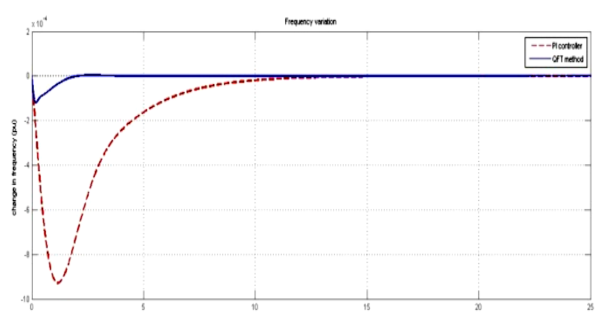

Fig. 9.Frequency variation following a small change in load

V. CONCLUSIONS

This paper presents a robust controller design for load frequency control based on quantitative feedback theory. Simulation results on a single machine infinite bus system following a small step change in load gives a better performance than conventional PI controller. Also the designed controller guarantees the robust stability and robust performance under a wide range of parametric uncertainty.

REFERENCES

[1] KundurPrabha, Power system stability and control. New York: McGraw-Hill; 1994.

[2] Zribi M, Al- Rashid, Alrifai M. "Adaptive decentralized load frequency control of multi area power systems." *International Journal of Electrical Power and Energy Systems*, vol 27(8), pp 575-583, 2005

[3] Aswin N. Venkat, Ian A. H, S.J Right, " Distributed MPC strategies with Application to power system automatic generation control.*" IEEE Transactions on Control System Technology*, vol 16(6) Nov 2008.

[4] J. Talaq and F. Al-Basri, "Adaptive fuzzy gain scheduling for load-frequency control," *IEEE Trans. Power Syst.*, vol. 14, no. 1, pp. 145–150, Feb. 1999.

[5] T.P.I Ahmed, P.S.N Rao, "A Neural network based Automatic generation controller design through reinforcement learning." *International Journal of Emerging Electrical Power Systems*, vol 6(1), pp 1-31, 2006.

[6] G. Ray, A. N. Prasad, G. D. Prasad, "A new approach to the design of robust load-frequency controller for large scale power systems," *Electric Power Systems Research*, vol. 51, pp. 13-22, 1999.

[7] H. Bevrani, "Robust load frequency controller in a deregulated environment: a µ-synthesis approach. *In proceedings of the 1999 IEEE International Conference on Control Applications, Hawai, USA,* Aug. pp.22–27, 1999.

[8] ChaudhuriBalarko et al. "Mixed sensitivity approach to H∞ control of power system oscillations employing multiple FACTS devices." *IEEE Transactions on Power Systems* 2003; 18(3): pp1149–56.

[9] A. Khodabakhshian, R. Hooshmand "A new PID controllers design for automatic generation control of hydro power systems." *InternationalJournal of Electrical Power and Energy Systems*; vol.32: pp.375–82, 2010.

[10] I. M. Horowitz, "Survey of quantitative feedback theory (QFT)," *International Journal of Robust and Non linear Control*, vol. 11, pp. 887-921, 2001.

[11] I. M. Horowitz, "Quantitative Feedback Design Theory (QFT), vol 1, QFT Publications, 4470 Grinnel, Colorado. USA 1992.

[12] C.Borghesani, Y. Chait, O. Yaniv, "The QFT frequency domain control design toolbox for use with Matlab, user's guide", 2003