Research Journal of Applied Sciences, Engineering and Technology 5(1): 94-99, 2013
DOI:10.19026/rjaset.5.5089
ISSN: 2040-7459; E-ISSN: 2040-7467
© 2013 Maxwell Scientific Publication Corp.
Submitted: March 10, 2012 Accepted: April 04, 2012 Published: January 01, 2013

Research Article

Multi-Machine Power System Stabilizer Design using Quantitative Feedback Theory

Sayed Mojtaba Shirvani Boroujeni, Babak Keyvani Boroujeni and Mostafa Abdollahi
Department of Electrical Engineering, Boroujen Branch, Islamic Azad University, Boroujen, Iran

Abstract: Power System Stabilizers (PSSs) are used to enhance damping of power system oscillations through excitation control of synchronous generator. The objective of the PSS is to generate a stabilizing signal, which produces a damping torque component on the generator shaft. Conventional PSSs are designed with the phase compensation technique in the frequency domain and include the lead-lag blocks whose parameters are determined according to a linearized power system model. The performance of Conventional PSSs (CPSSs) depends upon the generator operating point and the system parameters, but a reasonable level of robustness can be achieved depending on the tuning method. To overcome the drawbacks of CPSS, numerous techniques have been proposed in literatures. In this paper a robust method based on Quantitative Feedback Theory (QFT) Algorithm is used for tuning the PSS parameters. The proposed QFT-PSS is evaluated at a multi machine electric power system. The simulation results clearly indicate the effectiveness and validity of the proposed method.

Keywords: Low frequency oscillations, multi machine electric power system, power system stabilizer, quantitative feedback theory

INTRODUCTION

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating. These oscillations with small magnitude and low frequency often persist for long periods of time and in some cases they even present limitations on power transfer capability (Liu *et al*., 2005). In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is associated with generators at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as "intra-area mode" oscillations. The second type is associated with swinging of many machines in an area of the system against machines in other areas. This is referred to as "inter-area mode" oscillations. Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp both types of oscillations (Liu *et al*., 2005). The widely used Conventional Power System Stabilizers (CPSS) are designed using the theory of phase compensation in the frequency domain and are introduced as a lead-lag compensator. The parameters of CPSS are determined based on the linearized model of the power system. Providing good damping over a wide operating range, the CPSS parameters should be fine tuned in response to both types of oscillations. Since power systems are highly nonlinear systems, with configurations and parameters which alter through time, the CPSS design based on the linearized model of the power system cannot guarantee its performance in a practical operating environment. Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system (Liu *et al*., 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods (Linda and Nair, 2010; Yassami *et al*., 2010; Sumathi *et al*., 2007; Jiang and Yan, 2008; Sudha *et al*., 2009) and Fuzzy logic method (Hwanga *et al*., 2008; Dubey, 2007). Also the application of robust control methods for designing PSS has been presented by Gupta *et al*. (2005), Mocwane and Folly (2007), Sil *et al*. (2009) and Bouhamida *et al*. (2005).

In this study a robust method based on Quantitative Feedback Theory (QFT) Algorithm is used for tuning the PSS parameters. A multi machine electric power system is considered as case study. Simulation results show that the proposed method greatly enhances the dynamic stability of multi machine power system.

SYSTEM UNDER STUDY

In this study IEEE 14 bus test system is considered to evaluate the proposed method. The system data are

Corresponding Author: Sayed Mojtaba Shirvani Boroujeni Department of Electrical Engineering, Boroujen Branch, Islamic Azad University, Boroujen, Iran Tel.: +989133830490; Fax: +983824229220
This work is licensed under a Creative Commons Attribution 4.0 International License (URL: http://creativecommons.org/licenses/by/4.0/).

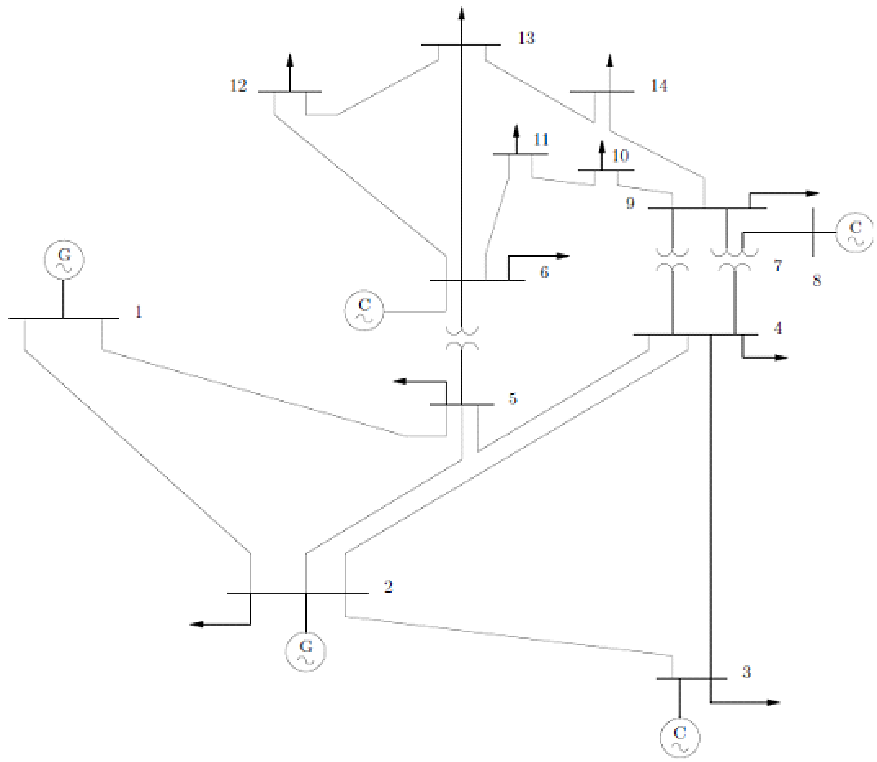

Fig. 1: IEEE 14 bus test system

completely given in IEEE standards. The system uncertainties are obtained by 40% changing load and parameters from their nominal values. Figure 1 shows the proposed test system.

Nonlinear dynamic model of the system: The nonlinear dynamic model of the system is given as (1):

$$\begin{cases} \omega_i = \dfrac{(P_m - P_e - D\omega)}{M} \\ \delta_i = \omega_0(\omega - 1) \\ E'_{qi} \dfrac{(-E_q + E_{fd})}{T'_{do}} \\ E_{fdi} = \dfrac{E_{fd} K_a (V_{ref} - V_t)}{T_a} \end{cases} \quad (1)$$

where, i = 1, 2, 3, 4, 5 (the generators: 1 to 4); δ, rotor angle; ω, rotor speed; P_m, mechanical input power; P_e, electrical output power; E'_q, internal voltage behind x'_d; E_{fd}, equivalent excitation voltage; Te, electric torque; T'_{do}, time constant of excitation circuit; K_a, regulator gain; T_a, regulator time constant; V_{ref}, reference voltage; V_t, terminal voltage.

Linear dynamic model of the system: In the PSS design, the power system is usually linearized in order to perform the small signal analysis. Therefore, the system in Eq. (1) is linearized around one operating condition of the power system and is given in Eq. (2),

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases} \quad (2)$$

where, A is the power system state matrix, B is the input matrix, C is the output matrix and D is the feed-forward matrix. From Eq. (2), the transfer functions of power system from inputs (such as mechanical input (T_m) or excitation system input) to outputs (such as Δω) can be easily obtained.

POWER SYSTEM STABILIZER

As mentioned before, in large interconnected power systems, the damping torque of system is reduced and system need to PSS for stability. The basic function of PSS is to add damping torque to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations (Kundur, 1993). The PSS configuration is given in as (3), where, ω is the speed deviation in p.u. This type of PSS consists of a washout filter, a dynamic compensator. The output signal is fed as a supplementary input signal to the excitation of generator. The washout filter, which is a high pass filter, is used to reset the steady state offset in the PSS output. In this paper the value of the time constant (Tw) is fixed to 10 s. The dynamic compensator is made up

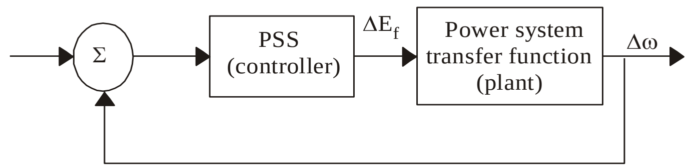

Fig. 2: The structure of control system

to two lead-lag stages with time constants, T1-T4 and an additional gain K_{DC}.

$$U = K_{DC}\frac{ST_w}{1+ST_w}\frac{1+ST_1}{1+ST_2}\frac{1+ST_3}{1+ST_4}\Delta\omega \tag{3}$$

The major point in the PSS design is to find the optimal values of K_{DC} and T1-T4. In this paper a robust method is used to find the best values of the proposed parameters. Where, the optimum values of K_{DC} and the time constants of T1-T4 are obtained by using QFT in the next section a brief introduction about the QFT is presented.

QUANTITATIVE FEEDBACK THEORY

Quantitative Feedback Theory (QFT) is a unified theory that emphasizes to use of feedback for achieving the desired system performance tolerances despite plant uncertainty and plant disturbances. QFT quantitatively formulates these two factors as following form:

- Sets $\tau_R = \{T_R\}$ of acceptable command or tracking input-output relations and sets $\tau_D = \{T_D\}$ of acceptable disturbance input-output relations.
- Sets $\rho = \{P\}$ of possible plants.

The object is to guarantee that the control ratio (system transfer function) $T_R = Y/R$ is a member of τ_R and $T_D = Y/D$ is a member of τ_D for all P(S) in ρ. QFT is essentially a frequency-domain technique and in this paper is used for Multiple Input-Single Output (MISO) systems. It is possible to convert the MIMO system into its equivalent sets of MISO systems to which the QFT design technique is applied. The objective is to solve the MISO problems, i.e., to find compensation functions which guarantee that the performance tolerance of each MISO problem is satisfied for all P in ρ. The detailed step-by-step procedure to design controllers using QFT technique is given by Dazzo and Houpis (1988) and Horowitz (1982).

DESIGN METHODOLOGY

In this section the PSS parameters tuning based on the QFT is presented. The test system has five generators and it is possible to install five PSSs. In this paper just one PSS is considered to install on generator

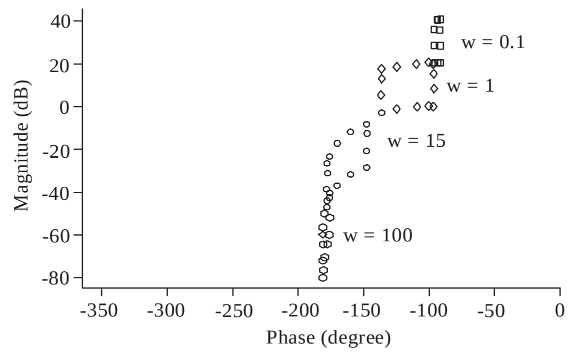

Fig. 3: Templates of plant

1. Based descriptions in previous section, the power system transfer function (plant) and PSS (controller) can be considered like a control loop as shown in Fig. 2. It is clearly seen that the system is a SISO system and compensator (PSS) will be designed based on the plant. The power system transfer function from excitation system (ΔE_f) to speed deviations ($\Delta\omega$) can be obtained by using (2).

Based QFT technique (Dazzo and Houpis, 1988; Horowitz, 1982) the first step in the design process is to plot the plant uncertainties in Nichols diagram. This plot is known as system templates. The Templates of plant at various operating conditions are obtained by MATLAB software in some frequencies and shown in Fig. 3. The PSS is a cascade compensator and designed so that the variation of output response ($\Delta\omega$) be within the acceptable range under the uncertainties of plant.

In this problem, the output signal $\Delta\omega$ should driven back to zero after disturbances and in fact the system outputs are regulated by controllers. It means that in this problem the controller has regulatory characteristics and tracking characteristics are not considered. Therefore considering the tracking specifications is not necessary and consequently the tracking bounds are not considered. The output response ($\Delta\omega$) is acceptable if its magnitude be below the limits given by the disturbance rejection bounds. The disturbance rejection bounds are obtained according to QFT method using QFT toolbox of MATLB software. Since in this case the tracking bounds have not been considered, so the disturbance rejection bounds (B_D (jωi)) are considered as composite bounds (B_O (jωi)). Also, minimum damping ratios ζ for the dominant roots of the closed-loop system is considered as ζ = 1.2, this amount, on the Nichols chart

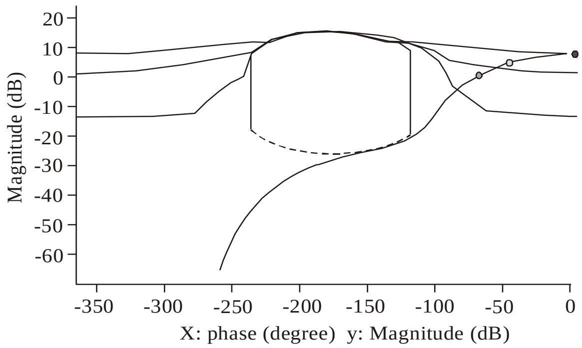

Fig. 4: Composite bounds, U-contour and an optimum loop shaping

Table 1: Parameters of stabilizer using QFT

	QFT algorithm				
Generator	K_{DC}	T_1	T_2	T_3	T_4
G_1	10.93	0.271	0.019	3.98	0.152

Table 2: Parameters of stabilizer using GA

	GA				
Generator	K_{DC}	T_1	T_2	T_3	T_4
G_1	7.77	0.301	0.01	0.38	0.01

establishes a region which must not be penetrated by the template of loop shaping (L_O) for all frequencies. The boundary of this region is referred to as U-contour. The U-contour and composite bounds (B_O (jωi)) and an optimum loop shaping (L_1) based these bounds are shown in Fig. 4. Figure 4 shows that the nominal open-loop transfer function (loop-shaping) is exactly based QFT bounds and according to QFT theory, the design objectives have been met. The PSS parameters are accuracy calculated using the proposed loop shaping and the results are listed in Table 1.

Also in order to show the effectiveness of the QFT method, the parameters of stabilizer are tuned using Genetic Algorithms (GA). In GA case, the performance index is considered as Integral of the Time multiplied Absolute Error (ITAE) which is given as (4):s

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt + \qquad (4)$$

where, the design procedure can be formulated as the following constrained optimization problem, where the constraints are the PSS parameter bounds (Shayeghi *et al.*, 2010):

Minimize ITAE

Subject to

$$K_{DC}^{\min} \le K_{DC} \le K_{DC}^{\max}$$
$$T_1^{\min} \le T_1 \le T_1^{\max}$$
$$T_2^{\min} \le T_2 \le T_2^{\max}$$
$$T_3^{\min} \le T_3 \le T_3^{\max}$$
$$T_4^{\min} \le T_4 \le T_4^{\max}$$

The optimal parameters of stabilizer are obtained by using GA and listed in Table 2.

SIMULATION RESULTS

Simulations are carried out on the test system given in section 2. To evaluate the system performance under different disturbances, two scenarios of fault are considered as follows:

Scenario 1:10 cycle three-phase short circuit in bus 3
Scenario 2: 6 cycle three-phase short circuit in bus 1

The simulation results are presented in Fig. 5-9. Each figure contains two plots for QFT-PSS (solid

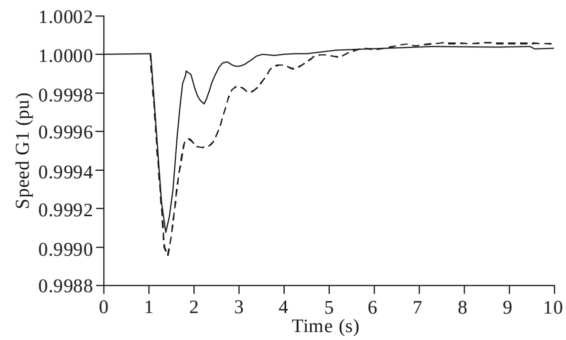

Fig. 5: Speed generator 1 under scenario 1solid (QFT-PSS), dashed (GA- PSS)

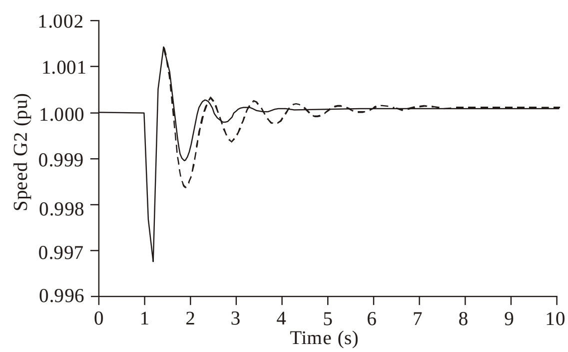

Fig. 6: Speed generator 2 under scenario 1solid (QFT-PSS), dashed (GA- PSS)

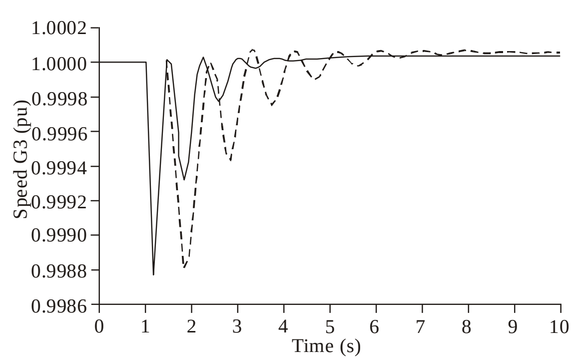

Fig. 7: Speed generator 3 under scenario 1solid (QFT-PSS), dashed (GA- PSS)

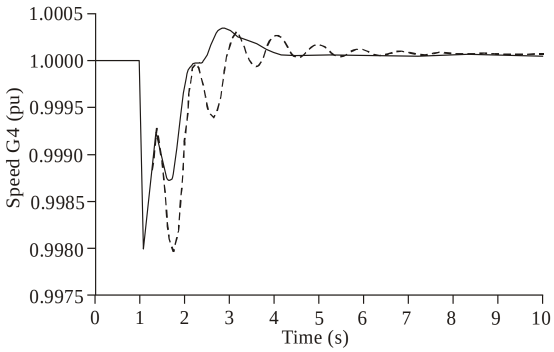

Fig. 8: Speed generator 4 under scenario 2solid (QFT-PSS), dashed (GA- PSS)

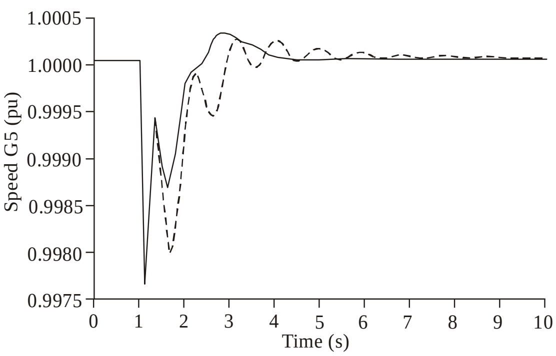

Fig. 9: Speed generator 5 under scenario 2 solid (QFT-PSS), dashed (GA- PSS)

line) and GA-PSS (dashed line). The simulation results show that applying the supplementary stabilizer signal greatly enhances the damping of the generator angle oscillations. The results clearly show that in large electric power systems, PSS can successfully increase damping of power system oscillations. The QFT-PSS has better performance than GA-PSS and results clearly show the validity of QFT method. QFT controller may be used to increase power system operation flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems. With changing fault, GA-PSS cannot guarantee a robust and acceptable response. But QFT-PSS is designed for a family of plants and with changing system operating condition, this PSS is robust under system changing and system responses are in the range of acceptable.

CONCLUSION

In this study dynamic stability of a multi machine electric power system has been successfully improved by using Power System Stabilizer. The PSS parameters were obtained by using QFT method. The power system has been installed with just one PSS. This application of just one PSS is near to real world applications. The simulation results on a multi machine electric power system showed that PSS can greatly enhance damping of power system oscillations in large electric power systems. Therefore the proposed method is a feasible and appropriate method to enhance dynamic stability of large multi machine electric power systems. The proposed PSS is very feasible and easy to implementation.

ACKNOWLEDGMENT

This paper is a result of an approved research project in Islamic Azad University, Boroujen branch. Therefore we know necessary to thank this academic unit staunch for its most grateful support.

REFERENCES

Bouhamida, M., A. Mokhatri and M.A. Denai, 2005. Power system stabilizer design based on robust control techniques. ACSE J., 5: 33-41.

Dazzo, J.J. and C.H. Houpis, 1988. Linear control system analysis and design: Conventional and modern. McGraw Hill Press.

Dubey, M., 2007. Design of harmony search algorithm based fuzzy logic power system stabilizers in multi machine power system. International Conference on Soft Computing and Intelligent Systems, pp: 214-219.

Gupta, R., B. Bandopadhya and A.M. Kulkarni, 2005. Power system stabilizer for multi machine power system using robust decentralized Periodic output feedback. IEEE Proc. Cont. Th. Appl., 152: 3-8.

Horowitz, I.M., 1982. Quantitative feedback theory. IEEE Proceedings. 129(6).

Hwanga, G.H., D.W. Kimb, J.H. Leec and Y. Joo, 2008. Design of fuzzy power system stabilizer using adaptive evolutionary algorithm. Eng. Appl. Artif. Intell., 21: 86-96.

Jiang, P. and W.W. Yan, 2008. PSS parameter optimization with Harmony Search algorithm. DRPT 2008, Nanjing China, pp: 900-903.

Kundur, P., 1993. Power system stability and control. McGraw-Hill, Inc., New York, pp: 700-822.

Linda, M.M. and N.K. Nair, 2010. Dynamic stability enhancement with fuzzy based power system stabilizer tuned by hottest non-traditional optimization technique. Second International conference on Computing, Communication and Networking Technologies, pp: 1-5.

Liu, W., G.K. Venayagamoorthy and D.C. Wunsch, 2005. A heuristic dynamic programming based power system stabilizer for a turbo generator in a single machine power system. IEEE Trans. Ind. Appl., 4: 1377-1385.

Mocwane, K. and K.A. Folly, 2007. Robustness evaluation of H_∞ power system stabilizer. IEEE PES Pow. Africa Conf. Exhib., pp: 16-20.

Shayeghi, H., H.A. Shayanfar, A. Safari and R.A. Aghmasheh, 2010. Robust PSSs design using PSO in a multi-machine environment. Energ. Convers. Manage., 51: 696-702.

Sil, A., T.K. Gangopadhyay, S. Paul and A.K. Maitra, 2009. Design of robust power system stabilizer using H∞ mixed sensitivity technique. Third International Conference on Power Systems, India, pp: 1-4.

Sudha, K.R., V.S. Vakula and R. Vijayasanthi, 2009. Particle swarm optimization in fine tuning of PID fuzzy logic power system stabilizer. International Conference on Advances in Computing, Control and Telecommunication Technologies, pp: 356-358.

Sumathi, N., M.P. Selvan and N. Kumaresan, 2007. A hybrid Harmony Search algorithm based power system stabilizer. International Conference on Intelligent and Advanced Systems, pp: 876-881.

Yassami, H., A. Darabi and S.M.R. Rafiei, 2010. Power system stabilizer design using strength pareto multi-objective optimization approach. Electr. Pow. Syst. Res.. 80: 838-846.