ELSEVIER

Electrical Power and Energy Systems 25 (2003) 695–704

ELECTRICAL POWER & ENERGY SYSTEMS

www.elsevier.com/locate/ijepes

Coordinated design of a PSS and an SVC-based controller to enhance power system stability

M.A. Abido*, Y.L. Abdel-Magid

Department of Electric Engineering, King Fahd University of Petroleum and Minerals, KFUMP Box No. 183,
Dhahran 31261, Saudi Arabia

Abstract

Power system stability enhancement via robust coordinated design of a power system stabilizer and a static VAR compensator-based stabilizer is thoroughly investigated in this paper. The coordinated design problem of robust excitation and SVC-based controllers over a wide range of loading conditions and system configurations are formulated as an optimization problem with an eigenvalue-based objective function. The real-coded genetic algorithm is employed to search for optimal controller parameters. This study also presents a singular value decomposition-based approach to assess and measure the controllability of the poorly damped electromechanical modes by different control inputs. The damping characteristics of the proposed schemes are also evaluated in terms of the damping torque coefficient over a wide range of loading conditions. The proposed stabilizers are tested on a weakly connected power system. The non-linear simulation results and eigenvalue analysis show the effectiveness and robustness of the proposed approach over a wide range of loading conditions.

Keywords: Power system stabilizer; Flexible alternating current transmission systems devices; Static VAR compensator; Genetic algorithms

1. Introduction

Since 1960s, low frequency oscillations have been observed when large power systems are interconnected by relatively weak tie lines. These oscillations may sustain and grow to cause system separation if no adequate damping is available [1,2]. Nowadays, the conventional power system stabilizer (CPSS) is widely used by power system utilities.

Generally, it is important to recognize that machine parameters change with loading make the machine behavior quite different at different operating conditions. Since these parameters change in a rather complex manner, a set of stabilizer parameters, which stabilizes the system under a certain operating condition, may no longer yield satisfactory results when there is a drastic change in power system operating conditions and configurations. Hence, power system stabilizers (PSSs) should provide some degree of robustness to the variations in system parameters, loading conditions, and configurations.

H_∞ optimization techniques [3,4] have been applied to robust PSS design problem. However, the importance and difficulties in the selection of weighting functions of H_∞ optimization problem have been reported. In addition, the additive and/or multiplicative uncertainty representation cannot treat situations, where a nominal stable system becomes unstable after being perturbed [5]. Moreover, the pole-zero cancellation phenomenon associated with this approach produces closed loop poles whose damping is directly dependent on the open loop system (nominal system) [6]. On the other hand, the order of the H_∞-based stabilizer is as high as that of the plant. This gives rise to complex structure of such stabilizers and reduces their applicability.

Kundur et al. [7] have presented a comprehensive analysis of the effects of the different CPSS parameters on the overall dynamic performance of the power system. It is shown that the appropriate selection of CPSS parameters results in satisfactory performance during system upsets. In addition, Gibbard [8] demonstrated that the CPSS provide satisfactory damping performance over a wide range of system loading conditions. Robust design of CPSSs in multi-machine power systems using genetic algorithm is presented in Ref. [9], where several loading conditions are considered in the design process.

Although PSSs provide supplementary feedback stabilizing signals, they suffer a drawback of being liable to cause great variations in the voltage profile and they may even

---

* Corresponding author. Tel.: +966-3-860-4379; fax: +966-3-860-3535.
E-mail address: mabido@kfopm.edu.sa (M.A. Abido).

0142-0615/03/$ - see front matter © 2003 Published by Elsevier Science Ltd.
PII: S0142-0615(02)00124-2

result in leading power factor operation under severe disturbances. The recent advances in power electronics have led to the development of the flexible alternating current transmission systems (FACTS). Generally, a potential motivation for the accelerated use of FACTS devices is the deregulation environment in contemporary utility business. Along with primary function of the FACTS devices, the real power flow can be regulated to mitigate the low frequency oscillations and enhance power system stability.

Recently, several FACTS devices have been implemented and installed in practical power systems [10, 11]. In the literature, a little work has been done on the coordination problem investigation of excitation and FACTS-based stabilizers. Mahran et al. [12] presented a coordinated PSS and SVC control for a synchronous generator. However, the proposed approach uses recursive least squares identification, which reduces its effectiveness for on-line applications. Rahim and Nassimi [13] presented optimum feedback strategies for both SVC and exciter controls. However, the proposed controller requires some or all states to be measurable or estimated. Moreover, it leads to a centralized controller for multi-machine power systems, which reduces its applicability and reliability. Noroozian and Anderson [14] presented a comprehensive analysis of damping of power system electromechanical oscillations using FACTS, where the impact of transmission line loading and load characteristics on the damping effect of these devices have been discussed. Wang and Swift [15] have discussed the damping torque contributed by FACTS devices, where several important points have been analyzed and confirmed through simulations. However, all controllers were assumed proportional and no efforts have been done towards the controller design. On the other hand, it is necessary to measure the electromechanical mode controllability in order to assess the effectiveness of different controllers and form a clear inspiration about the coordination problem requirements. A comprehensive study of the coordination problem requirements among PSSs and different FACTS devices has been presented in Ref. [16]. However, no efforts have been done towards the coordinated design of the stabilizers investigated.

In this paper, a comprehensive assessment of the effects of the excitation and SVC control when applied independently and also through coordinated application has been carried out. The design problem is transformed into an optimization problem, where the real-coded genetic algorithm (RCGA) is employed to search for the optimal settings of stabilizer parameters. A controllability measure-based on singular value decomposition (SVD) is used to identify the effectiveness of each control input. In addition, the damping torque coefficient is evaluated with the proposed stabilizers over a wide range of loading conditions. For completeness, the eigenvalue analysis and non-linear simulation results are carried out to demonstrate the effectiveness and robustness of the proposed stabilizers to enhance system dynamic stability.

2. Power system model

2.1. Generator

In this study, a single machine infinite bus system as shown in Fig. 1 is considered. The generator is equipped with PSS and the system has an SVC at the midpoint of the line as shown in Fig. 1. The line impedance is $Z = R + jX$ and the generator has a local load of admittance $Y_L = g + jb$. The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation [1,2]. The swing equation is divided into the following equations

$$\rho\delta = \omega_b(\omega - 1) \tag{1}$$

$$\rho\omega = (P_m - P_e - D(\omega - 1))/M \tag{2}$$

where P_m and P_e are the input and output powers of the generator, respectively; M and D are the inertia constant and damping coefficient, respectively; δ and ω are the rotor angle and speed, respectively; ρ is the derivative operator d/dt. The output power of the generator can be expressed in terms of the d-axis and q-axis components of the armature current, i, and terminal voltage, v, as

$$P_e = v_d i_d + v_q i_q \tag{3}$$

The internal voltage, E'_q, equation is

$$\rho E'_q = (E_{fd} - (x_d - x'_d)i_d - E'_q)/T'_{do} \tag{4}$$

Here, E_{fd} is the field voltage; T'_{do} is the open circuit field time constant; x_d and x'_d are d-axis reactance and d-axis transient reactance of the generator, respectively.

2.2. Exciter and PSS

The IEEE Type-ST1 excitation system shown in Fig. 2 is considered. It can be described as

$$\rho E_{fd} = (K_A(V_{ref} - v + u_{PSS}) - E_{fd})/T_A \tag{5}$$

where K_A and T_A are the gain and time constant of the excitation system, respectively; V_{ref} is the reference voltage. As shown in Fig. 2, a conventional lead–lag PSS is installed in the feedback loop to generate a stabilizing signal u_{PSS}. In

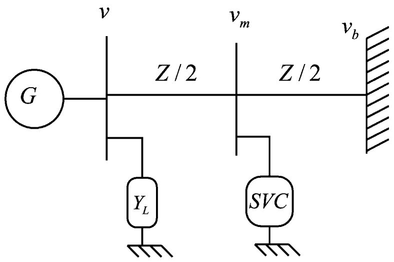

Fig. 1. Single machine infinite bus system.