ELSEVIER

Electrical Power and Energy Systems 23 (2001) 69–79

ELECTRICAL POWER & ENERGY SYSTEMS

www.elsevier.com/locate/ijepes

Coordinated design of damping controllers for robustness of power systems stability

A.S. Bazanella[a,*], A.S. e Silva[b]

[a]Department of Electrical Engineering, Universidade Federal do Rio Grande do Sul, Av. Osvaldo Aranha 103, 90035-190 Porto Alegre RS, Brazil
[b]Department of Electrical Engineering, Universidade Federal de Santa Catarina, 88040-900 Florianópolis SC, Brazil

Abstract

This paper considers the coordinated design of power system stabilizers and supplementary control of flexible AC transmission systems (FACTS) devices aiming at the robustness of the control scheme for drastic changes in the operating condition. The problem is treated as the design of a single state feedback controller for the whole power system. The existence of several controllers is taken into account by introducing structural constraints in the design. A design method that explicitly considers both the coordination and the robustness issues is presented. The method is based on the formulation and solution of an augmented Riccati equation. A benchmark illustrates the limitations of the classical control design and the robustness achieved by the proposed design method. © 2000 Published by Elsevier Science Ltd.

Keywords: Damping controllers; Robustness; Coordinated design

1. Introduction

The severe restrictions imposed on the expansion of the network transmission of modern power systems due to economic constraints, environmental impact and right-of-way limitations has led to the operation of power systems under increasingly stressed conditions, implying increasingly tight transient and steady-state stability margins. This poses new demands on the power system controllers in order to attain safe operation as well as to comply with the system performance requirements. New avenues for achieving these goals have been opened up by the recent developments in high-power electronics technology. Power electronics devices such as static VAr compensators (SVCs), thyristor controlled series capacitors (TCSCs) and electronic phase shifters not only improve power system performance by controlling voltage, power flows over transmission lines and other system variables, but can also be provided with supplementary controllers aiming at the improvement of dynamic and transient stability of power systems. Because these devices are usually associated with the concept of flexible AC transmission systems (FACTS) they are generically named FACTS devices.

Regarding the dynamic stability issue, power system stabilizers (PSSs) have been successfully applied for a long time. The fact that the classical design of PSSs is based on simplified models that do not consider explicitly and systematically the interactions among the several controllers and the possible variation of the system's operating condition has not prevented this from being a very effective solution to the damping of electromechanical oscillations. However, it is not clear whether this will still happen as the typical operating conditions of power systems become more and more stressed. The use of additional sources of damping, such as supplementary signals to FACTS devices, may be of major importance in this scenario.

Also very appealing to the enlargement of power systems stability margins in this scenario is the explicit and systematic formulation of two major issues in the design of these controllers, namely: the interactions among the various controllers and the ability of the control scheme to provide satisfactory performance for a large variety of operating conditions. The first one of these issues is tackled by designing all the controllers at a time, in a coordinated fashion, instead of sequentially. The second one is called the *robustness* of the control scheme and can be dealt with by several approaches. Either one of these issues has been previously dealt with in the recent power systems literature (see Refs. [8,21,22] for the coordinated design and Refs. [4,6,10,11,14,23,24] for the robustness issue), also considering the use of supplementary signals for FACTS devices. A design method that considers both these issues at a time is presented in this paper. The method is based on time domain

* Corresponding author. Fax: +55-51-316-3293.
E-mail addresses: bazanela@delet.ufrgs.br (A.S. Bazanella), aguinald@labspot.ufsc.br (A.S. e Silva).

0142-0615/01/$ - see front matter © 2000 Published by Elsevier Science Ltd.
PII: S0142-0615(00)00030-2

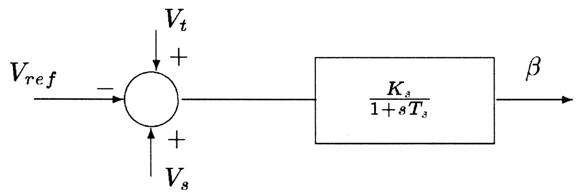

Fig. 1. SVC model.

modeling and a Riccati equation approach [3,7] and is applied to the coordinated design of PSSs and supplementary signals for FACTS in a benchmark system.

The paper is organized as follows. Section 2 presents the power system model, including the FACTS devices. Section 3 presents the robust control method applied in this work. Section 4 describes the benchmark system studied in the paper. Section 5 presents the numerical results obtained by the application of this method to the test system. Finally, Section 6 presents the conclusions.

2. Power system modeling

The analysis and control design in this paper are performed in the time domain, so that the models for the power system components can be taken directly from the nonlinear algebraic and differential equations that describe the physical phenomena in the system. These models are used for simulation. Since the paper deals with dynamic stability, a linear controller is designed using linear modeling for the overall power system [13].

2.1. Component modeling

The power system components considered in this paper are the ones most relevant to the dynamic stability of the system, namely synchronous machines and their controllers, loads, FACTS devices and the network. The synchronous machine's behavior is described by a set of differential equations and by algebraic equations representing its connection to the network [2]. A third-order model, described in Appendix A, is used.

The excitation system is modeled by the following first-order linear model in the simulations

$$\dot{E}_{\rm f} = \frac{1}{T_{\rm a}}[-E_{\rm f} + K_{\rm a}(V_{\rm r} - V_{\rm t})]$$

where $V_{\rm r}$ is the reference voltage and $V_{\rm t}$ is the machine terminal voltage. The time constant $T_{\rm a}$ is neglected for the purpose of design for numerical reasons. The resulting static model for the excitation system is

$$E_{\rm f} = K_{\rm a}(V_{\rm r} - V_{\rm t}) \tag{1}$$

The power input to the generator shaft is assumed constant. The network is represented by a set of algebraic equations. The loads are modeled by constant impedances.

The FACTS devices considered in this paper are SVCs and TCSCs. The SVC is a shunt element whose admittance is controlled by thyristors. For stability studies the SVC can be modeled by a first-order transfer function as shown in Fig. 1 [17]. The output is the net shunt susceptance. The SVC primary controller regulates the bus voltage at which the SVC is placed. A supplementary controller is added to the summing point aiming at the improvement of the dynamic stability of the system, as indicated in Fig. 1. Suitable signals such as bus frequency or active power over a line can be used as the input signal to this controller.

The TCSC is a series element controlled by thyristors. The admittance value can be controlled aiming at the control of the active power flow or current over a line. In this paper the power flow is controlled through a proportional-integral controller. The TCSC model is represented in Fig. 2 [13,16]. The output of this model is the net series admittance between the terminal nodes of the TCSC. A supplementary controller can be added for the purpose of damping electromechanical oscillations. The supplementary control output actuates directly on the firing of the thyristors, so that it is not hindered by the power flow control.

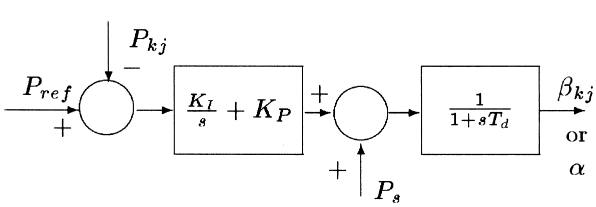

Fig. 2. TCSC model.

2.2. Overall system modeling

Taking the models for each generator, load and FACTS device in the power system and connecting them adequately via the network algebraic equations, a set of differential–algebraic equations is obtained [2]:

$$\dot{x} = f(x, z, u) \tag{2}$$

$$0 = g(x, z, u) \tag{3}$$

where x is the state, z is a vector of algebraic variables and u is the input vector. This model is used for the purpose of simulation.

A linear uncertain model is used for the purpose of control design. This model is obtained from Eqs. (2) and (3) as described in the sequel. Linearizing these equations around an equilibrium point, the following small-signal model is obtained:

$$\begin{bmatrix} \Delta\dot{x} \\ 0 \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta z \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \Delta u \tag{4}$$

with obvious definitions for J_1, J_2, J_3, J_4, B_1 and B_2. The variables Δz can be eliminated from Eq. (4) and dropping Δ in order to simplify the notation, the system equation