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STATCOM controller design for power system stabilization with sub-optimal control and strip pole assignment

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Abstract

This paper solves the problem of power system stabilization by using the advanced static VAR compensator (STATCOM) to increase the damping of the electromechanical and exciter modes of the power system. The dynamic oscillations are repressed by the proposed STATCOM controller, which is designed using a two-level optimization output feedback control and the strip poles assignment method. The linear quadratic regulator method does not require pre-specified weighting matrices. The two output feedback control schemes, designed using the direct and minimum error excitation methods, respectively, are compared. To show the effectiveness of the dynamic oscillation suppression, eigenvalue analysis and nonlinear simulation were used to demonstrate that the proposed STATCOM controller significantly improves the dynamic performance of the power system. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: STATCOM; Strip pole assignment; Minimum error excitation; Power system stabilization

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1. Introduction

Due to the increase in power requirements, it is important to supply power more effectively. High voltage DC transmission provides improved power transmission for networks. The flexible AC transmission system (FACTS) is a conventional AC transmission system with added power electronic conditioners for greater efficiency. Advanced static VAR compensator (STATCOM) is one of the FACTS equipment packages. In 1992, an 80 MVA static VAR generator (SVG) was developed for industry by Japan. This was a proof that the SVG can increase system damping, power system stabilization, and power transmission limits. In 1994, the biggest SVG was equipped in the United States. This unit decreased low frequency oscillation and made the voltage more stable [1].

In a power system, oscillations occur when there are disturbances in the system such as a change in load or a fault in the system. The damping of the system should be great enough that the synchronous generators can return to a steady state after disturbances [2]. These oscillations can injure the power transmission. Several studies have provided various methods for oscillation damping, such as excitation control [3], static VAR compensator (SVC) [4–6], the NGH scheme [7], static phase-shifters [8] and superconducting magnetic energy storage (SMES) [9,10], etc. STATCOM is a second generation FACTS equipment based on a voltage source inverter. The major advantages of STATCOM over the conventional SVC are, significant size reduction and reduced number of passive elements due to the development of supercapacitor technology and the ability to supply required reactive power even at low bus voltages [11].

This study examined the application of STATCOM for damping electromechanical oscillation in a power system. We considered a power system with static and dynamic loads. When a disturbance occurs, the STATCOM controller can provide a damping torque signal to improve the system stabilization to make the system return to a steady state quickly, make the system damping large enough to decrease the oscillations, and pre-specify the system eigenvalues to a stable range for the desired relative stability. The output feedback controller can be used to design a STATCOM controller for damping system oscillations under the structure constrained in a practical system.

2. System model

This power system consists of a synchronous generator connected to two parallel lines through a single line to the infinite bus. A static, dynamic load and a STATCOM unit

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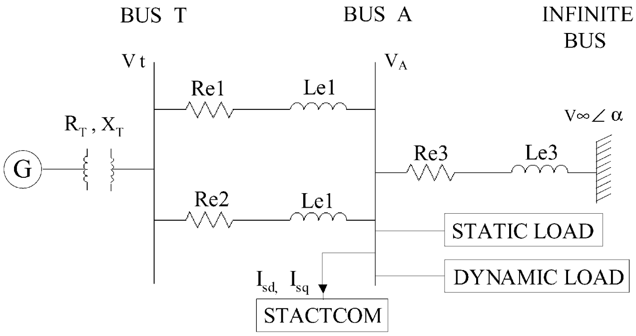

Fig. 1. System model.

are located at the load bus, as shown in Fig. 1. The dynamic generator equation can be described as a two-axis model [2], where the transient voltage equations are

$$\dot{E}'_{\mathrm{d}} = [-E'_{\mathrm{d}} - (X_{\mathrm{q}} - X'_{\mathrm{d}})I_{\mathrm{q}}]/T'_{\mathrm{q0}} \tag{1}$$

$$\dot{E}'_{\mathrm{q}} = [E_{\mathrm{FD}} - E'_{\mathrm{q}} + (X_{\mathrm{d}} - X'_{\mathrm{d}})I_{\mathrm{d}}]/T'_{\mathrm{d0}} \tag{2}$$

The swing equations are

$$\dot{\omega} = (P_{\mathrm{m}} - D_{\mathrm{g}}\omega - P_{\mathrm{e}})/M_{\mathrm{g}} \tag{3}$$

$$\dot{\delta} = \omega_{\mathrm{b}}(\omega - 1) \tag{4}$$

where $P_{\mathrm{e}} = E'_{\mathrm{d}}I_{\mathrm{d}} + E'_{\mathrm{q}}I_{\mathrm{q}}$ is the electromagnetic power of the generator.

The system excitation for the synchronous generator was selected as the IEEE Type-1 excitation system with a constant prime mover mechanical torque, and a *s*-domain block, as shown in Fig. 2 [12].

The static load is generally represented by voltage dependent nonlinear functions. The load equations which describe the active and reactive power are [13–15]

$$P_{\mathrm{L}} = c_{\mathrm{p}}V_{\mathrm{A}}^{n_{\mathrm{p}}} \qquad Q_{\mathrm{L}} = c_{\mathrm{q}}V_{\mathrm{A}}^{n_{\mathrm{q}}} \tag{5}$$

where the weighted coefficient percentages c_{p} and c_{q} describe the amount of power. The exponents, n_{p} and n_{q}, identify the load characteristics and are usually determined using measured load mixed data for the load buses.

The dynamic load is constructed by a group of induction motors [15–17]. For stability study purposes, these motors can be combined into an equivalent one using the aggregation method [18]. A fifth-order dynamic model of the induction motor was used in this study to obtain a more detailed result. The dynamic equations are

$$\frac{\mathrm{d}}{\mathrm{d}t}[I] = [L]^{-1}\{-[R][I] + [V]\} \tag{6}$$

$$\frac{\mathrm{d}\omega_{\mathrm{r}}}{\mathrm{d}t} = (T_{\mathrm{me}} - T_{\mathrm{mm}})/2H_{\mathrm{m}} \tag{7}$$

where

$$[I] = \begin{bmatrix} I_{\mathrm{qsm}} & I_{\mathrm{dsm}} & I_{\mathrm{qrm}} & I_{\mathrm{drm}} \end{bmatrix}^{\mathrm{T}}$$

$$[V] = \begin{bmatrix} V_{\mathrm{qA}} & V_{\mathrm{dA}} & 0 & 0 \end{bmatrix}^{\mathrm{T}}$$

$$[L] = \begin{bmatrix} L_{\mathrm{SS}} & 0 & L_{\mathrm{M}} & 0 \\ 0 & L_{\mathrm{SS}} & 0 & L_{\mathrm{M}} \\ L_{\mathrm{M}} & 0 & L_{\mathrm{rr}} & 0 \\ 0 & L_{\mathrm{M}} & 0 & L_{\mathrm{rr}} \end{bmatrix}$$

$$[R] = \begin{bmatrix} R_{\mathrm{S}} & -\omega L_{\mathrm{SS}} & 0 & -\omega L_{\mathrm{M}} \\ \omega L_{\mathrm{SS}} & R_{\mathrm{S}} & \omega L_{\mathrm{M}} & 0 \\ 0 & -(\omega - \omega_{\mathrm{r}})L_{\mathrm{M}} & R_{\mathrm{r}} & -(\omega - \omega_{\mathrm{r}})L_{\mathrm{rr}} \\ (\omega - \omega_{\mathrm{r}})L_{\mathrm{M}} & 0 & (\omega - \omega_{\mathrm{r}})L_{\mathrm{rr}} & R_{\mathrm{r}} \end{bmatrix}$$

$$T_{\mathrm{me}} = L_{\mathrm{M}}(I_{\mathrm{dsm}}I_{\mathrm{qrm}} - I_{\mathrm{drm}}I_{\mathrm{qsm}})$$

The STATCOM unit configuration, as shown in Fig. 3, contains a $Y - \Delta/Y - Y$ connected transformer, a 12-pulse cascaded bridge type converter/inverter, and a capacitor bank parallel with the leakage resistance. The forced-commutated GTO converter/inverter controls the firing angles θ_{s} of the cascaded converter/inverter and provides the STATCOM with the ability to control the reactive power flow in the three-phase AC bus.

The STATCOM mathematical model can be written with

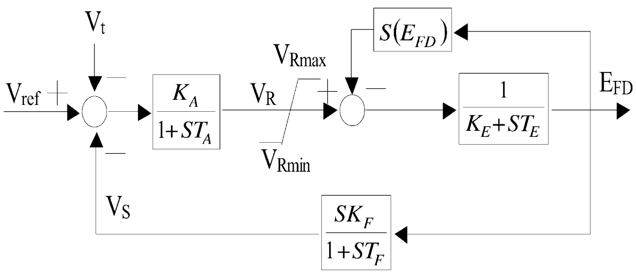

Fig. 2. Exciter.

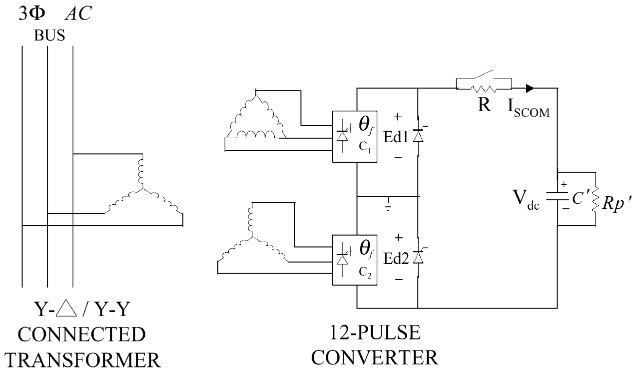

Fig. 3. Schematic configuration of STATCOM unit.