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Application Lyapunov Theory to Determine Control Strategy of Static Var Compensator for Damping Power System Oscillation

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Abstract: Problem statement: The disturbance in power system is unavoidable situation. It causes in power system oscillation. **Approach:** This study applied the Static Var Compensator (SVC) to damp power system oscillation. The stability criterion of the Lyapunov is applied to derive the control strategy of SVC. The simulation results are tested on a Single Machine Infinite bus. The proposed method is equipped in sample system with disturbance. The generator rotor angle curve of the system without and with a SVC is plotted and compared for various cases. **Results:** It was found that the system without a SVC has high variation whereas that of the system with a SVC has much smaller variation. **Conclusion:** From the simulation results, the SVC can damp power system oscillaton.

Key words: Power system, power system oscillation, Flexible AC Transmission Systems (FACTS), static var compensator, thyristor controlled phase shifter transformer, thyristor controller series capacitor, static synchronous compensator, static synchronous series compensator, unified power flow controller, inter-line power flow controller, control strategy

INTRODUCTION

Flexible AC Transmission Systems (FACTS) devices are increasingly being applied to improve power system control, thus helping to utilize transmission systems to their rating (Hojat *et al*., 2010; Samimi *et al*., 2009; Fua'ad *et al*., 2009). For many years, one of the major interests of power utilities is the improvement of power system dynamic behavior. Now, power engineers are much more concerned about stability problem due to blackout in northeast United States, Scandinavia, England and Italy. A number of Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, have been proposed for power flow control in steady state and dynamic state. The various forms of FACTS devices are the Static Var Compensator (SVC), Thyristor Controlled Phase Shifter Transformer (TCPST), Thyristor Controller Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and Inter-line Power Flow Controller (IPFC) (Barbuy *et al*., 2009; Kumkratug, 2010).

The control strategy of FACTS devices plays an important role for effective improvement of dynamic performance of a power system. Many research used in linear control schemes of SVC for this purposes. However, modern power system is a large and complex network and disturbances usually cause in nonlinear response (Rudez and Mihalic, 2009; Ahmad and Mohamed, 2009; Ahmed Hafaifa *et al*., 2009; Majee and Roy, 2010; Zacharie, 2009; Bagher *et al*., 2009; Chamsai *et al*., 2010).

This study describes a control strategy of a SVC on a power system and it is selected very carefully to satisfy the Liapunov's stability criterion. It is found that the control strategy of SVC depends on both nonlinear function of machine angle and speed. The above control strategy is then applied to a SVC placed in a power system to investigate the improvement of the power system.

MATERIALS AND METHODS

Mathematical model: Consider a single machine infinite bus system is equipped with a SVC at bus m as shown in Fig. 1a. The dynamics of the machine, in classical model, can be expressed by the following differential equations:

$$\dot{\delta} = \omega \tag{1}$$

$$\dot{\omega} = \frac{1}{M}\left[P_m - P_e^{sh}\right] \tag{2}$$

Here, δ,ω, P_m and M are the rotor angle, speed, input mechanical power and moment of inertia, respectively, of the machine. P_e^{sh} is output electrical power of machine with the SVC. Without the SVC, the electrical output power of the machine (P_{e0}) can be expressed as:

$$P_{eo} = E' V_b B_o \sin\delta \tag{3}$$

Here:

- E' and V_b = The machine voltage behind transient reactance and infinite bus voltage, respectively
- B_o = The transfer susceptance between the machine internal bus and the infinite bus

The transfer susceptance is given by:

$$B_o = \frac{1}{X_1 + X_2} \tag{4}$$

Here:

- X_1 = The sum of the machine transient reactance and transformer leakage reactance
- X_2 = The equivalent reactance of the lines between bus m and the infinite bus

Thus without a SVC, the system dynamic equation, in general form, can be written as:

$$\dot{x} = f_0(x) \tag{5}$$

Where:

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \delta \\ \omega \end{bmatrix}$$

and:

$$f_0(x) = \begin{bmatrix} f_{01}(x) \\ f_{02}(x) \end{bmatrix} = \begin{bmatrix} \omega \\ \dfrac{P_m - P_{e0}}{M} \end{bmatrix}$$

When a SVC is placed at bus m, it can be represented by a variable shunt reactance X_s (or susceptance B_s) between bus m and ground as shown in Fig. 1b. By using star-delta transformation, Fig. 1b can be represented by its equivalent circuit as shown in Fig. 1c. In Fig. 1c, the electrical output power of the machine has no effect on the shunt reactances X_{10} and X_{20}. However, the output power of the machine, for a given E' and V_b, depends on the transfer reactance X_{eq}. The value of the transfer reactance is given by:

$$X_{eq} = X_1 + X_2 + \frac{X_1 X_2}{X_s} \tag{6}$$

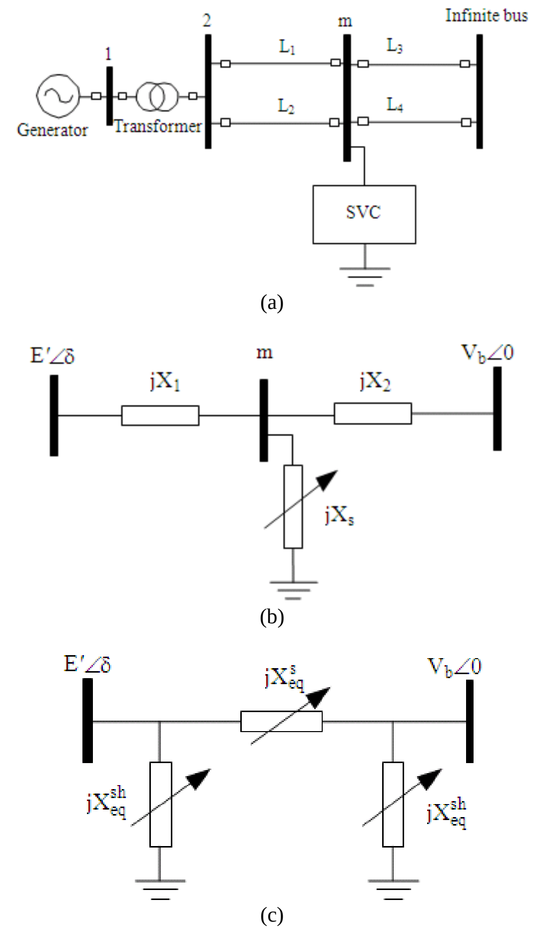

Fig. 1: A Single Machine Infinite Bus (SMIB) system (a) single line diagram (b) Equivalent circuit of system with SVC (c) Equivalent circuit after star-delta transformation

Thus with the SVC, the electrical output power (P_{es}) of the machine can be expressed as:

$$P_e^{sh} = E_q' V_b B_{eq} \sin\delta \tag{7}$$

Here $B_{eq} = 1/X_{eq}$. By using Eq. 4 and 6, B_{eq} can be written as:

$$B_{eq} = B_0(1+u) \tag{8}$$

Where:

$$u = \left[\frac{B_s}{B_{12} + B_s}\right] \text{ and } B_{12} = \left[\frac{X_1 + X_2}{X_1 X_2}\right]$$

Thus the electrical output power of the machine with a SVC, becomes:

$$P_e^{sh} = P_{e0} + uP_{e0} \quad (9)$$

From (1), (2) and (9) Thus with the SVC, the dynamic equations of the machine can be written as:

$$\dot{x} = f(x,u) = f_0(x) + uf_1(x) \quad (10)$$

Where:

$$f_1(x) = \begin{bmatrix} f_{11}(x) \\ f_{12}(x) \end{bmatrix} = \begin{bmatrix} 0 \\ \frac{P_{eo}}{M} \end{bmatrix}$$

In this study, the control strategy of dynamic Eq. 10 is investigated to improve the stability of the system.

Control strategy: The control strategy of the SVC in a single machine infinite bus system is determined from the basis of the Lyapunov's second or direct method. The Lyapunov function of the system may be considered as

$$E(\delta,\omega) = \frac{1}{2}M\omega^2 - P_m\delta - P_{max}\cos\delta + C_0 \quad (11)$$

In the second method of Lyapunov, the sign behaviors of a scalar function E (also called Lyapunov function) The Lyapunov method states that, if a scalar function $\dot{E}$ is negative semi-negative definite, then the system is stable. Furthermore, if $\dot{E}$ is negative definite, the system is not only stable but also asymptotically stable. The time derivative of E is given by:

$$\begin{aligned} \dot{E}(x) &= \frac{\partial E(x)}{\partial x} \times \frac{\partial x}{\partial t} = \nabla E(x) f(x,u) \\ &= \nabla E(x) f_0(x) + \nabla E(x) u f_1(x) \end{aligned} \quad (12)$$

Using (5), (10) and (11), the time derivative of the energy function of the system with a SVC is given by:

$$\dot{E}(x) = -u\omega P_{max}\sin\delta \quad (13)$$

To satisfy the Lyapunov stability criterion, the control u is to be selected very carefully. One of the possible control of u (or B) that guarantees the negative semi-negative definiteness of $\dot{E}(x)$ is:

$$B = k\omega\sin\delta \quad (14)$$

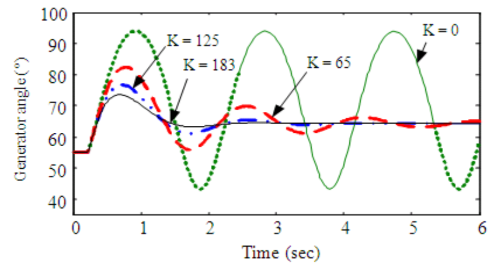

Fig. 2: Swing curve of the machine with various gain controls

The proposed control is based on the single machine infinite bus. However it can be applied to multimachine system that it has similar configuration in single machine infinite bus.

RESULTS

The proposed control energy function and control strategy of a power system with a SVC are tested on system of Fig. 1a. It is considered that a three-phase self-clearing type fault appears near bus m at 200 msec and it cleared at 250 msec by opening the faulted line from both ends. Fig. 2 shows the swing curve of the system without and with a SVC.

DISCUSSION

It can be seen in Fig. 2 that, without the SVC (k = 0), the machine has undamped oscillations. However, the damping of the machine increases as gain control is increased.

CONCLUSION

This study derives the nonlinear control strategy of a Static Var Compensator (SVC) in a power system to enhance power system dynamic performance. The control strategy of the SVC is selected very carefully to satisfy the Lyaponov's stability criterion. It is found that the SVC control depends on both nonlinear function of machine angle and speed. The proposed control is based on the single machine infinite bus. The simulation results are tested on Single Machine Infinite Bus (SMIB) system. From the simulation results, it was fond that the SVC with proposed control strategy can damp power system oscillation.

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