ADAPTIVE FUZZY SLIDING MODE CONTROL OF SVC AND TCSC FOR IMPROVING THE DYNAMIC PERFORMANCE OF POWER SYSTEMS

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Abstract

The FACTS devices have recently received great attention in the damping of a power system. In this paper, the simultaneous application of TCSC and SVC is proposed to improve the power system dynamics . In order to obtain a better performance, different control methodologies can be used to control the FACTS devices. In this paper the adaptive fuzzy sliding mode control (AFSMC) system is employed for the control of SVC and TCSC to improve the dynamic stability. The results show that the proposed scheme with AFSMC system can greatly improve the dynamic performance of the sample power system.

Keywords

Power System Stabilisation, Adaptive Fuzzy Sliding Mode Control (AFSMC), Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), and FACTS devices.

1. INTRODUCTION

It is well known that shunt and series compensation can be used to improve the power system stability. With the improvement in current and voltage handling capabilities of power electronic devices that have allowed for the development of FACTS, the possibility has been arisen of using different types of controllers for efficient shunt and series compensation. Thus thyristor based FACTS such as SVC's and TCSC's have been used by several utilities to compensate their systems [1]. More recently various types of controllers for series and shunt compensator have been proposed and developed. For the control of SVC and TCSC different control systems have been used [2]. In many cases linear control of devices is efficient in solving the dynamic problem caused by small disturbances. In the case of larger disturbances the traditional control systems based on linearised system model are of limited value also do not guarantee the insensitivity of plant parameter variations, which are very important in improving the dynamic performance of power systems. To solve the problems the variable structure control (VSC) strategy using sliding mode has been used before. This control theory has been focus of many researchers for the control of non-linear systems for many years [3,4]. The sliding mode controller has been used to improve the power system stability due to its robust response characteristic [5,6]. As the selection of switching surface is the most important part, in the design of the control system, in this paper a new switching surface of the sliding mode based on lyapunov approach is proposed. In general sliding mode control, the upper bound of uncertainties, which include parameter variations and external disturbances, must be available, which is difficult to obtain in advance. Therefore , fuzzy sliding mode control is used in which the fuzzy inference mechanism can estimate the uncertainty, so the chattering and steady state error can be reduced. The fuzzy sliding mode control can be further improved by adapting the centers of the membership functions. Therefore the proposed AFSMC system combines the advantages of the sliding mode control, the fuzzy inference mechanism and the adaptive algorithm. This control system has been used to control the nonlinear systems [7] and to control the motor drives [8]. In this paper the AFSMC system is employed for the control of SVC and TCSC to improve the stability of the single machine infinite bus (SMIB) system. In order to demonstrate the effectiveness of the proposed controller and also the effectiveness of the simultaneous application of SVC and TCSC, computer simulations are carried out under the application of large disturbances. To show the effectiveness and its superiority over the conventional controllers, such as PID, comparison has been made using the simulation results. The results show that the proposed AFSMC system can greatly improve the dynamic stability .

2. SYSTEM DESCRIPTION AND MODELLING

The system considered is a synchronous generator connected to an infinite bus through a double circuit transmission line as shown in Fig. 1. To improve the dynamic performance of this system, SVC and TCSC have been used as shunt and series compensation. The dynamic behavior of the studied system can be described by mathematical model. The synchronous generator is described by a 4^{th} order nonlinear equation [9].

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2-1. Excitation System

The equation of the excitation system is obtained as follows

$$\dot{E}_{Fd} = [-E_{Fd} + K_a(V_{ref} - V_t)]/T_a \qquad (1)$$

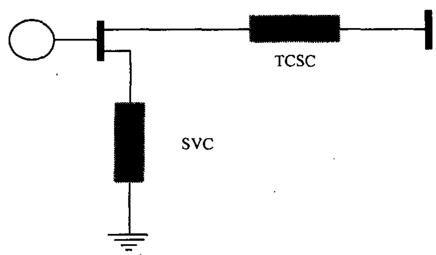

Fig. 1. Studied system with FACTS devices.

2-2. Static Var Compensator(SVC)

The applied SVC is shown in Fig. 2 which is a FC/TCR type and connected to the generator terminal. The magnitude of the SVC admittance is obtained by :

$$B_s = B_c - B_L(\alpha) \qquad (2)$$

$$B_L(a) = \frac{2\pi - 2\alpha + \sin 2\alpha}{2\pi X_L} \qquad (3)$$

According to the variations in terminal voltage and angular speed, the suceptance of the inductor B_L and then B_s can be regulated as shown in Fig. 3

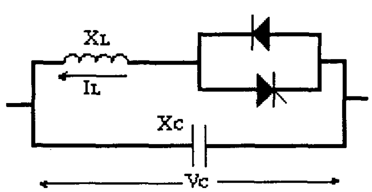

Fig. 2 FC/TCR type of SVC and TCSC

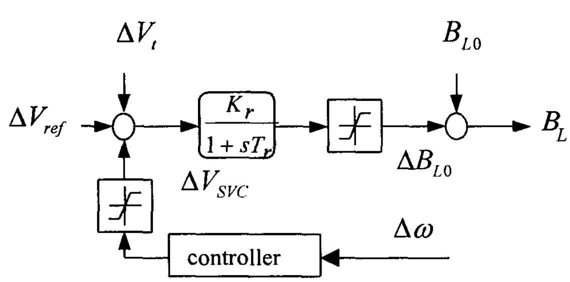

Fig. 3 Block diagram of the SVC controller

The equations of SVC are obtained as follows:

$$\dot{B}_L = [k_r(\Delta V_{ref} - \Delta V_t + \Delta V_{svc}) - B_L]/T_r \qquad (4)$$

$$B_L = B_{L0} + \Delta B_L \qquad (5)$$

2-3. Thyristor Controlled Series Compensator (TCSC)

The TCSC has the arrangement of FC/TCR which is connected in series with transmission line. According to the change of angular speed by adjusting the firing angle of the thyristor, the equivalent reactance of the TCSC is controlled between two limits [10]. The block diagram of the TCSC model is shown in Fig.4.

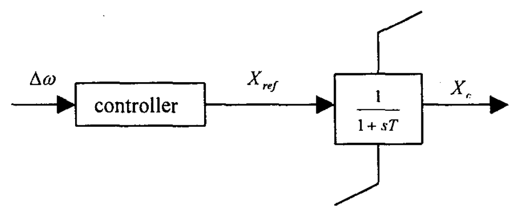

Fig. 4 Block diagram of the TCSC

3. CONTROL SYSTEM DESIGN

In this study the two aforementioned types of FACTS devices have been applied to the same system of reference [11]. The parameters of the system are found in this reference. The design procedure of the different controllers is described in the following sections.

3-1. Sliding Mode Control (SMC)

The variable structure control is a branch of nonlinear control theory which has been applied to the stabilisation of power systems due to its robust response characteristics. The nonlinear state equation of power system of Fig. 1 is given as :

$$\dot{X} = A(X) + B(X)U \qquad (6)$$

The control signal U should be determined so that the state trajectory from any point in state space plane drives to switching surface S=CX=0. For convenience an exponential law is adopted for the switching surface as:

$$\dot{S} = -Q_s \operatorname{sgn}(S) - K_s S \qquad (7)$$

where sgn is the sign function and Q_s, K_s are positive constants. On the other hand

$$\dot{S} = C\dot{X} = C[A(X) + B(X)U] \qquad (8)$$

from the above equations the following control law is obtained,

$$U = -[CB(X)]^{-1}[CA(X) + Q_s \operatorname{sgn}(S) + K_s S \qquad (9)$$

constants K_s and Q_s can be determined by trial and error. In this paper a new switching surface of the sliding mode based on lyapunov approach is proposed [12]. Consider the system given in equation (6). Assuming that (A,B) is controllable, there exists a stabilising feedback gain K such that A+BK=As is asymptotically stable. It follows that there exists a positive define matrix P that solves the lyapunov equation.

$$PAs + As^T P = -Q \qquad (10)$$

now we choose the switching surface

$$S(X) = DB^T PX = 0 \qquad (11)$$

where D is a nonsingular matrix. A special choice of $D=(B^TPB)^{-1}$ will diagonalize the control coefficient matrix to the dynamics for S:

$$\dot{S} = DB^T PAX + U \qquad (12)$$

so we have the following control law;

$$U = -(DB^T PA + K_s DB^T P)X - Q_s \operatorname{sgn}(S) \qquad (13)$$

In this case in obtaining the desired response the parameter Q_s can be determined independent of other parameters.

3-2. Fuzzy Sliding Mode Control (FSMC)

In this paper a fuzzy sliding mode controller is proposed in which a fuzzy inference mechanism is used to estimate the value of Q_s in equation (13). The control block diagram of fuzzy sliding mode controller is shown in Fig. 5. The membership functions for the fuzzy sets corresponding to switching surface S , $\dot{S}$ and Qs are defined in Fig. 6
The fuzzy inference rules are as follows :

IF {(S is P AND $\dot{S}$ is P) OR (S is N AND $\dot{S}$ is N)} THEN Q_s is PH

IF {(S is P AND $\dot{S}$ is Z) OR (S is N AND $\dot{S}$ is Z)} THEN Q_s is PB

IF {(S is P AND $\dot{S}$ is N) OR (S is N AND $\dot{S}$ is P)} THEN Q_s is PM

IF {(S is Z AND $\dot{S}$ is P) OR (S is Z AND $\dot{S}$ is N)} THEN Q_s is PS

IF (S is Z AND $\dot{S}$ is Z) THEN Q_s is ZE

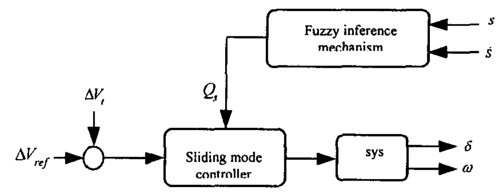

Fig. 5 Block diagram of FSMC

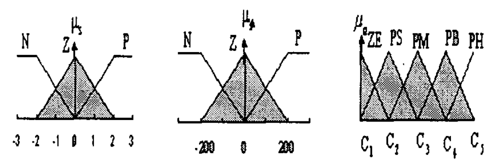

Fig . 6 Membership functions of fuzzy sets

Fuzzy output Qs can be calculated by the center of area defuzzification as :

$$Q_s = \frac{\sum_{i=1}^{5} W_i V_i}{\sum_{i=1}^{5} W_i} = \frac{[V_1 .. V_5]\begin{bmatrix} W_1 \\ \vdots \\ W_5 \end{bmatrix}}{\sum_{i=1}^{5} W_i} \qquad (14)$$

where $V=[V_1,\ldots,V_5]$ is a adjustable parameter vector, V_1 through V_5 are the center of the membership functions of Q_s. It should be noted that the appropriate determination of these parameters is an important issue to obtain the correct value for Q_s . These parameters can be adjusted according to the different operating conditions (that is states being close to or far from the switching surface) to get the optimum value for Q_s, as described in the following section.

3-3. Adaptive Fuzzy Sliding Mode Control (AFSMC)

In this paper to determine the optimum value of Q_s, an adaptive algorithm is proposed. According to the operating conditions and based on the proposed algorithm the centers of the membership functions of the fuzzy inference mechanism are adapted by the following adaptive law [8].

$$\dot{V} = \alpha \; V B|S|W \qquad (15)$$

in which α is a positive constant. It is obvious that when parameter variations or disturbances occur, the fuzzy inference mechanism and the adaptive law will be excited to find the new value of Q_s.

4. SIMULATION RESULTS

In order to illustrate the effectiveness of the proposed AFSMC system and also the effectiveness of the proposed AFSMC system and also the effectiveness of the simultaneous application of SVC and TCSC, time domain simulations are performed based on a nonlinear system model, using Matlab software. Dynamic responses of the generator to a 4 cycle three phase fault which occurs at the infinite bus, under different controllers for SVC and TCSC are considered. To show the effectiveness of the controller and its superiority over the conventional controller, comparison has been made between PID and AFSM controller. Generator angle and speed deviations obtained using PID controller and AFSM controller are shown in Fig. 7 and 8 respectively. The results show that the proposed control system con greatly improve the dynamic performance of the power system. To demonstrate the superiority of the AFSM controller, simulation studies are also performed for LQG, VSC, FSMC as well as PID and AFSMC under the same disturbance. The results relating to the deviation of rotor angle are shown in Table 1.

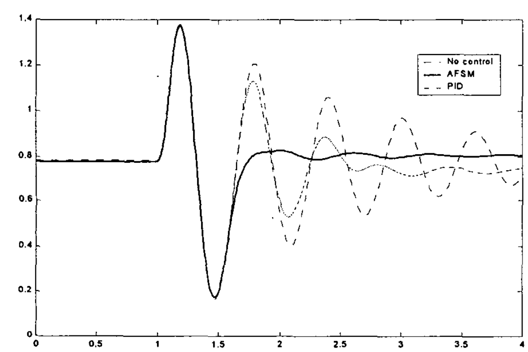

Fig 7 Rotor angle variations

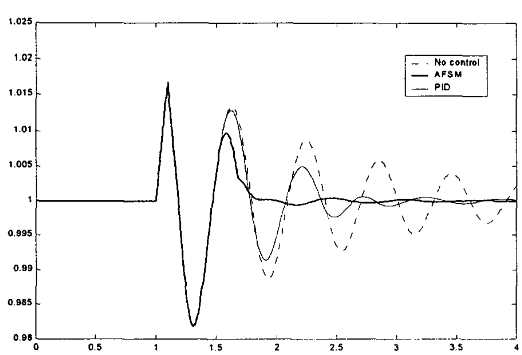

Fig 8 Speed variations

Controller	Settling time (second)	Overshoot (Percent)
No controller	6	75.66
PID	1.5	75.60
LQG	1	57.5
VSC	1.5	76
FSMC	0.7	76
AFSMC	0.6	59

Table. 1 Comparison of controllers (For δ)

5. CONCLUSION

Damping of generator oscillations is investigated using two types of FACTS devices using adaptive fuzzy sliding control system. The results show that these FACTS based type stabilizers can offer good damping characteristic under 3-phase fault condition. The results show the role and effectiveness of the proposed controller in damping power system when the power system experiences a large disturbance, such as a 3 phase fault.

6. REFERENCES

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