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Modelling of TCSC dynamics for control and analysis of power system stability

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Abstract

A Thyristor Controlled Series Compensator (TCSC) exhibits great nonlinearity and performs in a complex dynamic process. The aim of this paper is to propose a method that can accurately simulate this process when carrying out power system stability analysis, so that the impact of TCSC on power system stability can be more reasonably evaluated. A method that can incorporate the analysis of the electromagnetic transient process of TCSC into the power system stability analysis is described. Simulation studies using different modelling methods of TCSC are presented. The simulation results show the advantages of using the utilisation of the modelling method in power system control and stability analysis. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Thyristor controlled series compensator; Modelling; Transient process; Power system stability

1. Introduction

Power system stability enhancement using a Thyristor Controlled Series Capacitor (TCSC) has been topical for many years [1–6]. Prevailing power system stability analysis tools focus on the electromechanical process analysis. In this case the TCSC is often treated as a variable reactance of transmission line. Thus when evaluating effects of the TCSC on the power system stability, the electromagnetic transient process of the TCSC is not modelled and TCSC is simply considered as a linear component with nonlinear limits [3,5,6]. This has the effect of overestimating the stability improvement attributable to the compensator.

The main circuit of the TCSC is shown in Fig. 1. An indispensable component is the metal oxidised varistor (MOV), a highly nonlinear component; it operates in both the steady state and transient processes of the power system. During a transient, the MOV bypasses excessive currents and limits the voltage across the capacitor banks. This produces distortion of the TCSC voltage waveform and, consequently, sharply changes the fundamental frequency reactance of the TCSC.

It is well known that the reactance adjusting of TCSC is a complex dynamic process. Effective design and accurate evaluation of the TCSC control strategy depend on the simulation accuracy of this process. Indeed, the detailed study of the characteristics of the TCSC as a whole can be carried out using electromagnetic transient simulation software packages such as EMTP, EMTDC and PSPICE. However, these software packages are not suitable for simulation studies of large-scale power system stability.

This paper presents a strategy to incorporate the electromagnetic transient process of the TCSC into the common power system stability analysis software packages. The modelling of the TCSC, the interactive solution of the electromechanical process of the power system and the electromagnetic transient of TCSC are described in detail. Comparative simulation studies are presented to assess different models of the TCSC when used in power system stability analysis. Simulation results show the advantages of using the modelling method when performing control and stability analysis in a power system involving the TCSC.

2. Modelling of the dynamics of TCSC

The main circuit of a TCSC is shown in Fig. 1. It consists of four components, capacitor banks C, bypass inductor L, bidirectional thyristors SCR and a MOV. The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to the system voltage. This process can be modelled as a fast switch between two equivalent circuits, corresponding to the thyristor blocking or conduction state.

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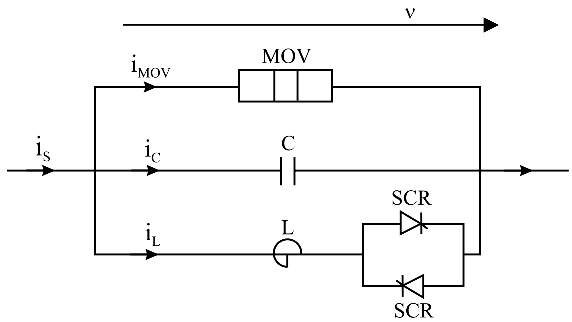

Fig. 1. The main circuit of TCSC.

2.1. Thyristor blocking state

When the thyristors are off, the equivalent circuit of TCSC is shown in Fig. 2 and the TCSC circuit can be described as follows:

$$i_C = C\frac{dv}{dt} \tag{1}$$

$$i_{MOV} = pv^q \tag{2}$$

$$i_S = i_L + i_{MOV} \tag{3}$$

where i_{MOV} and i_C are the instantaneous values of the currents in the MOV and capacitor banks, respectively; i_S the sum of i_{MOV} and i_C in the power system, i_S is thus the instantaneous current of the controlled transmission line; v the instantaneous voltage across the TCSC; and p and q are constants.

2.2. Thyristor conduction state

When the thyristors are fired, the equivalent circuit of TCSC is as shown in Fig. 1. The TCSC can be mathematically described as follows:

$$i_{MOV} = pv^q \tag{4}$$

$$i_C = C\frac{dv}{dt} \tag{5}$$

$$v = L\frac{di_L}{dt} \tag{6}$$

$$i_S = i_C + i_{MOV} + i_L \tag{7}$$

where i_L is the instantaneous current in inductor L; the meanings of other variables being the same as those described in Section 2.1.

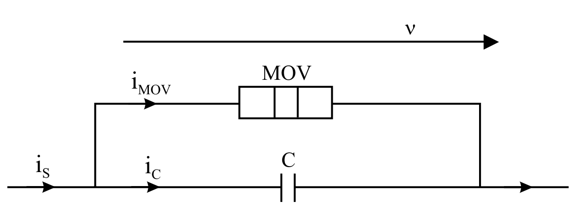

Fig. 2. Equivalent circuit of TCSC when thyristors are in block state.

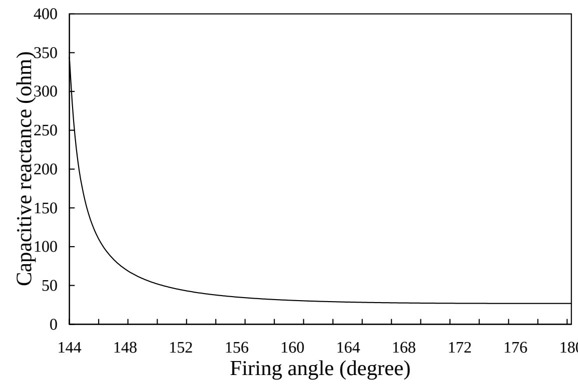

Fig. 3. Relationship between X_{TCSC} and α.

3. Operation of TCSC

It can be seen from Fig. 1 that control of the TCSC is achieved by the firing angle signal, which changes the fundamental frequency reactance of the compensator. However, there exists a steady-state relationship between the firing angle α and the reactance X_{TCSC}. This relationship can be described in the following equation:

$$X_{TCSC} = X_C - \frac{(X_C + X)(2\gamma + \sin(2\gamma))}{\pi} + \frac{4X^2(\cos^2\gamma)(k\tan(k\gamma) - \tan(\gamma))}{\pi X_L} \tag{8}$$

where

$$\omega_0 = \sqrt{1/LC}, \qquad k = \omega_0/\omega$$

$$X_C = 1/\omega C, \qquad X_L = \omega L$$

$$X = X_C X_L/(X_C - X_L)$$

$$\gamma = \pi - \alpha$$

With the parameters of a TCSC being those given in the Appendix, the steady-state relationship between the firing angle and fundamental frequency reactance X_{TCSC} is shown as in Fig. 3. In practical applications, a lookup table method is used to describe this relationship. When the desired value of reactance, X_{TCSC}, is determined from the power system state in accordance with the chosen control algorithm, the required value of the firing angle is obtained from this table.

Obviously, in the aforementioned control method, a fast acting process is assumed which neglects the time delay between firing angle and actual output reactance of TCSC. Determined by the parameters of the TCSC and the power system, this time delay can range from 50 to 180 ms.

Most importantly, in practical operations, the MOV is an indispensable part of the TCSC. It can be described by Eq.