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IMPROVEMENT OF TRANSIENT STABILITY IN POWER TRANSMISSION SYSTEM VIA TCSC

Danzhen Gu   Yong Wang   Shengchun BI
Department of Electrical Engineering
Shanghai University of Electric PWR
#2103 Pingliang Rd., Shanghai, 200090, P. R. China

ABSTRACT

A physical and typical high voltage, heavy loaded, long distance transmission system is examined. The comparisons of transient stability with and without controlling of the system are made. An excellent controller is developed. The digital simulation has demonstrated the effects of the improvement.

KEY WORDS: Power transmission, Transient stability, TCSC, Modeling, Simulation

1. INTRODUCTION

Thyristor Controlled Series Compensation (TCSC) is a key technique in Flexible Alternate Current Transmission Systems (FACTS)[3]. It can be used to adjust load flow, increase existing transmission facilities, improve system stability [1], damp power oscillation, etc, by various controlling strategies. At present, there have been several real projects being putting into operation in the world. However, only a few of them are built in China.

In this paper, a physical and typical high voltage, heavy loaded, long distance transmission system in China is studied. The comparisons of transient stability with and without control scheme are made. An excellent controller is developed. The Effects of the improvement are demonstrated by digital simulations.

2. TCSC MODEL AND ITS CONTROL

I. A SIMPLIFIED TCSC MODEL AND PRINCIPLE [1,4]

A simplified TCSC model used in the study is shown in Figure 2. The TCSC module consists of a series capacitor, a parallel path with a thyristor valve and a series inductor. It also consists of a metal-oxide varistor (MOV) for over voltage protection and bypass breaker. A complete TCSC system may be made up of several of these modules in series, and may also include a conventional (fixed) series capacitor bank as part of the overall system.

The power flowing through the transmission line is the function of capacitance and phase angle. It is described as follows,

$$P = \frac{U_1 U_2}{X_L - X_c} \sin\delta \qquad (1)$$

Where,

U_1, U_2 -----Voltage magnitude at the both ends of the line
X_L ----------Line inductance
X_c ----------Capacitance of series capacitor
δ ------------Phase angle of the line

Assuming a small disturbance is applied, i.e., $X_{TCSC} = X_{TCSC0} + \Delta X_{TCSC}$ and $\delta = \delta_0 + \Delta\delta$, equation (1) can be written as follows,

$$\Delta P = \frac{U_1 U_2}{X_L - X_{TCSC}} \cos\delta_0 \Delta\delta + \frac{U_1 U_2}{X_L - X_{TCSC0}} \sin\delta_0 \Delta X_{TCSC} \qquad (2)$$

Let

$$\Delta X_{TCSC} = A\Delta\omega = Ap\Delta\delta = \frac{d}{dt}, K = 1/A > 0$$

$$a = \frac{U_1 U_2}{X_L - X_{TCSC}} \cos\delta_0, b = \frac{U_1 U_2}{X_L - X_{TCSC0}} \sin\delta_0$$

The relation between ΔP and ΔX_{TCSC} can be got as follows,

$$\Delta P = aK \int \Delta X_{TCSC} dt + b\Delta X_{TCSC} \qquad (3)$$

The second order small disturbance model of the generator is

$$T_j p^2 \Delta\delta + Dp\Delta\delta + \omega_0 \Delta P = 0 \qquad (4)$$

Substituting equation (3) into equation (4), we can get

$$T_j p^2 \Delta\delta + \{D + Kb\} p\Delta\delta + \omega_0 a \Delta\delta = 0 \qquad (5)$$

From equation (4) to equation (5), the coefficient for system-damping increases from D to D+kb, i.e., the system stability increases, too.

II. MODEL OF THE CONTROLLER (SCHEME I)

In order to improve damping oscillation, the controller should make the line compensation degree comply with the power system swing. As shown above, the input $-\Delta P$ is related with the output ΔX_{TCSC}. The equations for the synchronous generator are shown as below:

$$p\delta = \omega - \omega_0 \qquad (6)$$

$$\frac{1}{f\ddot{O}_B} Mp\omega = P_m - P_e \qquad (7)$$

$$P_e = \frac{E_q^{'} U}{X\Sigma} \sin\delta \qquad (8)$$

Where, $p = \frac{d}{dt}$, $X\Sigma = X_d^{'} + X_T + X_L + X_{TCSC}$

ΔX_{TCSC} is assumed the same phase with $\Delta\omega$. When $\Delta\omega > 0$, which means that the generator speed increases, and $\Delta X_{TCSC} > 0$, lead to decrease $X\Sigma$ and increase P_e, which decreases acceleration of the generator. When $\Delta\omega < 0$, the case becomes opposite If ΔX_{TCSC} is lagged the line power change ($-\Delta P$), ΔX_{TCSC} is the same phase with the generator speed change ($(\Delta\omega)$.

The frequency range of line oscillation is about 0.2~2HZ[1]. Figure 3 shows the power oscillation damping controller model block. By the control block, when the reactance change is adjusted to lag the line power change, the TCSC compensation degree changes the same phase with $\Delta\omega$, where the parameters are

$\mathrm{T_w} = 1, T_1 = .2, T_2 = .07, T_3 = .2, T_4 = .05, T_{TCSC} = .06.$

III. PI CONTROLLER MODEL WITH TRANSIENT CONTROL(SCHEME II)[5]

Proportional-Integration (PI) controller is widely used in industry. When PI control is used in TCSC control model block, the bus voltage change at TCSC terminal is used as input. The transmission function is shown as Figure 5 and Figure 6.

IV. THE TCSC CONTROLLER WITH TRANSIENT CONTROL (SCHEME III)[6]

In order to improve the stability in the first swing, it is necessary to increase the system synchronous power. One of the ways is to use the maximum series compensation at operation to minimize the initial power phase difference. However, it is impossible because there is conflict with the dispatch of power flow and voltage control. So, to improve the stability of the generators at power plant A, it is necessary for part of the series compensation facilities to be put into operation during fault occurs. Figure 4 shows the principle.

V. DIGITAL SIMULATION

1. Studied system In this paper, the project is a typical high voltage, heavy loaded and long distance transmission system in east China. As shown in Figure 1, In order to use two transmission lines instead of three ones, fixed series compensation facilities are equipped at Bus D now.

2. Simulation The data is based on the plan of the system operation in year 2010. One typical operation modes are selected, in which the power flow conditions is shown as Table 1 and Table 2. As shown in the tables, the voltage at these power network main buses is rated above 500KV. There is no overload happened on lines. The generators at power plant A use detailed model on dq axes, the excitation model is thyristor-controlled static excitation, with quick response and high initial exciting voltage response. The load uses inductive motor and constant reactance composite model, where impedance is in portion of 40% and inductive motor 60% respectively.

Table 1 Studied Case of the System Operation (Voltage)

Bus	Voltage（kV）	Power Angle（degree）
A	521.239	24.74
B	519.542	15.41
C	522.318	6.60
D	521.009	4.89
E	515.000	0.00
F	521.136	5.12

Table 2 Studied Case of the System Operation (Power Flow)

Line	Voltage （kV）	Real Power （WM）	Reactive Power （Mvar）
F——D	521.136	250.400	8.033
D——E	521.009	352.558	-65.160
C——D	521.009	-724.317	-72.338
C——E	522.318	587.842	-10.558
A——B	521.239	643.387	-89.284

Figure 7 shows the generator power angle curve when the short circuit fault occurs at Bus A. Under the normal condition, the real power injection of Bus A is 1600MW, and the 40% fixed series compensation facilities are in service near Bus C. Under the fault condition, there is short circuit occurred near Bus A, after 0.1 second, the faulted line is switched off by protection devices. From Figure 7, it can be seen that the fixed series compensation facilities improve the system stability. However, the damping condition of the system is poor, the oscillation of the line power last a long time.

In order to improve that, instead, TCSC is applied. In Figure 8 ~ Figure 11, under fault conditions: a phase-ground fault occurs on lines A-B at 0 second, and three lines are tripped by protection devices at 0.1 second.

Figure 8 shows that the system, with SC but without TCSC, keeps the stability until 0.900 seconds.

Figure 9 shows that the system keeps the stability until 1.100, while there is TCSC in Scheme I in the system.

Figure 10 shows that the system keeps the stability forever and poor suppressing, while there is TCSC in Scheme II in the system.

Figure 11 shows that the system keeps the stability forever and excellent suppressing, while there is TCSC in Scheme III in the system.

4. CONCLUSION

To summarize, it can be seen that

- The main problem of long distance transmission system is the voltage phase angle is quite large between both ends, which makes system stability margin quite small. Under such condition, it is easy for the system to become unstable. Furthermore, long distance transmission system will have large capacitive reactance power, which results large voltage.
- The system with series compensation facilities is more stable than the one without it.
- TCSC can improve system stability to a great extent.
- The Scheme III, developed in this paper, is an excellent controller for the project.

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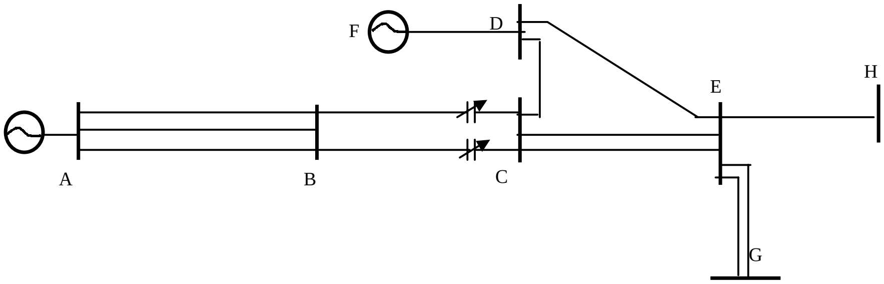

Figure 1 The simplified power transmission system to be studied

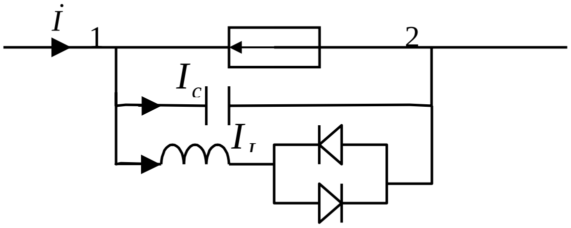

Figure 2 A simplified TCSC module

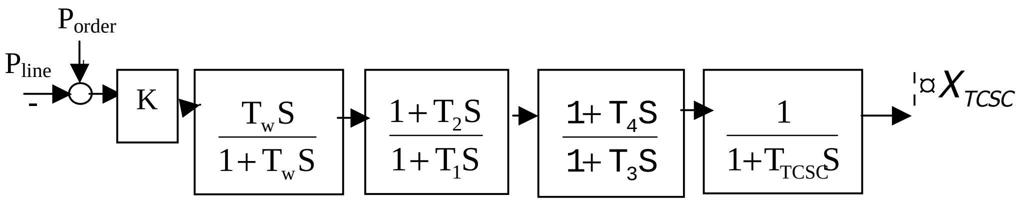

Figure 3 Power oscillation damping controller

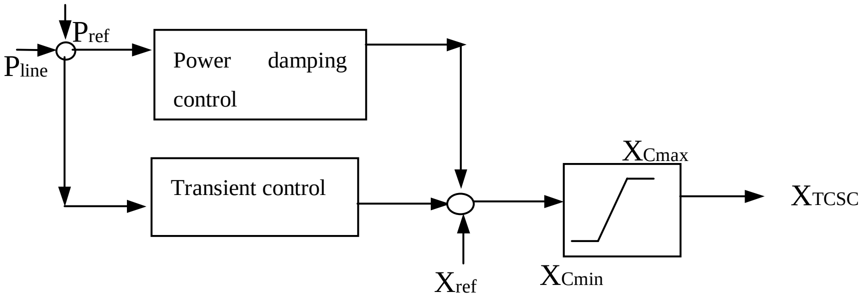

Figure 4 TCSC controller with Transient control

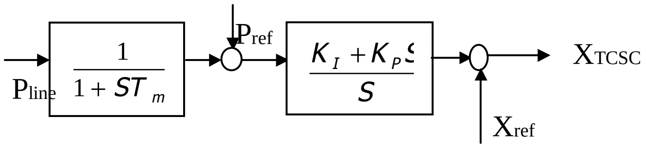

Figure 5 PI controller

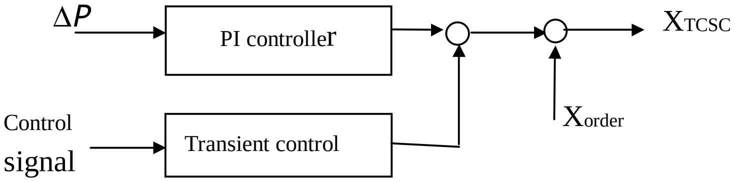

Figure 6 PI controller with transient control

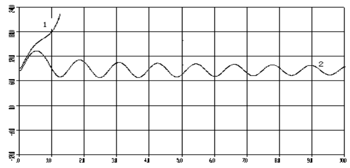

Figure 7 The generator no series compensation and fixed series compensation

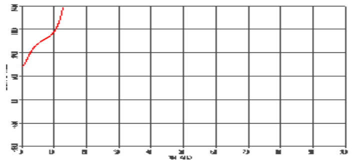

Figure 8 The power angle swing curve of generator at power plant A with fixed series compensation facilities

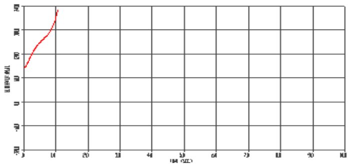

Figure 9 The power angle swing curve of generator at power plant A with TCSC under power damping control

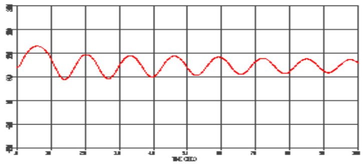

Figure 10 The power angle swing curve of generator at power plant A with TCSC under PI control and transient control

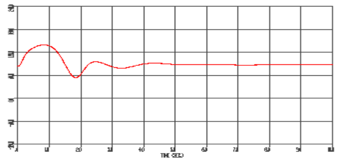

Figure 11 The power angle swing curve of generator at power plant A with TCSC under power damping control and transient control