American Journal of Applied Sciences 9 (10): 1602-1605, 2012
ISSN 1546-9239
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Voltage Stability of Medium Transmission Line Equipped with a Thyristor Controlled Series Capacitor

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Abstract: Problem statement: Power-Voltage curve provides very important information for voltage stability analysis. The exact medium transmission line model consists of the resistance and the reactance. The resistance causes in the active line loss. It is not an easy task to achieve the power-voltage curve characteristics of power system with the exact medium line model equipped with a. Thyristor Controlled Series Capacitor (TCSC). **Approach:** This study applies the concept of the Newton-Raphson method to iteratively solve the nonlinear power flow equations. The Power-Voltage (P-V) curve characteristic of the system without line loss and with line loss are plotted and compared with various cases. **Results:** It is found from the study that the resistance of the line obviously provides the negative effects on the voltage stability. The line loss causes in the decrement of the critical point. In addition, it is found that the leading power factor can increase the critical point of P-V curve. **Conclusion:** The exact medium line model should be considered for voltage stability analysis of the system with the medium transmission line.

Key words: Power system stability, voltage stability, critical clearing time, FACTS devices, resistance, reactance, capacitance, transmission line, medium transmission line, two-port network

INTRODUCTION

Power system stability is classified as rotor angle stability and voltage stability. Voltage stability is stability in power systems which are heavily loaded, disturbance or have a shortage of reactive power. Nowadays, the demand of electricity has dramatically increased and a modern power system becomes a complex network of transmission lines interconnecting the generating stations to the major load points in the overall power system in order to support the high demand of consumers. It is becoming increasingly important to fully utilize the existing transmission system assets due to environmental legislation, rights-of-way issues and costs of construction and deregulation policies that introduced in recent years. A number of Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, has been proposed for better utilization of the existing transmission systems (Lokman *et al*., 2010; Omar and Sulaiman, 2010; Osuwa and Igwiro, 2010; El-Shennawy *et al*., 2010; Zarate-Minano *et al*., 2010).

The evaluation of the Power-Votage (P-V) curve of the power system is one of the most important research areas for power engineers because it indicates the maximum power load. If the load is increased beyond the maximum value, the voltage will be collapsed and then the system is considered as unstable.

The Thyristor Controlled Series Capacitor (TCSC) is the series FACTS devices. It consists of the capacitor bank reactor bank and thyristor as shown in Fig. 1. The thyristors control the reactance or susceptance that dictates the power flow through a line. The TCSC can be applied for improving stability of power system (Subramani, 2012).

The evaluation of Critical Clearing Time (CCT) of power system is one of the most important research areas for power engineers because it indicates the robustness of the faulted power system. The rotor angle of the synchronous generator determines the stability of the power system. Although the stability of the synchronous machine is used to represent the stability of the power system, all of the power system components such as transmission line and transformer affect the stability of the power system.

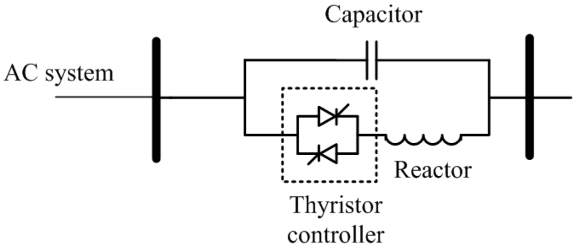

Fig. 1: Schematic diagram of TCSC

The transmission line is one of the most important parts in power system components. Most of the fault occurs at the transmission line. The transmission line is generally divided into three major categories; short, medium and long model whose distance are about 80 km, above 80-250 km and above 250 km, respectively. Many previous researches used simple transmission line model by neglecting its resistance or capacitance. To fully utilize the existing system, the exact transmission line should be further investigated.

This study will investigate the capability of the TCSC on voltage stability of the SMIB system with the exact medium transmission line model. The concept of two-port network is applied to simplify the mathematical model of the power system. The sample system consisting the practical medium transmission line is used to investigate in this study. The proposed method is tested on various cases.

MATERIALS AND METHODS

Mathematical model: Figure 2a shows the single line diagram of power system consisting of a medium transmission line series with a Thyristor Controlled Series Capacitor (TCSC). The voltage on the generator bus ($\mathbf{V}_S$) is considered as a constant value. The medium transmission line model is represented by an implement $\mathbf{Z}$. The load is represented by the active (P_R) and reactive power (Q_R).

The ABCD constants of medium transmission line model in two port network are given by Eq. 1-4:

$$A_1 = 1 \tag{1}$$

$$B_1 = Z \tag{2}$$

$$C_1 = 0 \tag{3}$$

$$D_1 = 1 \tag{4}$$

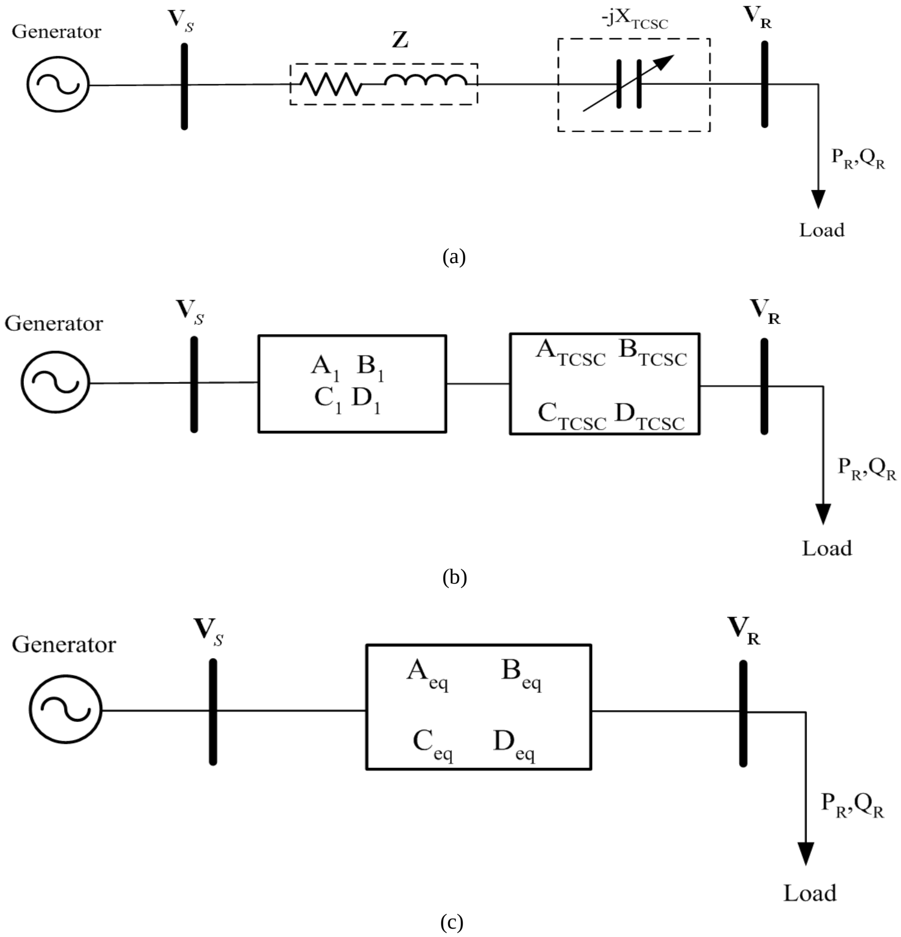

Fig. 2: Single machine infinite bus system with a TCSC (a) schematic diagram (b) equivalent circuit (c) two port network diagram (d) a successive two-port network

The ABCD constants of a TCSC in two port network are given by Eq. 5-8:

$$A_{TCSC} = 1 \tag{5}$$

$$B_{TCSC} = -jX_{TCSC} \tag{6}$$

$$C_{TCSC} = 0 \tag{7}$$

$$D_{TCSC} = 1 \tag{8}$$

With the series combination of a transmission line and TCSC in two port network as shown in Fig. 2b, a successive two port network is shown in Fig. 2c and its constant parameters are given by Eq. 9-12:

$$A_{eq} = A_1 A_{TCSC} + B_1 C_{TCSC} \tag{9}$$

$$B_{eq} = A_1 B_{TCSC} + B_1 D_{TCSC} \tag{10}$$

$$C_{eq} = A_{TCSC} C_1 + C_{TCSC} D_1 \tag{11}$$

$$D_{eq} = B_{TCSC} C_1 + D_1 D_{TCSC} \tag{12}$$

Then the active and reactive power load is given by:

$$P_R = \frac{V_R V_S}{B_{eq}} \cos(\theta_B - \delta) - \frac{A_{eq} V_R^2}{B_{eq}} \cos(\theta_B - \theta_A) \tag{13}$$

And;

$$Q_R = \frac{V_R V_S}{B_{eq}} \sin(\theta_B - \delta) - \frac{A_{eq} V_R^2}{B_{eq}} \cos(\theta_B - \theta_A) \tag{14}$$

The objective of this study is to evaluate the voltage at load bus (V_R) with various cases of load. This study applies the Newton-Raphson method to iteratively solve the nonlinear Eq. 13 and 14 given by Eq. 15:

$$\begin{bmatrix} \Delta P_R \\ \Delta Q_R \end{bmatrix} = \begin{bmatrix} \frac{\partial P_R}{\partial \delta} & \frac{\partial P_R}{\partial V_R} \\ \frac{\partial Q_R}{\partial \delta} & \frac{\partial Q_R}{\partial V_R} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{15}$$

RESULTS

The proposed method is tested on the sample system consider the diagram of sample system is shown in Fig. 2. The system supplies power which is transferred through a 40 km transmission line to the load. The system voltage at the generator bus is 220 kV.

It is considered that the variable capacitive reactance of a TCSC is operated at 25% of the line reactance. The comparison of the Power-Voltage (P-V) curve of the system with and without a TCSC for various power factors is shown in Fig. 3-7. Table 1 summarizes the critical point (P_R^{cr}, V_R^{cr}) of the system without and with a TCSC for various power factors.

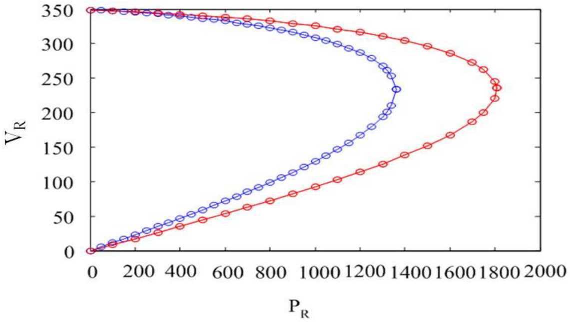

Fig. 3: P-V curve of the system without and with a TCSC for unity power factor

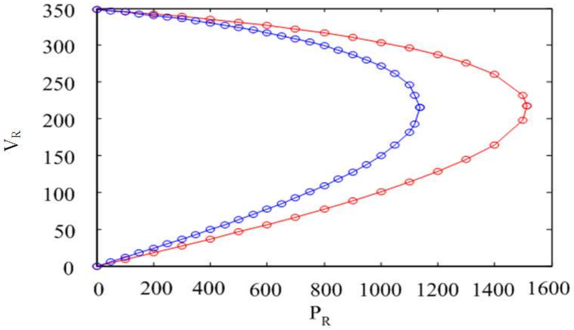

Fig. 4: P-V curve of the system without and with a TCSC for

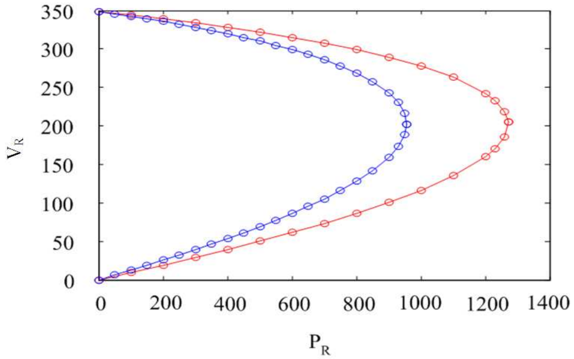

Fig. 5: P-V curve of the system without and with a TCSC for tan $\phi = 0.4$

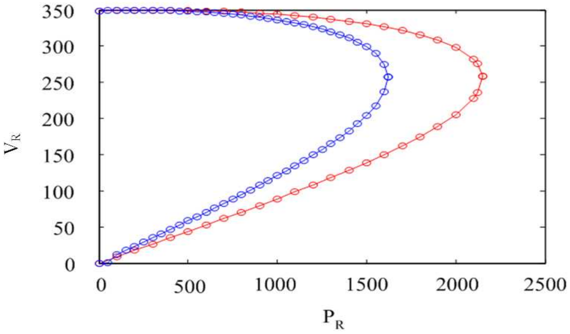

Fig. 6: P-V curve of the system without and with a TCSC for

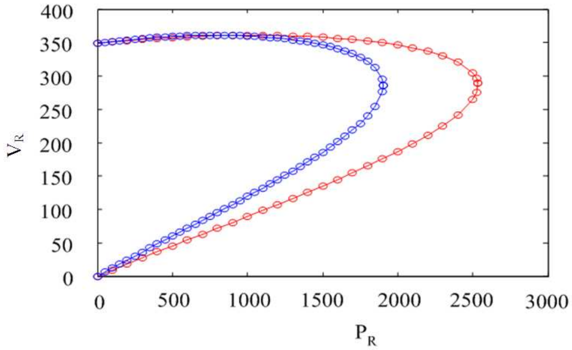

Fig. 7: P-V curve of the system without and with a TCSC for

Table 1: The maximum and minimum rotor angle of the system with a TCSC and various parameters of the medium transmission line

		Without TCSC		With a TCSC	
		P_R^{cr}	V_R^{cr}	P_R^{cr}	V_R^{cr}
Case	tan ϕ	(W)	(kV)	(W)	(kV)
1	0.4	955	202	1271	205
2	0.2	1138	215	1514	217
3	0.0	1360	233	1809	236
4	-0.2	1619	256	2153	258
5	-0.4	1905	286	2533	289

DISCUSSION

It can be seen from the Fig. 3-7 and the Table that a TCSC can improve voltage stability of the system. Without a TCSC and unity power, the critical point (P_R^{cr}, V_R^{cr}) is at 1360 W and 233 kV. In this case, it indicates that the maximum power load is around 1360 W. However, with a TCSC, the maximum power load is increased to 1809 W. This study investigates the effect of power factor on the critical point. With the lagging power factor, the critical point point is reduced whereas with the leading power factor, the critical point point is increased. With tan ϕ = 0.4 and with a TCSC, the maximum power is reduced to 955 W whereas tan ϕ =-0.4 and with a TCSC, the maximum power is increased to 2533 W.

CONCLUSION

This study investigated the effects of the Thyristor Controlled Series Capacitor (TCSC) on the voltage stability improvement of the Single Machine Infinite Bus (SMIB) system with the consideration of the exact medium transmission line model. The mathematical model was systematically derived by using the concept of the two-port network. This concept can help us to obtain a mathematical model of the system in the simplest way.

The presented methods were tested and compared with various cases. It was found from the simulation results that the TCSC improve the voltage stability performance. The leading power factor and a TCSC operated in capacitive mode can improve voltage stability.

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