



A Computerized Behavioral Study of Series Energy Controller for Energy Flow Control

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Abstract: The Flexible Alternating-Current Transmission Systems, incorporating a wide range of possibilities for better utilization. Improvement of voltage and current limits on the power electronics devices leads to a fast development in the last decade. Solid state power electronic devices or Flexible Alternating-Current Transmission Systems technologies has brought an scope for electric utilities to operate their bulk power flow network close to their thermal limits while maintaining and/or improving network security or reliability. High-power electronic devices can provide unprecedented control over electricity flow in transmission networks. Flexible Alternating-Current Transmission Systems devices responds quickly enough to changing network conditions to provide real-time power flow control, which is essential when large numbers of power transactions occur in a fully deregulated electric industry. In this paper a MATLAB / SIMULINK model of 3-phase series controller has been developed for quick power flow control between two Areas connected by 100 km transmission line. The effect of TCSC controller firing angle variation on power flow is also studied.

Keywords: Firing angle, System flexibility, Flexible AC Transmission System, Thyristor Controlled Series Capacitor (TCSC), Power system stability, Power Flow, Simulink.

I. INTRODUCTION

Flexible AC Transmission System is a concept proposed by Hingorani (1) that involves the application of high power electronic controllers in AC transmission networks. Flexible AC Transmission System is not a particular controller but a group of controllers (2) which enable fast and reliable control of power flows and voltages. Flexible AC Transmission system (FACTS) controllers can balance the power flow and thereby use the existing system network most efficiently. Because of their fast response, FACTS controllers can also improve the stability of an electrical power system by helping critically disturbed generators to give away the excess energy gained through the acceleration during fault. [3, 4]

The Flexible AC Transmission System Technology has already proved itself to be superior over the switched capacitor or reactor blocks due to fast response time and extended range of operation. (5) The Flexible AC Transmission System devices employ control circuitry for controlling the conduction range of power converters so as to control either the DC bus voltage and/or controlling the reactive power fed to the power system. One of the promising series Flexible AC Transmission System devices is the thyristor controlled series capacitor (TCSC) (6). It is able to control the power flow, provide damping to the inter-area and local mode oscillations, and improve transient stability.

The thyristor controlled series capacitor (TCSC) is a second generation Flexible AC Transmission System controller which controls the effective line reactance by connecting a variable reactance in series with the line.(7,8) The variable reactance is obtained using a fixed capacitor

and a thyristor controlled reactor combination with mechanically switched capacitor sections in series. Use of series compensation is usually a preferable alternative .Use of TCSC reduces the Sub synchronous Resonance due to adverse torsional interaction with generator- turbine shafts. The TCSC is useful for increasing power flow capability of lines as compared to shunt compensators as the rating required for series compensators are significantly smaller (9-11).

II. TCSC IN POWER TRANSMISSION SYSTEM

The power transfer between two areas can be affected by adjusting the net series impedance. One such conventional method of increasing transmission line capacity is to install a series capacitor. This reduces the overall series impedance of the transmission line. Thus allowing more power to be transferred. The limitation of this method is large switching time. The series electronic controllers such as TCSC are able to rapidly and continuously control the series line compensation. The system stability determines (12, 13) whether the system can settle down to a new or original steady state after the transient subsides. Although system stability is an integral property of the system, for the system analysis, it is divided in two classes, steady state stability or small signal stability and transient stability. For a particular operating condition, a energy system is said to be steady state stable if, following any small disturbance, it reaches a steady state operating condition which is identical as or close to the pre-disturbance operating condition. For a particular operating condition, a energy system is said to be transient stable and

for a particular (large) disturbance or sequence of disturbances if, following the disturbance(s) it reaches an acceptable steady state operating condition. One of the main functions of TSCS is in the voltage increment on the transmission line whenever there is a disturbance happened [14]. TCSC has the capability to provide a continuous variable capacitor by controlling the firing angle delay of the thyristor [15] and able in mitigating the sub synchronous resonance that induced by the generator. Another advantage of using TCSC at the transmission line is the thyristor switching is allowed for unlimited number of operations. The basic circuit of TCSC is shown in Fig. 1 with resistances have been neglected (16-18).

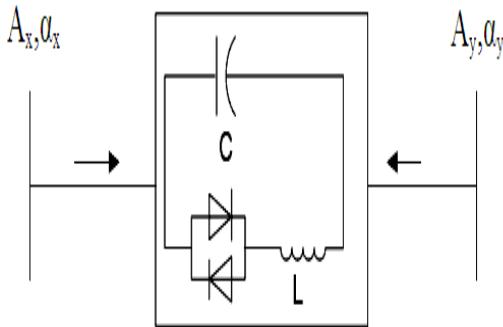


Fig. 1 Basic Module of TCSC

Thyristor Controlled Series Capacitor (TCSC) is the combination of series capacitor with the Thyristor Controlled Reactors (TCR) connected in parallel. The TCSC consists of a capacitor C connected in a parallel thyristor-controlled inductor L. The firing angle (α) of the thyristors is controlled to adjust the TCSC reactance (X_{TCSC}) in response to system parameter variations. TCSC operates such that the TCSC is seen by the circuit as, virtually, having an increased reactance beyond the original reactance of the of TCSC capacitor, i.e., the TCSC is seen as controllable equivalent reactance.

A TCSC can provide continuous control of power on the ac line over a wide range. The Thyristor controlled series compensator, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line [19]. TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. Many relevant benefits can be achieved by flexibly and quickly adjusting the reactance of the TCSC, examples are better utilization of transmission capability, fault current limitation, power oscillation damping, control over sub synchronous resonance (SSR), efficient power flow control, and transient stability improvement [20].

There exists a relationship between firing angle (α) and the TCSC reactance (X_{TCSC}). This relationship is described by the following equation .

$$X_{TCSC} = X_C - \frac{X_C^2}{(X_C - X_p)} \frac{2\beta + \sin 2\beta}{\pi} + \frac{4X_C^2}{(X_C - X_p)(k^2 - 1)} \frac{\cos^2 \beta}{\pi} \frac{(k \tan k\beta - \tan \beta)}{(k^2 - 1)}$$

Where

$$K = (X_C / X_p)^{1/2} = \text{Compensation Ratio}$$

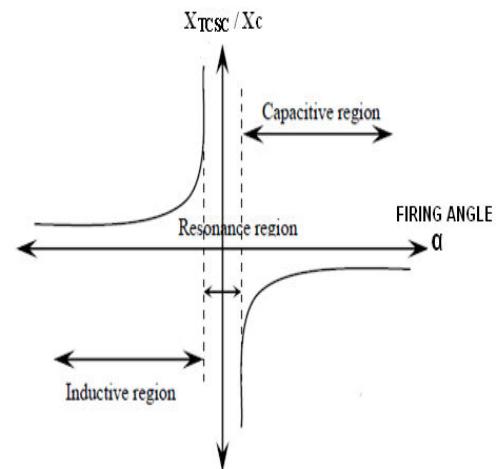
$$\beta = \pi - \alpha = \text{conduction angle of TCSC controller}$$

$$X_C = \text{Nominal Reactance of the fixed Capacitor}$$

$$X_p = \text{Reactance of Inductor L}$$

The relationship between firing angle (α) and the TCSC reactance is a unique valued function therefore TCSC is modeled as a variable capacitive reactance. The TCSC is used in capacitive zone (21-23) .Fig. 2 shows the variation of X_{TCSC} / X_C as a function of firing angle (α).

There is a value of the firing angle which causes steady state resonance. The device can be controlled in the capacitive or inductive zone, avoiding steady state resonance. For the inductive region, which is not used in steady state, acceptable values of the firing angle are between 90° and α_{maxL} , where $\alpha_{maxL} < \alpha_{Res}$, with the resonant value of the firing angle being determined by the ratio X_C / X_L .The capacitive region is limited by 180° and α_{minC} .TCSC allows the fundamental capacitive reactance to be smoothly controlled over a wide range. The TCSC controller can be designed to control the power flow, to increase the transfer limits or to improve the transient stability (24-26). The TCSC controller can provide a very fast action to increase the synchronization power through quick changing of the equivalent capacitive reactance to the full compensation in the first few cycles after a fault, hence subsequent oscillations are damped. TCSC controller provides variable impedance, which is required for the compensation.

Fig. 2 X_{TCSC} / X_C Vs FIRING ANGLE (α) CURVE

Series capacitors offer certain major advantages over the shunt capacitors. With series capacitors, the reactive power increases as the square of line current, whereas with shunt capacitors, the reactive power is proportional to the square of bus voltage. For achieving same system benefits as those of series capacitors, shunt capacitors required are three to six times more reactive power rated than series capacitors. Furthermore shunt capacitors typically must be connected at the midpoint, whereas no such requirement (27-29) exists for series capacitors. A series capacitor is capable of compensating for the voltage drop of the series inductance in a transmission line. During low loading the system voltage drop is lower and at the same time the series compensation voltage is lower. When loading increases (30)

and the voltage drop becomes higher, the contribution of series compensation increases and therefore system voltage will be regulated as desired.

III. ENERGY SYSTEM DESIGN

Considering a energy system as shown in the Fig.3 having two 3- Phase Sources connected with a 100 Km Transmission line.

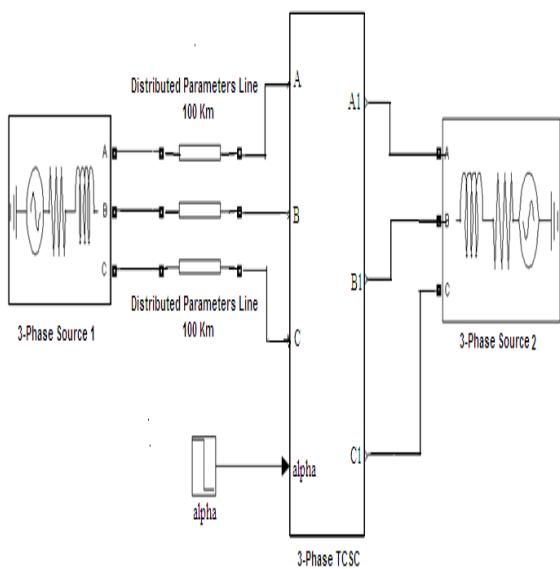


Fig. 3 Power System connected with Series Controller

A 3-Phase series controller (TCSC) is placed in one of the parallel lines. The detailed MATLAB model developed of above system is shown in Fig. 4.

IV. MATLAB SIMULATION

The energy system shown in Fig. 4 is studied through the computer simulation using the MATLAB/Simulink software.

Fig.5 (a)-5(c), Fig.6 (a)-6(c) shows the TCSC reactance and Power flow when the TCSC firing is started at $t = 0.1$ sec., firing pulse generator is synchronized to current as the current has lesser harmonics. A 90 degree shift is then given so that it becomes synchronized with the capacitor voltage. The firing angle is varied from 160 to 150 degrees [Fig 5(a), Fig.6 (a)]. The firing angle is further varied from 150° to 140° [Fig 5(b), Fig.6 (b)] and 140° to 130° [Fig 5(c), Fig.6(c)].

It has been observed from Fig. 5 (a) that a variation of firing angle from 160° to 150° leads to an increase in TCSC reactance and thus increases power flow [Fig 6(a)]. This shows the power flow control capabilities of TCSC.

From Fig 5(b) a further reduction of delay angle from 150° to 140° at one second causes an increase in effective capacitive reactance but with decrease in power flow [Fig 6(b)]. This is due to the fact that for the firing angle between 150° to 140° TCSC reactance may reaches in Resonance region (Fig.2) which causes large value of TCSC reactance.

From Fig.5 (c) a further reduction of delay angle from 140° to 130° causes further increase in the TCSC reactance close to steady state resonance point. This causes further reduction in power flow [Fig 6(c)]. Thus the device has to be controlled in the capacitive or inductive zone, avoiding Resonance region.

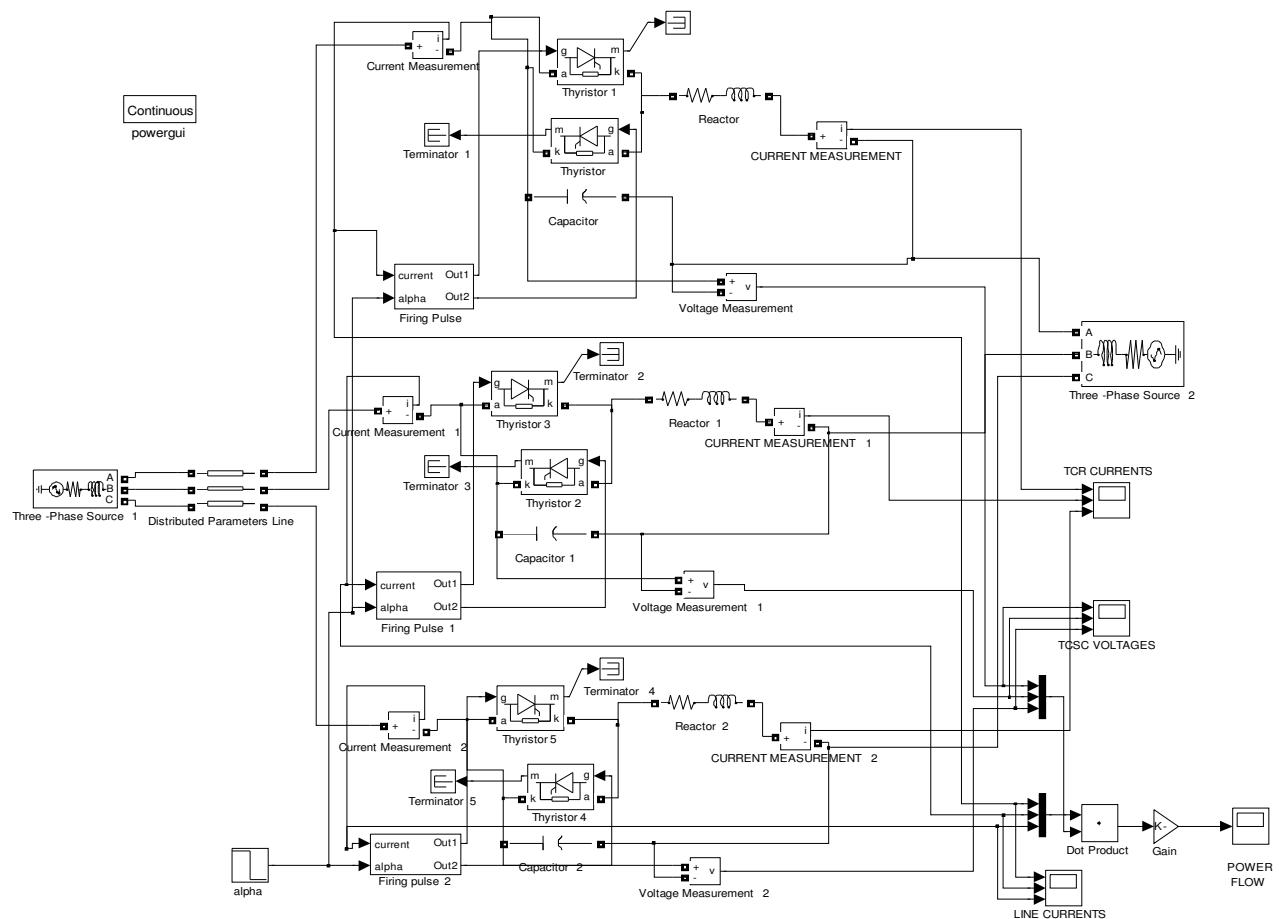


Figure. 4 Matlab /Simulink model

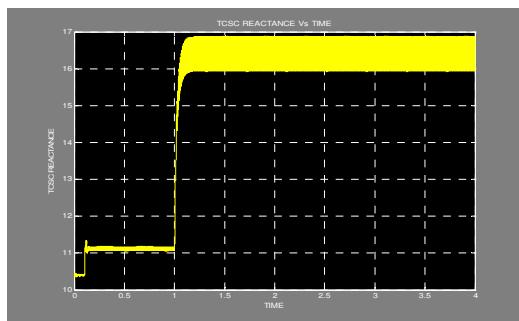


Fig 5(a)

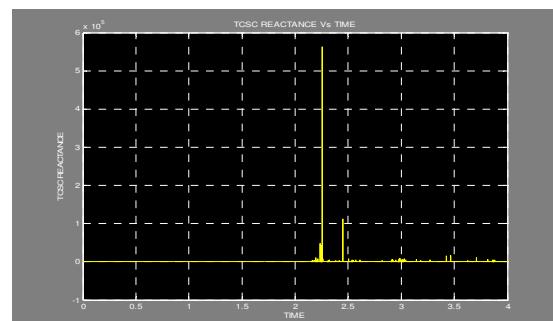


Fig 5(c)

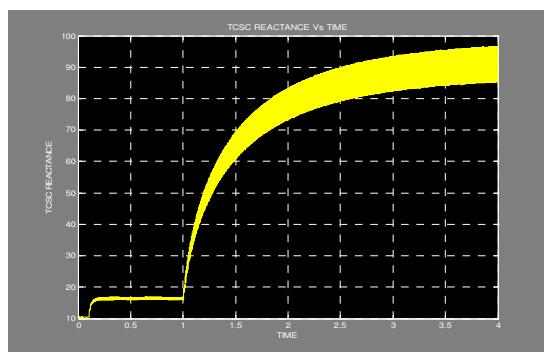


Fig 5(b)

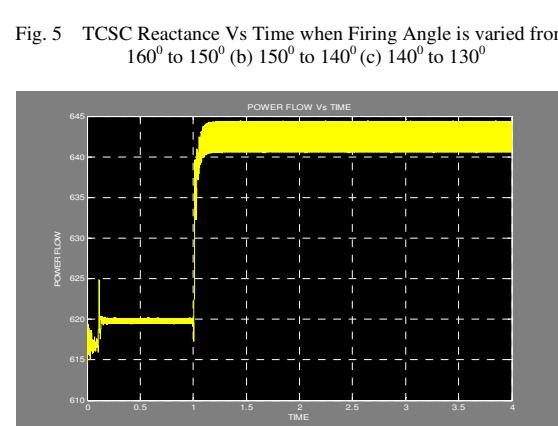


Fig. 5 TCSC Reactance Vs Time when Firing Angle is varied from (a) 160° to 150° (b) 150° to 140° (c) 140° to 130°

Fig 6(a)

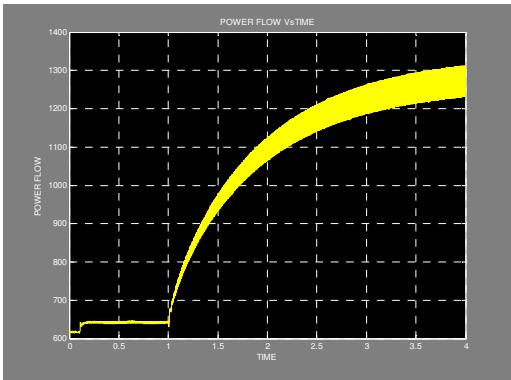


Fig 6(b)

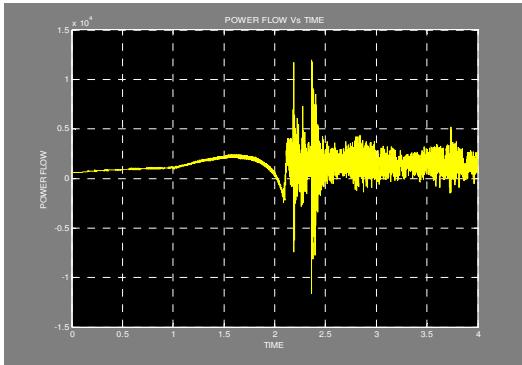


Fig 6(c)

Fig. 6 Power Flow Vs Time when Firing Angle is varied from (a) 160° to 150° (b) 150° to 140°
(c) 140° to 130°

V. CONCLUSION

The above MATLAB simulation results shows that for power flow enhancement through the existing transmission lines, TCSC controller is an effective technique. The reactance of the TCSC controller is a function of its thyristor firing angle. It has been shown through simulations that the device has to be controlled either in the capacitive or inductive zone and avoiding resonance region.

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