Power Transfer Capability Improvement of Transmission Line using TCSC

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Abstract—this paper deals with the single phase Thyristor controlled series capacitor (TCSC) to improve the power transfer capability in transmission line. The Aim of this work is to show the possibilities of using TCSC and its MATLAB/SIMULINK modelling of a simple model of electrical network with two parallel lines simulate the behaviour of TCSC in terms of power flow control through the lines. The simulation results show that TCSC controller provides a better performance in the open loop system and desire control of power flow in the incorporate of TCSC line can achieve.

Key words: TCSC, FACTS, Power Flow Control, Power System, Modelling of TCSC, MATLAB/Simulink

I. INTRODUCTION

The electricity is an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Nowadays, the demand of electricity has dramatically increased and a modern power system becomes highly complex in nature. Due to the excessive demand of electrical power, the size and complexity of power systems is increasing equally. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. Therefore, the Grid companies are more interested in raising and controlling the power-flow through the main transmission lines without losing system reliability.

In reality, the power transfer capability of transmission line is reduced by a number of various mechanisms, including stability, voltage and thermal constraints. Different components and transmission lines in a large interconnected power system can also be affecting the transfer capability on some certain transmission paths. The changes of inductive impedance of line greatly affect the active power flow. Power flow is based on the inverse of the transmission line impedance. Hence, the need to transfer power over long transmission lines is becoming very important.

Therefore, FACTS devices were proposed, which have facilitate the power control, enhance the power transfer capacity, decrease the line losses and generation costs, and improve the stability and security of the power system. The significant device from the group of FACTS is a TCSC, which finds application in solving many problems in the power system. Its properties can increase the power transmission capacity and power flow control.

II. TCSC CONTROLLER

The basic structure of TCSC is shown in Fig.1. Which consist of a fixed series capacitor (FC) connected with parallel TCR. Where, The TCR is formed by a reactor in series with a bi-directional thyristor switch.

Fig. 1: Block Diagram of TCSC

The TCSC device is simply to increase the fundamental frequency voltage across a fixed capacitor by appropriate variation of the firing angle of TCR. This enhanced voltage changes the effective value of series capacitive reactance.

The steady-state impedance of the TCSC is that of a parallel LC circuit, consisting of a fixed capacitive impedance, Xc, and a variable inductive impedance, Xl(α), that is,

\[ X_{\text{eff}}(\alpha) = \frac{X_c X_l(\alpha)}{X_c + X_l(\alpha)} \]

where \( X_c \leq X_{\text{eff}}(\alpha) \leq \infty \)

\[ X_l(\alpha) = X_L - \omega L \]

\[ \alpha \] is the delay angle measured from the crest of the capacitor voltage or equivalent zero crossing of the line current. As the impedance of the controlled reactor, \( X_l(\alpha) \), is varied from its maximum (infinity) toward its minimum (ωL), the TCSC increases its minimum capacitive impedance, \( X_{\text{TCSC,min}} = X_C = 1/\omega C \), (and thereby the degree of series capacitive compensation) until parallel resonance at \( X_C = X_l(\alpha) \) is established and \( X_{\text{TCSC,max}} \) theoretically becomes infinite. Under normal operating conditions TCSC can operate in four modes of operation, namely: blocked mode, bypassed mode, capacitive and inductive mode.

The effective reactance of TCSC operates in three regions:-
1) Inductive region: \( 0 \leq \alpha \leq \alpha_L \text{lim} \) range,
2) Capacitive region: \( \alpha_L \text{lim} \leq \alpha \leq 90 \) range,
3) Resonance region: \( \alpha_L \text{lim} \leq \alpha \leq \alpha_C \text{lim} \) range,

Fig. 2: Reactance vs Firing Angle Characteristic Curve
III. TCSC MODELING USING SIMULINK

The block diagram of simple electrical two bus network consists of a voltage source, load, two parallel identical lines, and TCSC block. In this system, TCSC is installing in the second transmission line of two bus network. Therefore, the TCSC will control the power flow in second transmission line by reducing effective impedance of that line. The diagram of simple network with TCSC Controller has been shown in Figure 3.

Fig. 3: Block diagram of the model of electrical network with TCSC

The parameters of TCSC device are follows:
Inductance of TCR $L = 0.0012 \text{ H}$,
Capacitance of TCSC $C = 0.0011 \text{ F}$,
Ratio $X_l / X_c = 0.1256$.

With 90.4mH as the transmission line reactance, this line reactance is compensated by providing capacitive reactance of TCSC controller. The parameters of TCSC model were designed so that the Percentage of compensation of TCSC was approximately 40% when switching thyristors angle $\alpha = 70^\circ$, according to the following calculations:
Reactance of line No.2 is
$\therefore X_{line2} = 2\pi f \cdot L_{line} = 28.38$

Percentage of compensation can be determined by the equation[7]

$$K = \frac{X_{cap}(\alpha)}{X_c} \quad (0 < k < 1)$$

A. TCSC Integrated with System (Open Loop)

In the matlab model; A TCSC is placed on a 400kV, long transmission line, to improve power transfer. The nominal compensation is 40%, i.e. using only the capacitors (firing angle of 90deg). The natural oscillatory frequency of the TCSC is 148.54Hz. Since the resonance for this TCSC is around 56deg firing angle, the operation is prohibited in firing angle range 47deg - 67deg. The capacitive mode is achieved with firing angles 58-89.5 deg. The impedance is lowest at 90deg, and therefore power transfer increases as the firing angle is reduced.

In Figure 3The diagram of simple network with Single phase TCSC Controller; the parameter lines are the same, the flow of active and reactive power is distributed evenly on both lines, and i.e. the power flows of the given lines are equal. The voltage drops at the load due to loss of voltage on lines.

Incorporating of TCSC device to one of the lines changes the power flow in given lines according to level desired. This change is achieved by changing the impedance of line, in which is installed TCSC device. With the entry values of angle switching thyristors, TCSC can change the impedance of the line and thereby regulates the power flow as required.

Fig. 4: Matlab modeling of TCSC integrated with system

B. Modeling Single Phase TCSC Module

Controller block is the shown in figure 5. From the value of the capacitor voltage and inductive current of TCSC. We can get the value of impedance and angle alpha. Than these values are transferred to sub block of controller which generates the triggering pulse. There is firing block in which line current is matched using Phase Lock Loop. The TCSC is controlled by varying the phase delay of the thyristor firing pulses synchronized to the line current waveform through a PLL which Matched phase and frequency of line current along with angle alpha is used for generation of triggering pulses. So controller sub system block work as a feedback system for TCSC because it keeps that reference impedance to be matched with measured impedance.

Fig. 5: Modeling Of Singe Phase TCSC Module

C. Generation of Trigger Pulse

In Fig 4.3 show that the capacitor voltage, inductive current of TCSC block and angle alpha are input signals to the firing block sub system. Initially assumed to the value of firing pulse and voltage are equal to one then output of saturation block also gives one which is store in the memory block.

Now, if the value of the current signal is one(which is depend of nature of the cycle) then generate the output signal that is triggering pulse for the thyristor of controller.
IV. SIMULATION RESULTS

In the modeled electrical network, as Figure 6.4 shows at t=0 sec to t=2.5 sec, the firing angle change the value from $170^\circ$ to $150^\circ$. Impedance of TCSC is capacitive and Therefore there is a change in power flow on lines No.2, whose value has risen that is $P= 147$ MW to $P= 171$ MW (measured at the load).

Fig. 6: Trigger Pulse U

Fig. 7: Actual power flow for varying $\alpha=170^\circ$ to $150^\circ$

The variation in capacitance voltage $v_C$ and TCR current $i$ for different conduction angle is observed in The MATLAB – Simulink waveforms of the module. The Waveforms for $i$, $v_C$ and $i_L$ for varying firing angle from $170^\circ$ to $150^\circ$ is shown in Figure 8.

At firing angle $\alpha = 70$ deg, The corresponding waveform of capacitor voltage and TCR current are shown in below; The load voltage around 322 kv and The load current around 907 amp at receiving side which can be increased by reducing firing angle of TCR.

Fig. 9: The load voltage at $\alpha=70$

Fig. 10: The load current at $\alpha=70^\circ$

At particularly firing alpha = 70’, the power flow in second line is equal to 146 MW where the actual power flow in the system is about 300MW. Therefore the actual power will try to more flow in second line compare to other line.

Fig. 10: Active Power flow at firing angle alpha 70’

A. Analysis in Capacitive Region

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<th>ALPHA</th>
<th>$X_{tcs}(\alpha*\pi/180)$</th>
<th>POWER (MW)</th>
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<tr>
<td>60</td>
<td>-13.41</td>
<td>171</td>
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<tr>
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<td>89.5</td>
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Table 1:
In this paper power flow control in transmission line is done by using TCSC controller. TCSC device is implemented in a simple two bus electrical network and mathematic modeling of the system with open loop control strategy has been done with help of MATLAB/SIMULINK software and the performance of TCSC device has been found to be excellent.

The simulation results show that the power flow can vary in second transmission line as our desire level by changing firing angle of TCSC device. Furthermore, the reversal capacitor voltage is also reduced with help of TCSC device.

REFERENCES


