

## **Application of Thyristor Controlled Series Capacitor and its Impact on the Distance protection**

R. P. Dhote<sup>1</sup>, P. S. Patil<sup>2</sup>

<sup>1,2</sup>Department of Electrical Engineering  
Yeshwantrao Chavan College of Engineering, Nagpur, India  
rahuldhote44@gmail.com

### **Abstract**

Modern energy transmission systems suffer from great voltage drop and power transfer capability reduces due to the line reactance and thermal limits. Therefore, Thyristor Controlled Series Capacitor (TCSC) has been proposed to enhance the power transfer capability by changing the reactive power distribution in the power system. This paper discusses the impact of TCSC for power enhancement capability.

Further, the impact of TCSC on distance protection of transmission lines due to the fast response time of thyristor controllers with respective that of the protective devices is also investigated.

**Keywords**—Power system protection; distance protection relay; series compensation; thyristor controlled series capacitor (TCSC)

### **I. INTRODUCTION**

The rapid growth in electrical power networks has gradually led to the development of control devices. These devices are in series and shunt, active and passive, controlled and switched categories. Each of them is used for one or some purposes like reactive power compensation, voltage control, dynamic stability improvement and power oscillation damping [1-2]. Thyristor Controlled Series Capacitor (TCSC) consists of a series compensating capacitor shunted by a thyristor controlled reactor (TCR). TCSC is one of the Flexible AC Transmission Systems (FACTS) devices which is used for all mentioned purposes. TCSC has shown good capabilities in researches [3-6]. TCSC has advantages of using thyristor (with natural commutation) and low frequency switching. Therefore its cost, complexity and power loss have reduced. Thyristor and Gate-Controlled Series Capacitors are compared in [7]. The reactance characteristic and resonance condition of TCSC are discussed in [8]. Proper thyristor triggering base on inductor and capacitor size is presented in [9]. However, the employment of FACTS devices has a profound impact on the operation of other equipment in the system, such as transmission lines protection [10]. Distance protection relays have been widely applied as the primary protection in high voltage transmission lines due to their simple operating principle and capability to work independently [11]. The basic operation principle of distance relay is based on the fact that the line impedance is fairly constant with respect to the line length. However, the

implementation of FACTS Controllers in power system transmission for enhancing

the power system controllability and stability have introduced new power system issues in the field of power system protection that must be considered and analyzed [12]. The presence of the FACTS devices in the faulted loop introduces changes to the line parameters seen by the distance relay. The effect of FACTS device would affect both the steady state and transient Characteristics of the apparent impedance seen by distance relays due to the fast response time of FACTS Controllers with respect to that of the protective devices. Therefore, it important to study how distance relays would perform when protecting transmission lines equipped with FACTS Controllers. TCSC is one the FACTS Controller device that increases the power transmission capacity of long lines. In presence of TCSC in a fault loop, the voltage and current at relay point is changed. If the detected impedance is less or greater than actual impedance of line, distance relay operates incorrect, due to over reach and under reach [13][14].

In case of long transmission line, the main focus is given to compensate the reactance of the transmission line by using TCSC which will enhance the power transfer capability. The used of TCSC during fault will affect the impedance seen by the distance relay which will result in mal-operation of distance relay. TCSC has a remarkable fault current limiting feature. During normal operation, it generally operates in the capacitive region. During system faults, it operates in the inductive region to lower the fault current contribution. The distance

relay might under-reach or over-reaches only in the inductive and capacitive mode of the TCSC. Also the study on a scheme to mitigate the effect of the Thyristor Controlled Series Capacitor (TCSC) on distance protection [15] [19]

## II. TCSC MODEL AND STEADY STATE MODES OF OPERATION

### A. TCSC Model

Fig. (1) shows a TCSC module with different protective elements. Basically, it comprises a series capacitor (C), in parallel with a Thyristor Controlled Reactor (TCR) (Ls). A metal oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high capacitor over voltages. The amount of series compensation in the capacitive operating region is increased (or decreased) by varying the thyristor firing angle  $\alpha$ . The overall impedance of TCSC is given in equation (1).

$$X_{TCSC} = \frac{X_C X_L}{X_C - X_L(\alpha)} \quad (1)$$

Where,

$$X_L(\alpha) = X_{Lmax} \frac{\Pi}{\Pi - 2\alpha - \sin(2\alpha)}$$

$$X_{Lmax} = L\omega \quad X_C = \frac{1}{\omega C}$$

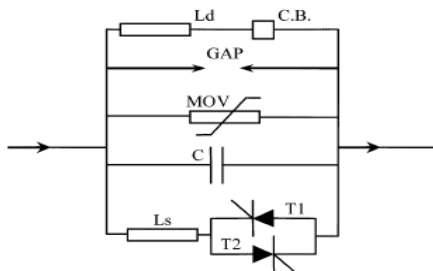


Fig. 1. Practical TCSC module.

### B. TCSC Modes of Operation in Steady State

In normal operating conditions, there are four modes of operation; blocking mode; bypass mode; capacitive boost mode; and inductive boost mode [1] [2].

**Blocking mode:** When the thyristor valve is not triggered and the thyristors are kept in non-conducting state the TCSC is operating in blocking mode. The line current passes only through the capacitor bank. In this mode, the TCSC performs like a fixed series capacitor.

**Bypass mode:** If the thyristor valve is triggered continuously the valve stays conducting all the time

and the TCSC behaves like a parallel connection of the series capacitor bank with the inductor in the thyristor valve. In this mode, the resulting voltage in the steady state across the TCSC is inductive and the valve current is somewhat bigger than the line current due to the current generation in the capacitor bank. For practical TCSC's with  $X_L/X_C$  ratio between 0.1 to 0.3 ranges, the capacitor voltage at a given line current is much lower in bypass than in blocking mode. Therefore, the bypass mode is utilized as a means to reduce the capacitor stress during faults.

**Capacitive boost mode:** If a trigger pulse is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line a capacitor discharge current pulse will circulate through the parallel inductive branch. The discharge current pulse adds to the line current through the capacitor bank. It causes a capacitor voltage that adds to the voltage caused by the line current. This is the normal operating mode of TCSC.

**Inductive boost mode:** In this condition the circulating current in the thyristor branch is bigger than the line current. In this mode, large thyristor currents result and further the capacitor voltage waveform is very much distorted from its sinusoidal shape. The peak voltage appears close to the turn on. The poor waveform and the high valve stress make the inductive boost mode less attractive for steady state operation.

### C. TCSC Control Model

**Open-loop Control:** The open-loop control scheme is the simplest method for TCSC, in which firing delay angle  $\alpha$  is obtained directly from the reactance order  $X_{ref}$ . **Close-loop Control:** In addition to open-loop control, closed-loop control scheme is another common control method in automation control area. There are three control methods for TCSC closed-loop control, which is defined as to the chosen control variable.

- [1] Constant Impedance(CI)
- [2] Constant Current(CC)
- [3] Constant Power(CP)

In this paper, the closed-loop constant impedance control scheme is used to generate the pulse for thyristor valve of TCSC. The outline of this control scheme is shown in Fig. (2). The measured impedance is compared with the actual reference value and the error is modulated by PI controller to the firing delay angle error.

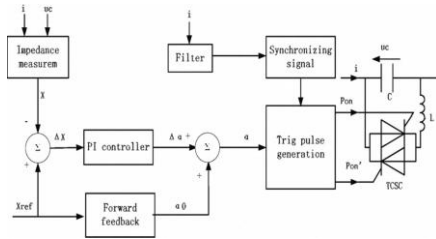


Fig. 2. TCSC closed-loop constant reactance control methodology.

### III. IMPEDANCE MEASURED BY MHO DISTANCE PROTECTION WITH AND WITHOUT TCSC

The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with the reach point impedance. If the measured impedance ( $Z_{seen}$ ) is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point. The reach point of a relay is the point along the line impedance locus that is intersected by the boundary characteristic of the relay. MHO Distance relay has been widely used in the protection of EHV and HV transmission lines. The basic principle of operation of distance protection is shown in figure.3.

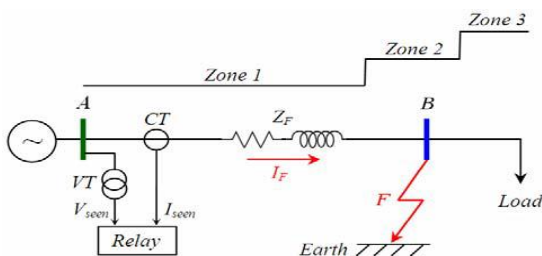


Fig. 3. MHO distance protection in case of phase to earth fault with  $R_f$ .

The input to the MHO distance relay point is the phase voltages and line currents transformed with the help of voltage transformer (VT) and current transformers (CT). The voltage would fall towards zero at the point of the fault. In case of earth fault, The impedance measured  $Z_{seen}$  in phase (A) is calculated by flowing equation (2)

$$(2) \quad Z_{seen} = \frac{V_{relay}}{I_{relay}} = \frac{V_A}{I_A + K_0 I_T}$$

Where,

$$K_0 = \frac{Z_0 - Z_1}{3Z_1}$$

$$I_T = I_A + I_B + I_C$$

### Transmission line with TCSC in midline.

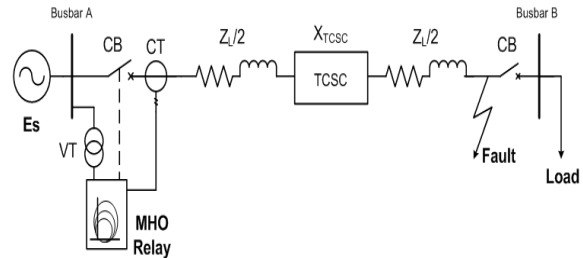


Fig. 4. Phase to earth fault current calculation on presence of a TCSC.

With TCSC inserted in midline, the total impedance of transmission line ( $Z_{AB-TCSC}$ ) is:

$$(3) \quad Z_{AB-TCSC} = R_{AB} - j[X_{AB} - X_{TCSC}(\alpha)]$$

### IV. MPACT OF THYRISTOR CONTROLLED SERIES CAPACITOR ON DISTANCE PROTECTION

As equation (3) shows when the TCSC is get connected along with the relay it changes the line impedance and the relay may over reaches or under reaches depending upon the delay angle[13]

**CASE-1:** In this case TCSC will be in capacitive mode, it will add the negative reactance ( $-X_c$ ) with the actual line reactance ( $X_L$ ). In this situation the relay will over reach as the measured impedance will be less than the actual impedance of the line the relay can sense the fault beyond its operating reach.

**CASE-2:** In this case TCSC will be in inductive mode, this mode will add the high value positive reactance. In this situation the relay will under reach as the measured impedance will be more than the below its operating reach. The relay cannot sense even a fault occurs in its reach hence under reach

#### Calculation And Results

Table-1

Sr. No.	Specifications	
	Parameters	Value
1	System Voltage	500 KV
2	TCSC main Capacitor	176 $\mu$ F
3	TCR inductance	9mH
4	System Frequency	50 Hz

A) PERFORMANCE OF TCSC ON TRANSMISSION PARAMETERS

Table-II

Parameters	Without TCSC	Fixed capacitor	With TCSC
Sending End Voltage	497.6 KV	497.7 KV	497.9 KV
Receiving End Voltage	488.0KV	491.2 KV	493.4 KV
Load side Active and Reactive power	P=285.9 MW Q=143 MVar	P=286.6 MW Q=144 MVar	P=291.9 MW Q=146.1 MVar

B) MID-POINT ACTIVE AND REACTIVE POWER

Table-III

Parameters	Active Power	Reactive Power
Sending end side	P=292.6 MW	Q=85.52 MVar
Receiving end side	P=292.5 MW	Q=95.87 MVar

C) SIMULATION RESULTS

In this section, the performance of the reactive power and load voltage are calculated with and without compensation. The TCSC is perform with continuous load and switch load (0.06-0.08sec)

ACTIVE POWER:

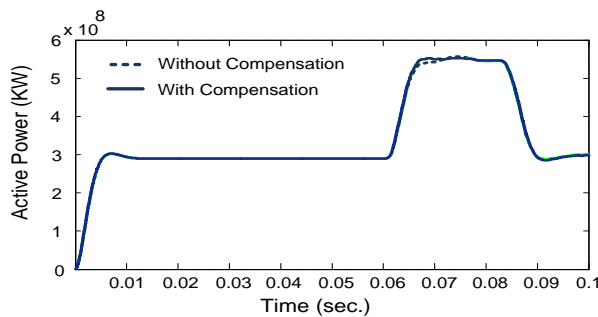


Fig. 5. Simulation result for active power.

REACTIVE POWER:

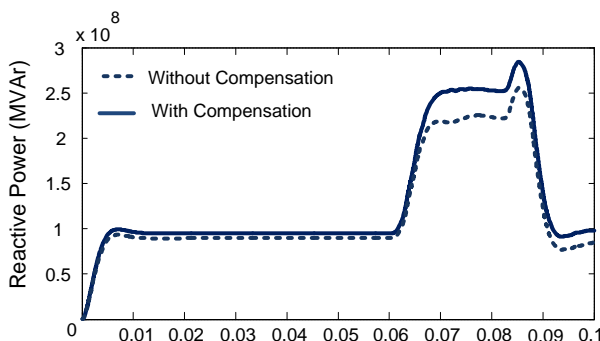


Fig. 6. Simulation result for reactive power.

**LOAD VOLTAGE (Without Compensation):** As the load increased at 0.2 to 0.3sec. the voltage drop appeared in the load voltage.

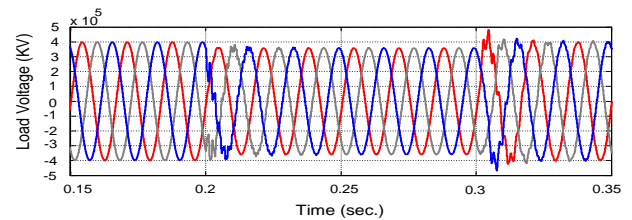


Fig. 7. Simulation result for load side voltage (without compensation)

**LOAD VOLTAGE (With Compensation):** Using TCSC the effect of voldtade drop due to increasing of the load is maintained at the system voltage level.

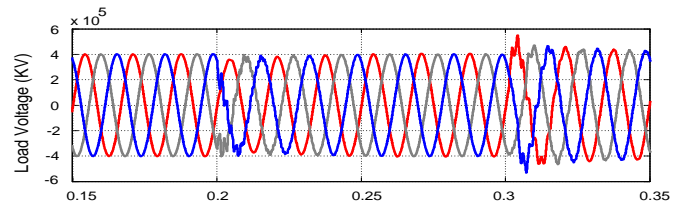


Fig. 8. Simulation result for load side voltage (with compensation)

The following network is simulated by using line impedance from [17].

For Zone A:  $R_A = 1.19025 \Omega$  and  $X_A = 29.75625 \Omega$   
 Zone B:  $R_B = 2.737575 \Omega$  and  $X_B = 43.20608 \Omega$

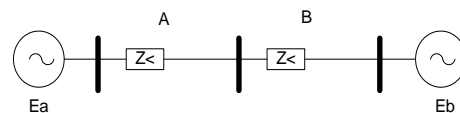


Fig. 9. Single line diagram of simulated network.

Considering network characteristics, the relay is set to detect faults with impedance below  $29.85 \Omega$ . Suppose the line is divided into three sections, if a fault occurs at time = 2 sec in last and first section of the line B, Fig.(10) and Fig.(11) show the apparent impedance determined by relay A before installation of TCSC. The measured impedance is greater than  $29.85 \Omega$ , so the relay has detected the fault at zone 2.

A TCSC is placed at the beginning of line B which is operated at  $\alpha = 158^\circ$ . When the fault occurs at last and first third of line B, the measured apparent impedances at those cases are shown in Fig. 12 and 13.



Fig. 10. Measured apparent impedance in point A without TCSC (fault at 2/3 line B)



Fig. 11. Measured apparent impedance in point A without TCSC (fault at 1/3 line B)

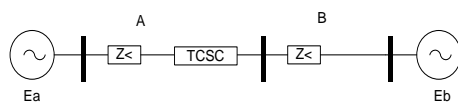


Fig. 12. Single line diagram of simulated network with TCSC.

As illustrated in Fig.14 when the fault occurs in the last section of the line B, the measured impedance is bigger than  $29.85 \Omega$ . But if the fault occurs in the first section of the line B, the impedance measured by the relay is less than  $29.85 \Omega$  (Fig. 14). So the relay has over reach problem.



Fig. 13. Measured apparent impedance in point A in presence of TCSC



Fig. 14. Measured apparent impedance in point A in presence of TCSC (fault at 1/3 line B)

## V. CONCLUSION

The simulation results show the salient features of TCSC, i.e. enhancement of power by operating TCSC in capacitive region. It is observed from table-III the reactive power after the compensation is improved by 10.35 MVar. Also the mitigate the voltage sag by using TCSC. The results of the impact of TCSC has been studied in the presence and absence of TCSC.

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