

## **Analysis of Power Flow Control in Power System Model using Thyristor Controlled Series Capacitor (TCSC)**

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### **ABSTRACT**

The characteristic of a thyristor controlled series compensator (TCSC) is usually defined by the overall reactance of the device versus the firing angle of the TCR that is connected in parallel with a fixed capacitor. We represent a model control circuit by using microcontroller to generate trigger pulses to fire the gate of the thyristors according to the set firing angle for required output. It brings out the operation of TCSC along with numerical equations. It also gives impedance characteristics curve of a TCSC device and specifies the range of inductance and capacitance region and also finds a suitable value of inductance and capacitance. We analyze the different waveforms in the capacitive as well as inductive region of TCSC, optimal setting of TCSC is determined through the software code written in MATLAB.

**Keywords** - *Firing angle, Thyristor Controlled Series Compensator (TCSC), Optimal Power Flow, Power system analysis, Zero Crossing Detector*

### **I. INTRODUCTION**

Modern electric power utilities are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities. With the lack of new generation and transmission facilities and over exploitation of the existing facilities make these types of problems more imminent in modern power systems. With the increased loading of transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor. The use of fixed capacitors to improve transient stability is well known. However, fixed capacitors in series with the transmission lines may cause sub synchronous resonance that can lead to electrical instability at oscillation frequencies lower than the normal system frequency. So there exists the need for switched series capacitors [1]. The switching sequences are determined, based on the sign

reversal of a 'decision function', which is derived from the equal-area criterion and requires knowledge of the final steady state. This method is very complicated and later in the author himself adopted a far simpler and more practical control approach. The control law adopted was to insert and bypass a series capacitor based on the speed deviation. At the time the above ideas in and were proposed, dynamically varying series compensation could only be achieved using capacitor banks switched in and out with mechanical circuit breakers; however such devices were in practice too slow and unreliable for high speed use. So these ideas remained on hold for nearly two decades until the evolution of FACTS devices. Flexible AC transmission System (FACTS) controllers use thyristor switching devices to provide greater control, speed and flexibility of ac transmission systems [2]. The Thyristor Controlled Series Compensator (TCSC) is a second generation FACTS controller capable of providing fast variable compensation. This paper focuses on the variable impedance capability of TCSC for enhancing the transient stability. It Mitigate sub synchronous resonance, Increase power transfer, Optimize power flow between the lines, Reduce system losses, Increase transient stability, Increase dynamic stability, Control current, Reduce damping oscillations, Increase voltage stability, Fault current limiting [1] [3]. There exists a class of control schemes for transient stability enhancement using TCSC. In this paper, transient stability control model scheme, namely: microcontroller based control is done for study. The controller is a simple speed deviation based controller and can provide a drastic improvement in transient stability. In addition to the transient stability enhancement, this controller provides power oscillation damping also. We calculate the various resonance points in the impedance characteristics of the TCSC with respect to various firing angle. We analyses and design the TCSC model using ORCAD and MATLAB. The rest of the paper as follows. Section II Literature Survey, Section III Benefits of TCSC, Section IV modeling of the TCSC, Section

V Analysis of steady state transient behavior the implemented TCSC circuit and finally conclusion and future work in section VI.

## II. LITERATURE SURVEY

The Equation of reactive power implies that impedance of series compensating capacitor cancels the portion of the actual line reactance & thereby effective transmission impedance is reduced.

$$Q = I^2 X_c = \frac{2V^2 k(1 - \cos\delta)}{(1 - k)^2}$$

As if the line was physically shortened or we can say that in order to increase the current in the given circuit series impedance of the actual physical line, the voltage across this impedance must be increased. This can be accomplished by an appropriate series connected circuit element such as capacitor, the impedance of which produces a voltage opposite to the prevailing voltage across the series line reactance and thus causing later voltage to increase. So Series compensator provides desired series compensation voltage when and where required if installed [4] [5].

According to S.Meikandasivam, Rajesh Kumar Nima and Shailendra Kumar Jain in their paper "Beaviour Study Of TCSC presented in World Academy of Science Engineering and technology 45 2008" World's first 3 phase [5], 2 X 165 MVAR, TCSC was installed in 1992 in Kayenta substation, Arizona. It raised the transmission capacity of transmission line by 30%, but it was soon realized that the device is also a very effective means for providing damping of electromechanical power oscillations. A third possible application of TCSC emerged from the onsite observations that it can provide series compensation without causing the same risk for sub-synchronous resonance (SSR) a fixed series capacitor. World's first TCSC for subsynchronous resonance (SSR) mitigation was installed in Stode, Sweden in 1998, by ABB. Specifically this period makes a valiant period for TCSC and makes the researchers to turn on to TCSC And while selecting inductance,  $X_L$  should be sufficiently smaller than that of the capacitor  $X_C$  to get both effective inductive and capacitive reactance across the device. Also  $X_L$  should not be equal to  $X_C$  value; or else a resonance develops that result in infinite impedance an unacceptable condition. Note that while varying  $X_L$  ( $\alpha$ ), a condition should not allow to occur  $X_L$  ( $\alpha$ ) =  $X_C$ .

Hailian Xie and Lennart Angquist designed a new control scheme instead of traditional firing angle control scheme called as the Static Voltage Reversal Control scheme. Following

that scheme the simulation results are analyzed using real time simulator.

T.Venegas and C.R. Fuerete Esquivel report on large scale power flow studies. The ASC model are developed in phase coordinates and incorporated into an existing Newton Raphson power flow algorithm and analysis is done on both balanced and unbalanced power network operating conditions.

Dragan Jovicic, member IEEE and G.N.Pillai presents an analytical, linear, state-space model of TCSC. First a simplified fundamental frequency model of TCSC is proposed and the model results are verified. Using the nonlinear TCSC segment, a simplified nonlinear state space model is derived where frequency of dominant TCSC complex poles shows linear dependence on the firing angle. The nonlinear element is linearized and linked with the AC network model along with TCSC model and is implemented on MATLAB and verified on EMTDC/ PSCAD in frequency and Time domain for a range of operating conditions.

## III. OPERATION AND ADVANTAGES OF VARIOUS MODES OF OPERATION, AND BENEFITS OF TCSC

### A. CONCEPT OF TCSC:

Concept behind TCSC is to decrease or increase overall effective series transmission impedance from sending end to the receiving end so as to control the transmission of power and the current in the reactor can be controlled from zero to maximum by the method of firing delay angle. Closure of the thyristor valve is delayed w.r.t. peak of the applied voltage in each half cycle thus duration of the current conduction interval is controlled [6].

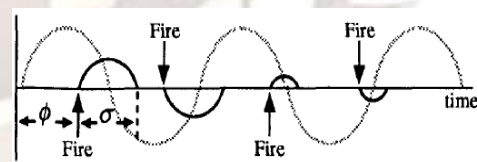


Figure 1. Various wave form shows the operation of thyristor with various firing and conduction angles.

There are three modes of operation of TCSC depending upon the firing angle of the pulses fed to the thyristor.

- Thyristor blocked mode
- Thyristor bypassed mode
- Vernier operating mode

### B. Thyristor blocked Operating Mode:

When the thyristor valve is not triggered and the

TCSC is operating in blocking mode. In this mode, the TCSC performs like a fixed series capacitor

### C. Thyristor bypass Operating mode:

In bypass mode the thyristor valve is triggered continuously and the valve stays conducting all the time; so the TCSC behaves like a parallel connection of the series capacitor with the inductor,  $L_s$  in the thyristor valve branch. 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 ratio ( $X_L/X_C$ ) 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 [7] [9].

### D. Vernier Operating Mode:

In Vernier control the TCSC dynamics are varied continuously by controlling the firing angle. The firing angle is possible from  $0^\circ$  to  $90^\circ$  for each half cycle when it is generated from the zero crossing of the line current hence divided into two parts:

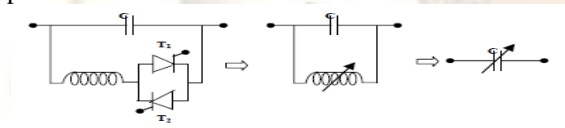


Figure 2. Equivalent circuit of TCSC in Vernier Mode

#### 1) Capacitive Boost mode:

In capacitive boost mode a trigger pulse is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line, so a capacitor discharge current pulse will circulate through the parallel inductive branch. The discharge current pulse adds to the line current through the capacitor and causes a capacitor voltage that adds to the voltage caused by the line current. The capacitor peak voltage thus will be increased in proportion to the charge that passes through the thyristor branch. The fundamental voltage also increases almost proportionally to the charge. From the system point of view, this mode inserts capacitors to the line up to nearly three times the fixed capacitor. This is the normal operating mode of TCSC [8] [15].

#### 2) Inductive Boost Mode:

In inductive boost mode the circulating current in the TCSC 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 [8].

### E. ADVANTAGES OF FACTS DEVICES IN AC SYSTEMS:

Table 1: Advantage of FACTS devices in AC Systems

FACTS DEVICE	Power Flow	Voltage Control	Transient Stability	Oscillation Damping
SVC	*	***	*	**
STATCOM	*	***	**	**
TCSC	**	*	***	**
SSSC	***	*	***	**
UPFC	***	***	***	***

Influence: \* Small, \*\* Medium, \*\*\* Strong

There are various types of FACT controllers in the market having their own advantages depending upon their individual characteristics. Here comparison study has been done on different FACT controllers to study their impact on various application, Table 1 shows the overall advantages of FACT devices in AC systems [10] [16].

### IV. MODELING OF THE TCSC

The circuit is modeled using Simulink in MATLAB and ORCAD. It uses the Simulink environment, allowing user to build a model using simple click and drag procedures. It can help draw the circuit topology rapidly, and can help in the analysis the circuit and its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB as its computational engine, we can also use MATLAB toolboxes and Simulink block sets. Here in mat lab various blocks like voltage generator, series RLC circuit block, series RLC load branch block, current meter, voltage meter, scopes to view various signals, power meter block, thyristor block, demultiplexer bus block all are interconnected to make an open loop TCSC Simulink model which is connected in series with the single source transmission line [14].

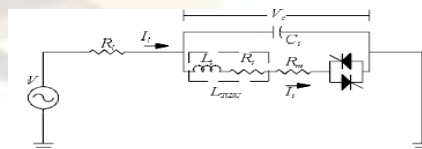


Figure 5. TCSC Circuit for simulation

For analyzing the thyristor, capacitor current and capacitor voltage, firing pulses are given to the circuit through pulse generator. To analyze the circuit in capacitive mode and inductive mode of TCSC, the pulse to be applied

are in region of Vernier capacitive which lies in  $160^\circ$  to  $180^\circ$  and  $90^\circ$  to  $135^\circ$  i.e. the delay of 8.8ms to 10ms and 5ms to 7.5ms respectively [11]. This gives the analysis of waveform of capacitor voltage, line current, thyristor current and capacitor current of TCSC as shown in fig.. It has been concluded that at if  $\alpha=117^\circ$  for positive waveform then there should be a difference or phase delay of  $180^\circ$  for the negative waveform then only thyristor will fire at the same interval and hence the conduction time will be equal and o/p will be symmetrical [12]. In practical applications, a lookup table method is used to describe this relationship. When the desired value of reactance  $X_{TCSC}$  is determined from the power system state, the required value of the firing angle is obtained from the table which shows the reactance step response of the TCSC to demanded change in from 1 p.u. to 2.1p.u., corresponding to a change in firing angle from to  $175^\circ$  to  $151^\circ$ . It can be seen from scope output that more than 200 ms is needed for the fundamental frequency reactance to reach its new steady-state value [13].

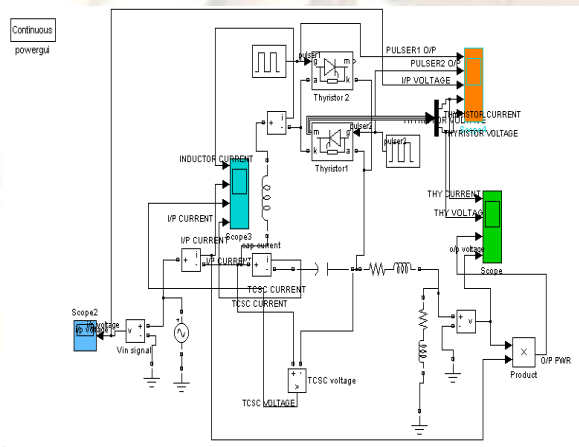


Figure 6. Simulink Model of TCSC

**V. ANALYSIS OF STEADY STATE TRANSIENT BEHAVIOR THE IMPLEMENTED TCSC**

Transient response of TCSC is analyzed by increasing the simulation time. The response got stable after few seconds of the firing as shown below.

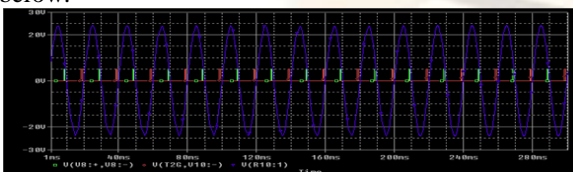


Figure 7. I/P voltage & o/p pulses of pulse generators.

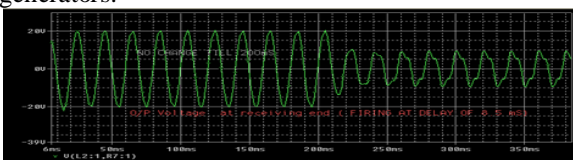


Figure 8. Output voltage a delay of 8.5ms.

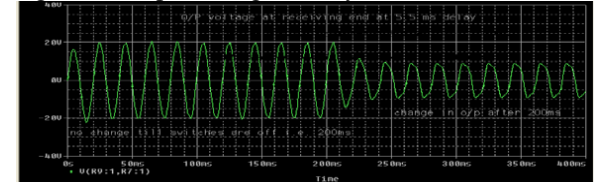


Figure 9. Out put voltage at delay of 5.5 ms

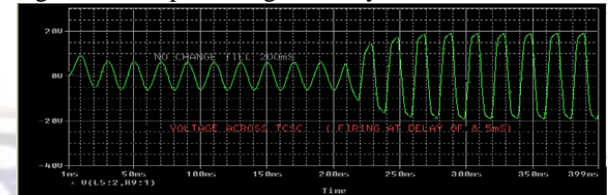


Figure 10. Voltage across TCSC at delay of 8.5ms

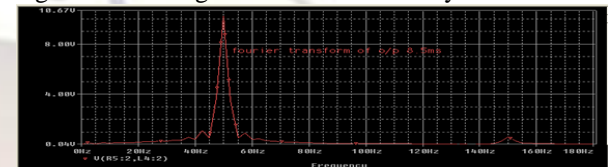


Figure 11. Fourier Transform of the O/P voltage.

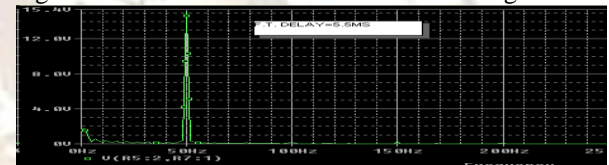


Figure 12. Fourier Transform at delay=5.5 ms

**A. Resultant Conclusion of TCSC modeling**

Three main signals of the TCSC (line current), thyristor current ( $I_t$ ) and capacitor voltage ( $V_c$ ) the first one with a firing angle= $16^\circ$  and the 2nd one with firing angle= $50^\circ$ . The TCSC can be used to modify the power transfer on transmission lines because it is able to experience a fast response when the firing angle is controlled appropriately. If the transient period lasts for a long time the system may turn eventually unstable. Another noteworthy point is the fact that the signals' amplitude in the transient period remains within proper limits. This is important because if the amplitude goes too high, the components may be damaged.

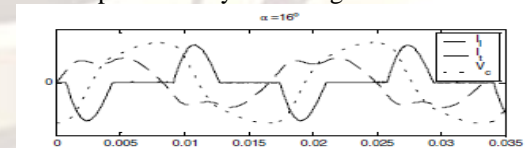


Figure13. Response when firing angle is  $16^\circ$ .

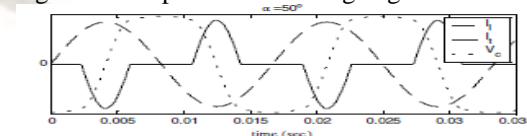


Figure14. Response when firing angle is  $50^\circ$ .

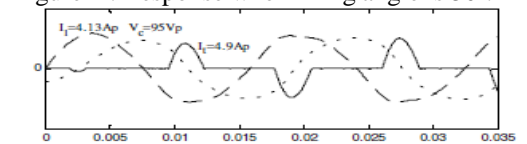


Fig.14. System response with firing angle =  $42^\circ$

## VI. CONCLUSION

The TCSC can be operated in capacitive and an inductive mode is rarely used in practice. The FACTS controller with its classification and performance of TCSC are included in this paper. The advantages of FACTS devices and various operating modes of TCSC are specified. This paper work can be extended in future for TCSC modeling with a number of bus system and determine the method for controlling the power flow. A linearized discrete-time model of a TCSC-compensated transmission line is presented in this paper. The model derived considers the proper characteristic of TCSC, the variation in its impedance with the firing angle of the TCR. Even though the line capacitance effects are neglected, they can be incorporated in the state equation without any major change in the model derivation, apart from an increase in the size of the matrices. The model derived is validated through digital computer simulation studies. It is shown that the eigen values of a TCSC-compensated transmission line has two complex conjugate pairs of poles whose real parts depend only on the line resistance and reactance. This model has shown the disturbances very accurately. Three different controllers are designed, based on this linearized model, which requires the measurements of local variables only. The performance of the proposed controllers under various disturbances are compared and analyzed.

Similarly in future implementation could be of a three-phase device as well as the simulation to series compensation may be by voltage sourced converters It can also be implemented with Neuro and fuzzy logic or some different strategies may now be developed to control the reactance of the TCSC through firing angle adjustments. In order to verify the performance of control strategies in actual operating conditions new techniques like instead of inductive load an original load could be implied.

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