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DESIGN AND SIMULATION OF SERIES COMPENSATOR FOR ENHANCEMENT ON ATC

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ABSTRACT- *There has been an increase in use of series connected controllers for dynamic power compensation and enhancement of active power transmission capacity. A thyristor controlled series capacitor (TCSC) is a series FACTS device, which can be employed to enhance power transfer capability of transmission line. This paper presents a conceptual study about the operation and different mode of TCSC device. It can govern the power either in inductive or capacitive operating region by selecting proper value L-C parameters and properly conduction angle. Mismatch in selection of parameters cause multi-resonance condition. This paper represents various steps to be followed in selection of TCSC parameters. A three phase transmission system is developed using MATLAB/simulink.*

KEYWORDS- *Thyristor controlled series compensator (TCSC), ATC, Reactance Characteristics curve, Degree of series compensation, Multi Resonance Condition*

I. INTRODUCTION

The Electric utility has been discovered major changes during its deregulation, restructuring and privatization. In recent years the load has increased significantly mainly due to the amount of individual power suppliers increases and rivals among electric power firms which is continuing on. On the other hand, some new conditions have been taken to constraining the physical development of the power transmission networks. These major drawbacks are environmental issues, economical matters constructing new transmission lines, and ground availability concerns especially in densely-populated areas and regions consisting of distribution networks. These facts indicate the importance of utilizing devices that enhance power transmission, security, reliability, and controllability of the power system known as Flexible Alternating Current Transmission System (FACTS). FACTS devices makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile.

ATC is defined as a measure of the transfer capability or available room in physical transmission network, for transfers of power for further commercial activity, over and above already committed uses.

This paper starts with basic discussion of TCSC device and its reactance characteristic curve. Section II, brings out the operation of TCSC. Section III gives different operating mode of TCSC device. Section IV, gives Reactance Characteristic curve. Section V, Selection of TCSC Parameter. Section VI, Simulation Model and Results.

II. OPERATION OF TCSC

The basic concept of TCSC device contains a fixed series capacitor in parallel with a thyristor controlled reactor (TCR).Here C is the series compensation capacitor, L is the inductor which connect in series with the two anti-parallel thyristor valve T1 and T2.However, a practical TCSC module also includes protective equipment normally installed with series capacitors as shown below.

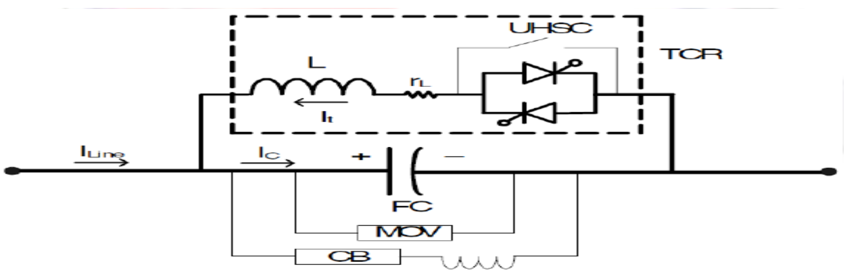

Figure1. Practical module of TCSC

A metal-oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high-capacitor over-voltages. Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in circuit even during fault conditions and helps improve the transient stability.

Circuit breaker installed across the capacitor, for controlling its insertion in the line. In addition, the CB bypasses the capacitor if severe fault or equipment-malfunction events occur.

If the TCSC valves are required to operate in the fully "on" mode for prolonged durations, the conduction losses are minimized by installing an ultra–high-speed contact (UHSC) across the valve.

III. DIFFERENT OPERATING MODES OF TCSC

Depending upon the firing angle of the pulses to apply to the thyristor an operation of TCSC can be classified into three modes as follows.

A. BYPASSED TYRISTOR MODE

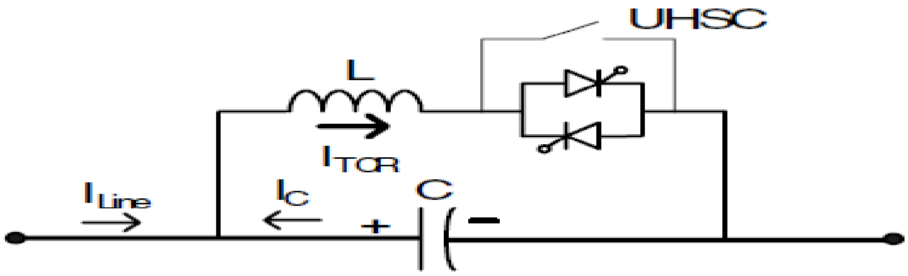

Figure2. Thyristor Bypassed Mode

In this mode, the conduction angle of thyristors is 180˚. When voltage across the thyristors reaches zero and becomes positive gate pluses are applied to thyrister pair, result in Current flow continuous in sinusoidal form through the thyrisor valves. The TCSC module behaves like a parallel capacitor–inductor combination. 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.

B. BLOCKED TYRISTOR MODE

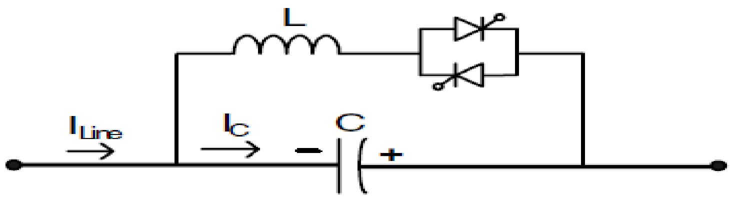

Figure3. Thyristor Blocked Mode

In this mode, also known as the waiting mode, the firing pulses to the thyristor valves are blocked. If the thyristors are conducting and a blocking command is given, the thyristors turn off as soon as the current through them reaches a zero crossing.

C. VERNIER OPERATING MODE

In vernier operating mode the TCSC device are varied continuously by controlling the firing angle. The firing angle is possibly varied from 0 to 90 for each half cycle.

a. CAPACITIVE BOOSTMODE

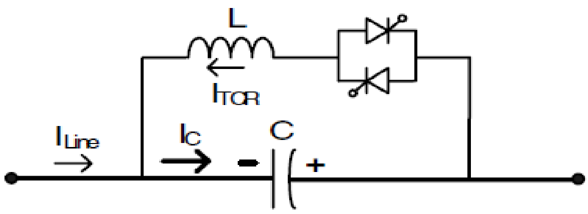

Figure4. Capacitive Boost Mode

In capacitive Vernier mode a forward voltage supplied to the thyristor just before the capacitor voltage crosses the zero line, so a capacitor discharge current pulse will flow 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.

b. INDUCTIVE BOOST MODE

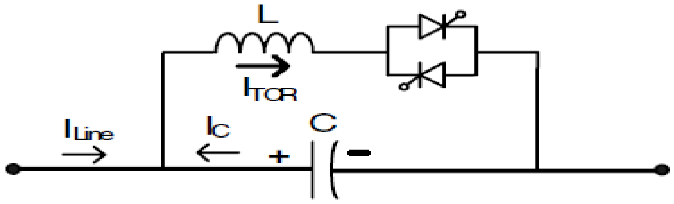

Figure5. Inductive Boost Mode

In inductive vernier 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. This mode increases the inductance of the line, so it is in contrast to the advantages associated with the application of TCSC for increasing the line load ability by decreasing the line impedance.

IV. REACTANCE CHARACTERISTIC

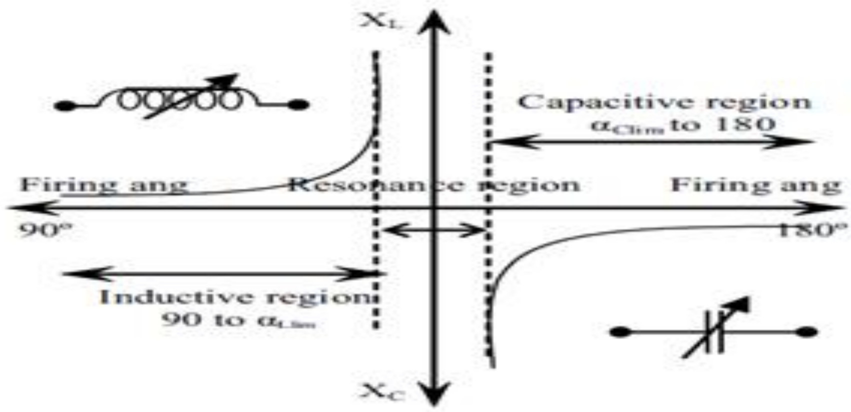

Figure6 Reactance characteristics curve

An effective reactance of TCSC device is varies for various degree of thyristor firing angle α. The given characteristic is divided into three region as inductive region, capacitive region and resonance region.

In inductive region TCR reactance increase for range of the firing angle (α) between $90^0 \leq \alpha \leq \alpha_{Llim}$ .Whereas its value is decreasing from infinity to capacitive reactance X_C for capacitive region of variation of firing angle $\alpha_{Clim} \leq \alpha \leq 180^0$. Between this two region when α is in the range $\alpha_{Llim} \leq \alpha \leq \alpha_{Clim}$ resonance occurs.

V. SELECTION OF TCSC PARAMETERS

An appropriate value for capacitor and inductor of a TCSC device is based on the net reactance of the transmission line and expected power demands in future. Capacitor value is chosen by a degree of series compensation (K). Normally up to 70% of line reactance is chosen for compensation. Choice of Inductor depends on the length of operating area required for inductive and capacitive region. It is perfectly decided by a factor 'ω', resonant factor. For selecting a capacitor and inductor for a TCSC device, three main significant measures have to be considered as follows:

A. DEGREE OF SERIES COMPENSATION (K)

Degree of series compensation (K) is a ratio of effective reactance of TCSC [$X_{TCSC}(\alpha)$] to net reactance of transmission line [X_{TL}].

$$K = \frac{X_{TCSC}(\alpha)}{X_{TL}} \qquad (0<k<1)$$

While choosing K, 100% compensation should not be provided to avoid series resonance in transmission line. Practically up to 70% of series compensation is chosen for line reactance compensation.

B. INDUCTIVE REACTANCE X_l SHOULD BE SUFFICIENTLY SMALLER THAN THE CAPACITIVE REACTANCE X_c

For selecting the TCSC inductor value, X_L should be sufficiently smaller than the X_C to get both effective inductive and capacitive reactance region in the TCSC device.

Consider an example of shunt network, X_C smaller than X_L and from the principle of circuit theory the effective reactance (X_{eff}) of the shunt combination follows the smaller value of the two reactance as shown in Fig 7 and (-) sign shows X_{eff} is in capacitive nature. Hence only one capacitive region is possible between 90˚ to 180˚ of firing angle in the reactance characteristics curve.

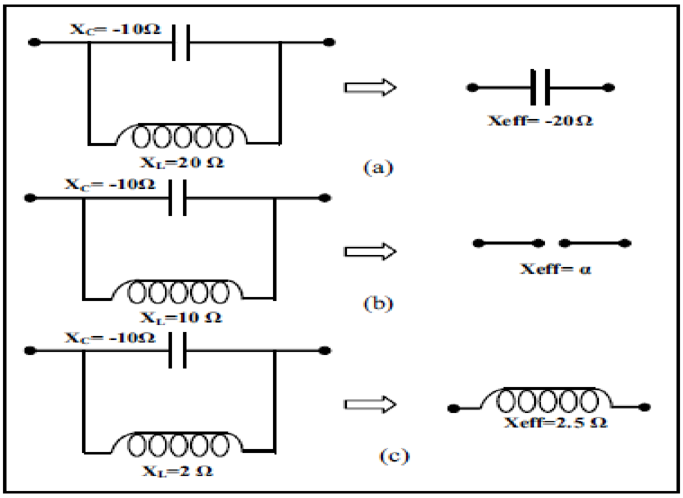

Figure7. Basic characteristics of TCSC

If X_L is equal to X_C value as shown in Fig. 7 (b); then resonance occurs that result in infinite reactance which is an unacceptable condition. Finally by choosing X_L smaller than X_C; makes effective reactance has inductive reactance as like Fig. 7 (c). Therefore $X_{TCSC}(\alpha)$ varies from inductive region to capacitive region with respect to 90˚ to 180˚ of firing angle. While varying the $X_{TCSC}(\alpha)$, the condition should not be allowed to occur "$X_L(\alpha) = X_C$", a resonance condition.
Generally, the X_L/X_C ratio for practical TCSCs would likely be in 0.1 to 0.3 ranges, depending on the application requirements and constraints. It is important that the natural resonance frequency of the TCSC does not coincide with, or is close to, two and three times the fundamental.

C. OCCURRENCE OF MULTI- RESONANCE CONDITION:

Between the inductive and capacitive region, a resonance region occurs. Occurrence of resonance in TCSC device is unavoidable. However, only one resonant region, explicitly one capacitive range and one inductive range, is allowable. Multiple resonant points will reduce the operating range of the TCSC. Thus, while selecting TCSC parameters, some measures have to be taken to ensure only one resonant point between 90˚ to 180˚ of α.
The resonance factor (ω) is defined as the ratio of resonance frequency (ω_o) of TCSC to power system frequency (ω_N).

$$\omega = \frac{\omega_0}{\omega_N} = \sqrt{\frac{X_C}{X_L}}$$

From, author referred that factor 'ω 'should be less than 3.

$$\omega = \sqrt{\frac{X_C}{X_L}} < 3$$

If both X_C and X_L are same, then factor 'ω 'becomes 1 and meets resonance condition. When it is less than 1, X_C is lesser than X_L, only capacitance region is possible. Thus 'ω' ≤ 1 are not permissible to get combined effect of inductive and capacitive region in TCSC.

VI. SIMULATION MODEL AND RESULTS

For the simulation of TCSC characteristics the appropriate values of the capacitor as well as the TCR reactor should be selected.

With 200mH as the transmission line reactance the different compensation at which the simulation is done is tabulated as follows:

$$L_{line} = 200mH$$

$$\therefore \quad X_L = 2\pi f L_{line} = 62.83185\ \Omega$$

A. FOR 75% COMPENASTION:

For this system

$$L_{tcr} = 40mH \qquad \therefore\ X_r = 12.5663$$

Also $\dfrac{X_r}{X_C} = 0.27 \qquad (0.1, 0.3)$

Also $\lambda = \dfrac{\omega_0}{\omega} = \dfrac{1}{\omega\sqrt{LC}} = \sqrt{\dfrac{X_C}{X_L}} = 1.92$

Resonance angle can be calculated as follows

$$\beta_{res} = (2m-1)\frac{\pi}{2}\frac{\omega_0}{\omega} = 46.875°$$

Therefore corresponding value of resonance angle $\alpha_{res} = 43.125$

Thus the firing angle is prohibited in the range (33.125, 53.125)

B. SIMULATION CIRCUITRY

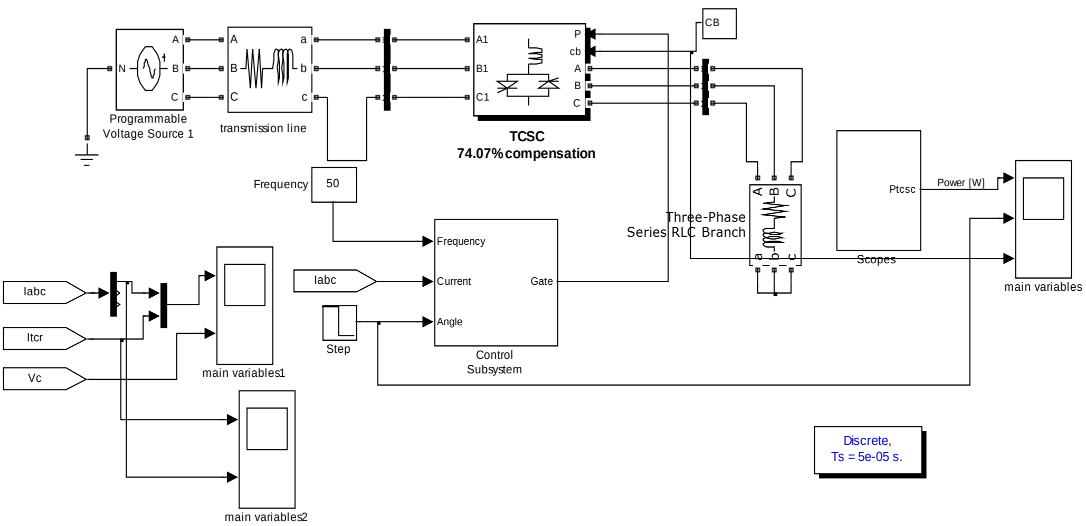

Figure8. Simulation model of TCSC device

C. SIMULATION RESULTS:

FOR 90˚ FIRING ANGLE (PURELY CAPACITIVE MODE)

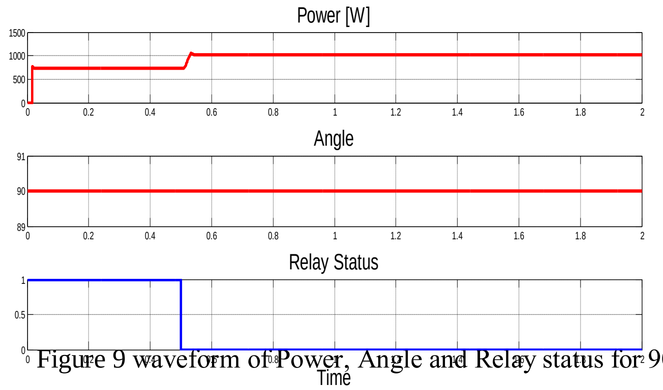

Figure 9 waveform of Power, Angle and Relay status for 90˚

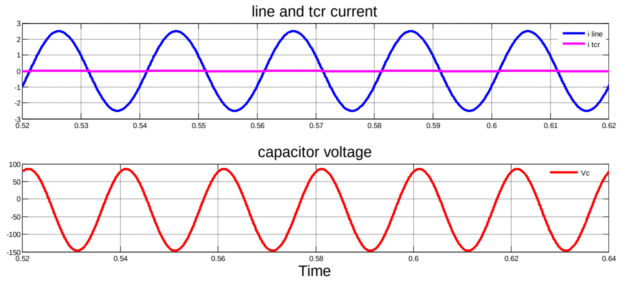

Figure 10 waveform of line current, TCR current and capacitor voltage for 90˚

FOR 75 ˚ FIRING ANGLE (CAPACITIVE MODE)

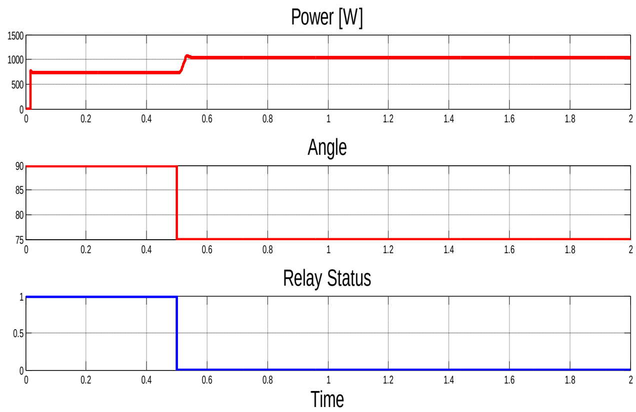

Figure 11 waveform of Power, Angle and Relay status for 75˚

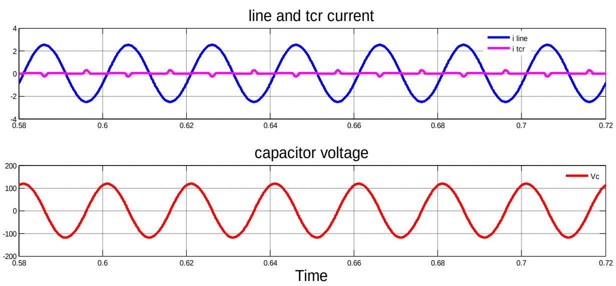

Figure 12 waveform of line current, TCR current and capacitor voltage for 75^0

FOR 0˚ FIRING ANG For purely capacitive the power flow is around 1021.6 W which is as above. The corresponding current through the TCR and line current are as shown in above fig. which the current through the TCR branch is nearly zero as the TCR reactance is nearly infinity:

FOR 0˚ FIRING ANGLE (PURELY INDUCTIVE MODE)

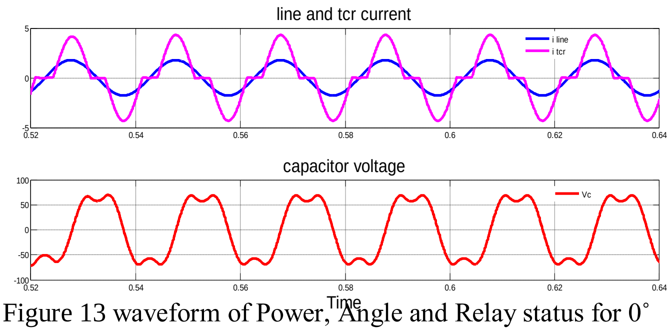

Figure 13 waveform of Power, Angle and Relay status for 0˚

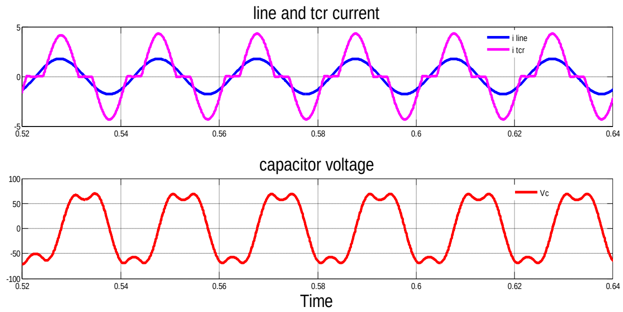

Figure4.13 waveform of line current, TCR current and capacitor voltage for 25˚

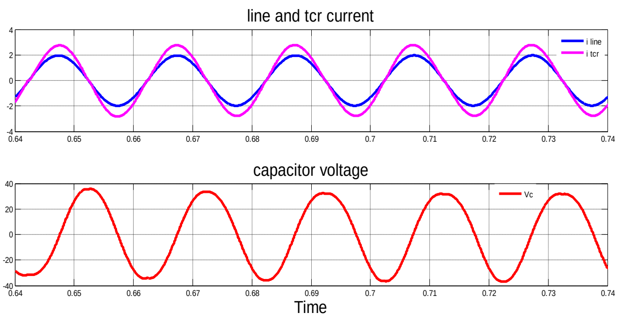

Figure 14 waveform of line current TCR current and capacitor voltage for 0˚

For purely inductive the power flow is around 591 W which is reduced as above.

FOR 25 ˚FIRING ANGLE (INDUCTIVE MODE)

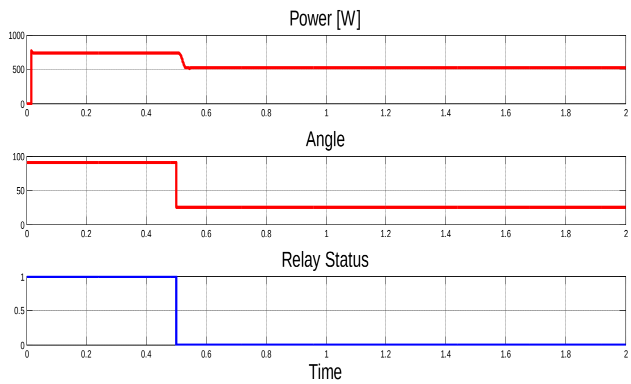

Figure15 waveform of Power, Angle and Relay status for 25˚

CONCLUSION

This paper discussed about the operation, reactance characteristic, ATC and resonance condition of TCSC. Also the different mode of TCSC can be discus. Simulation for a system is analyzed in MATLAB/simulink. Results are analyzed in inductive and capacitive mode. Effect of available power transfer capability by TCSC firing angle justified with results attached in this paper. Results are compared with mathematical calculations and proper reference.

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