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Performance Analysis of Split TCSC for Fine Power Flow

G. Naresh and U. Venkatesh

Abstract— With the increase in demand for electrical energy, the size and complexity of the power system has been increased. As a result of this, some transmission lines are heavily loaded and the system stability becomes a limiting factor for power transfer. Hence, power flow analysis is essential for a secure power system operation. A Thyristor controlled series capacitor (TCSC), the second generation of flexible AC transmission system (FACTS) devices, can control the line impedance through the series introduction of a thyristor controlled reactor across a fixed capacitor with the transmission line. The TCSC furnishes inductive as well as capacitive reactance compensation to alter the power flow of the transmission line. The difficulty in tuning the TCSC i.e., large change in reactance offered by TCSC at critical region makes inconvenience in increasing the transmission line loading capacity.

This paper presents fine-tuning of transmission line reactance by implementing split TCSC in place of single TCSC. The Newton-Raphson method of power flow analysis (NRPFA) is used to examine the fine-tuning of line reactance to compensate the small changes in the power demand. MATLAB based simulation studies are done to examine the fine tuning of line reactance to compensate the small change in power demand. Comparison of reactance offered at various firing angles and real power flow between single TCSC and split TCSC are also examined on standard IEEE 30-bus system.

Index Terms— Fine-tuning, IEEE 30-bus system, Power Flow, Reactance, Real Power, Single TCSC, Split TCSC.

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1 Introduction

Due to ever increasing load demand, electric power utilities are now forced to increase the utilization of existing transmission facilities. It is quite difficult to construct new transmission lines due to environmental and economic considerations. Thus modern power systems are forced to carry increasingly more power over long distances.

The basic requirement of power system is to meet the demand that varies continuously. Due to its fast control characteristics and continuous compensation capability, FACTS devices have been researched and adapted in power engineering area [1, 2]. There are so many advantages in FACTS device; it can increase dynamic stability, loading capability of lines and system security, which results in increased utilization of lowest cost generation [3,4]. The key role of FACTS device is to control the power flow actively and effectively. In other words, it can transfer power flow from one line to another within its capability. This paper focuses on the operation of the TCSC, which reduces the line reactance of the transmission line. The reduced value of transmission line reactance enhances active power flow in the line and may be loaded to their thermal limits without incurring much loss in the line. These salient features enhance the transmission system to transfer the desired power at right line [5, 6].

In load flow studies the TCSC can represented in many forms. For example, the model presented in [7] is based on the concept of a variable series compensator whose changing reactance adjusts itself in order to constrain the power flow across the branch to a specified value. The power transmitted over an ac transmission line is a function of the line impedance, the magnitude of sending end and receiving end voltages, and the phase angle between these voltages. Traditional techniques of reactive line compensation and step like voltage adjustment are generally used to alter these parameters to achieve power transmission control. Fixed and mechanically switched shunt and series reactive compensation are employed to modify the natural impedance characteristics of transmission line in order to establish the desired effective impedance between the sending and receiving ends to meet power transmission requirements.

The use of multiple TCSC [8, 9] has given the idea of possible benefits of splitting the degree of compensation (k) and the application of split TCSC in the transmission line in place of single TCSC. Mathur and Varma presented that the reactance versus current (*X*–*I*) capability curves for multi modules of TCSC reveals feasible combination of tuning multi-TCSC allowing for microtuning of net reactance in the line [10]. It is observed from the single TCSC reactance characteristic curve, that the change in reactance ΔX is small with increase in firing angle (α) of TCSC thyristors, except nearby resonance region, where each step of a makes a huge elapse of reactance. Hence fine-tuning of reactance is not possible.

The problem of huge elapse of reactance in single TCSC can be overcome by using split TCSC in place of single TCSC. It offers improved performance of compensator by fine tuning the line reactance. This paper presents an application of split TCSC in place of single TCSC for fine tuning the line reactance. The effects of fine-tuning of line reactance are analyzed with Newton-Raphson method of Power Flow Analysis (NRPFA). The power flow network equations are modeled by incorporating TCSC device in the transmission line. Fine tun-

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ing of line reactance is analyzed by splitting the TCSC for the same degree of compensation 'k'. Power flow improvements and power loss reductions in the transmission line are compared and benefits of split TCSC are pointed out against single TCSC.

Rest of the paper is structured as follows: The operation of single TCSC and split TCSC device are explained in Sections 2. Test system used for this study is given in Section 3. In Section 4 results are presented along with discussion. Finally, conclusions are summarized in Section 5.

2 Thyristor Controlled Series Capacitor(TCSC)

2.1 Single TCSC

Thyristor Controlled Series Capacitor (TCSC) consists of a capacitor in parallel with a Thyristor controlled reactor (TCR) connected between the buses 'i' and 'j' shown in Fig. 1. An actual TCSC system usually comprises a cascaded combination of many TCSC modules together with a fixed-series capacitor. TCSC vary the electrical length of the transmission line which enables it to be used to provide fast active power flow regulation. It also increases the stability margin of the system and has proved very effective in damping Sub Synchronous Resonance (SSR) and power oscillations [11, 12]. The simpler TCSC model exploits the concept of a variable series reactance. The series reactance is adjusted automatically, within limits, to satisfy a specified amount of active power flow through it.

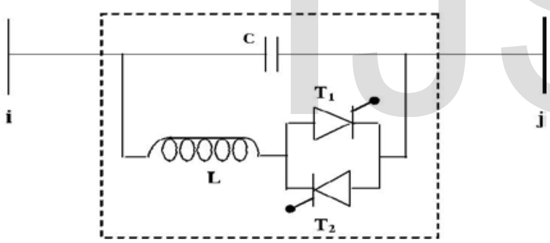

Fig. 1: Thyristor Controller Series Capacitor (TCSC)

The reactance characteristics curve of a TCSC drawn between effective reactance of TCSC and firing angle (α) is shown in Fig. 2. The effective reactance '$X_{TCSC}(\alpha)$' of TCSC operates in three regions: inductive region, resonance region and capacitive region. Inductive region starts increasing from inductive reactance $X_L \ || \ X_C$ value to infinity (parallel resonance condition i.e., $X_L(\alpha) = X_C$, and decreasing from infinity to capacitive reactance X_C for capacitive region. Between the inductive and capacitive regions, resonance occurs.

The reactance characteristics of TCSC in inductive, capacitive and resonance regions through variation of firing angle (α) as shown in Table 1.

TABLE 1: VARIOUS REGIONS OF OPERATION OF TCSC

Range of firing angle (α)	Region
$90^0 \le \alpha \le \alpha_{L\lim}$	Inductive Region
$\alpha_{L\lim} \le \alpha \le \alpha_{C\lim}$	Resonance Region
$\alpha_{C\lim} \le \alpha \le 180^0$	Capacitive Region

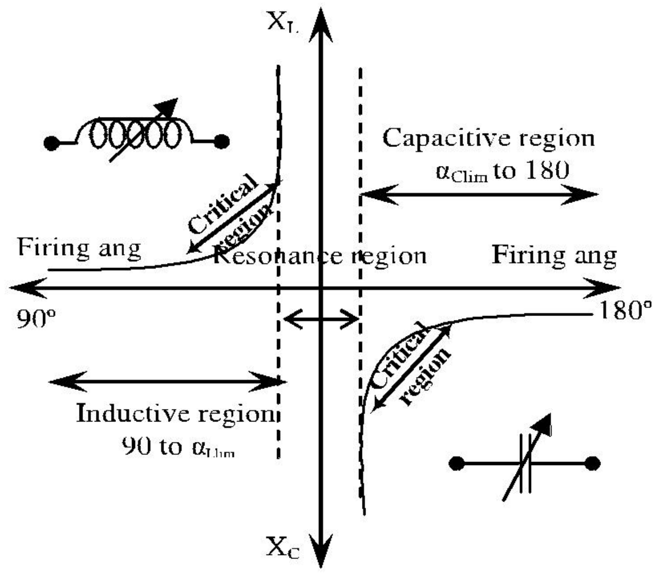

Fig. 2: Reactance characteristics curve of a TCSC

TCSC can operate either in inductive mode or in capacitive mode. The net reactance of the transmission line becomes $X_{Total} = X_{ij} \pm X_{TCSC}(\alpha)$. Here (+) sign is for inductive reactance and (−) sign for capacitive reactance and α is the firing angle of TCSC, which varies from 90^0 to 180^0.

The effective reactance '$X_{TCSC}(\alpha)$' offered by the TCSC is given by

$$X_{TCSC}(\alpha) = -X_C + C_1[2(\pi-\alpha) + Sin[2(\pi-\alpha)]] - C_2 Cos^2(\pi-\alpha)\{\omega Tan[\omega(\pi-\alpha)] - Tan(\pi-\alpha)\} \quad (1)$$

where,

$$C_1 = \frac{X_C + X_{LC}}{\pi} \quad (2)$$

$$C_2 = \frac{4X_{LC}^2}{\pi . X_L} \quad (3)$$

$$X_{LC} = \frac{X_C X_L}{X_C - X_L} \quad (4)$$

$$\omega = \sqrt{\frac{X_C}{X_L}} \quad (5)$$

Using above equations, TCSC reactance characteristic curve is drawn for ω = 2.77.

2.2 Split TCSC

Fig. 3 shows the split TCSC connected in the transmission line between the buses i and j. The split TCSC is a combination of two single TCSC; but splitted in terms of ratio of degree of series compensation ($k = k_1 + k_2$). The degree of series compensations k_1 and k_2 are appropriately chosen to get wide

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and fine reactance compensation in the network. Both the

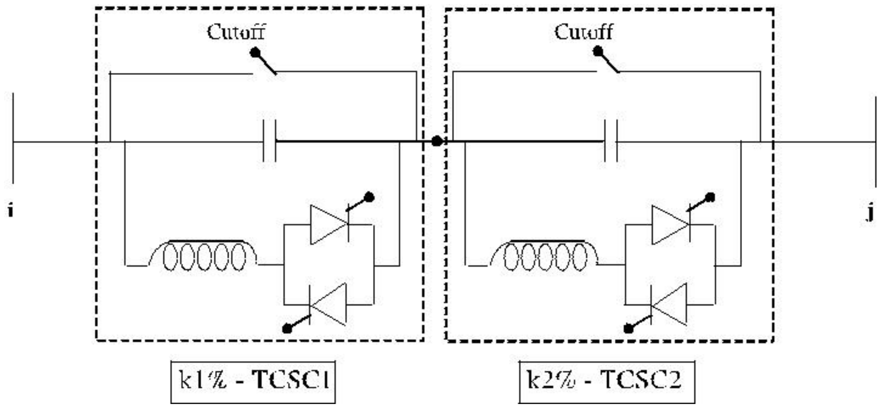

Fig. 3: Split TCSC in a transmission line

TCSC's are efficiently tuned and fine tuning of line reactance are achieved. Thus, the net line reactance becomes, $X_{Total} = X_{ij} + X_{TCSC_1}(\alpha_1) + X_{TCSC_2}(\alpha_2)$, where α_1 and α_2 are firing angles of split TCSC, each can be tuned separately between 90^0 to 180^0.

3 Test System

To test the performance of the proposed split TCSC, IEEE 30-bus test system shown in Fig. 4 with 230kV and 100MVA base has been considered. Specified power flow control over the transmission lines has been achieved by determining the converged firing angle, α. The TCSC has been designed with an inductance of 4.4 mH and capacitor of 300 μF.

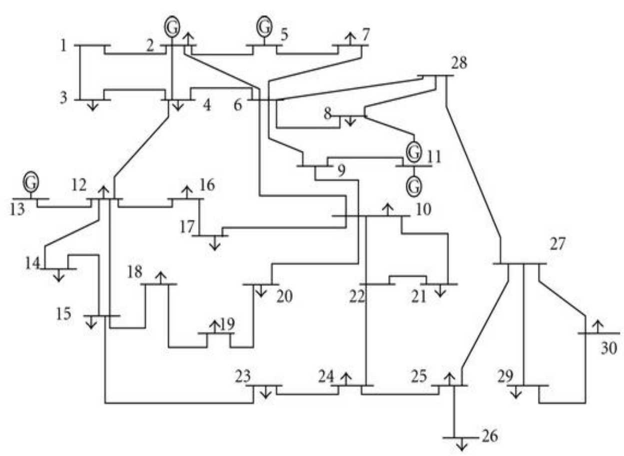

Fig. 4: The IEEE-30 bus System

Table 2 shows the percentage improvement in the real power flow with single TCSC and split TCSC placed individually in different lines of the system. Out of 41 lines available in the system, solutions for specific lines have been presented in this table. It can be observed from table 2 that maximum active power is transferred when Split TCSC is placed between the buses 6 and 28 (at branch number 41) i.e., there an improvement of 2.5780% in the real power flow with Split TCSC in line 41.

TABLE 2: MAXIMUM REAL POWER FLOW WITH SINGLE AND SPLIT TCSC

Branch	From Bus	To Bus	% Increase in maximum real power flow	
			with Single TCSC	with Split TCSC
1	1	2	1.0637	1.4904
4	3	4	1.3161	1.7113
14	9	10	0.9313	1.1005
22	15	18	1.0209	1.1670
40	8	28	0.6518	1.8223
41	6	28	1.2862	2.5780

4 Results And Discussion

Fig.5 shows the single TCSC Reactance (%) characteristics curve plotted in steps of 1^0 firing angle for a particular L and C values which are considered for single TCSC placed in the line connecting the buses 6 and 28 of IEEE 30 bus system.. The firing angle limitation under resonance region is considered from 146^0 to 149^0 where TCSC should not be tuned.

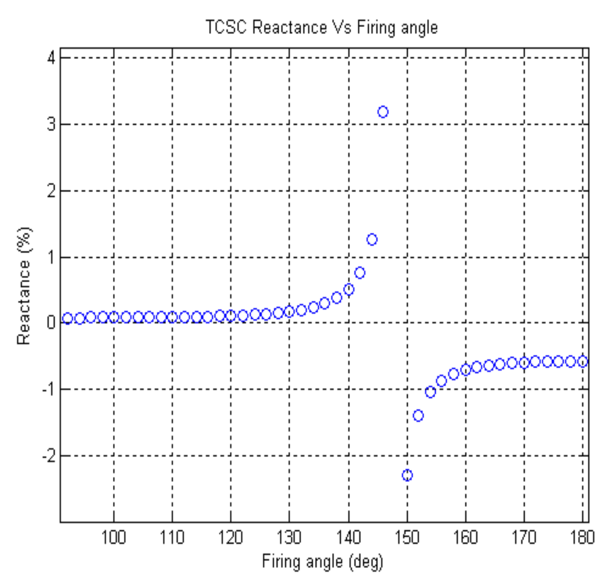

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Fig. 5: TCSC Reactance Vs Firing Angle

Fig.6 shows the Split TCSC reactance (%) characteristics curve is plotted against number of firing points which clearly explains that there is no limitation under resonance region which means the Split TCSC fine tunes.

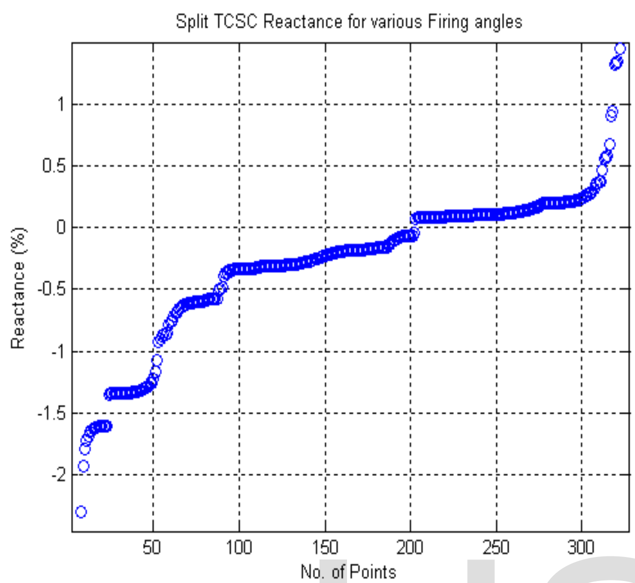

Fig.6: Split TCSC Reactance for various firing steps

Fig. 7 shows the characteristic curve of Real Power Transferred at different firing points when single TCSC is placed in between the selected bus number (6 and 28) for IEEE 30 bus system. The analysis shows that power is not transferred in the resonance region which is overcome by implementing the proposed Split TCSC.

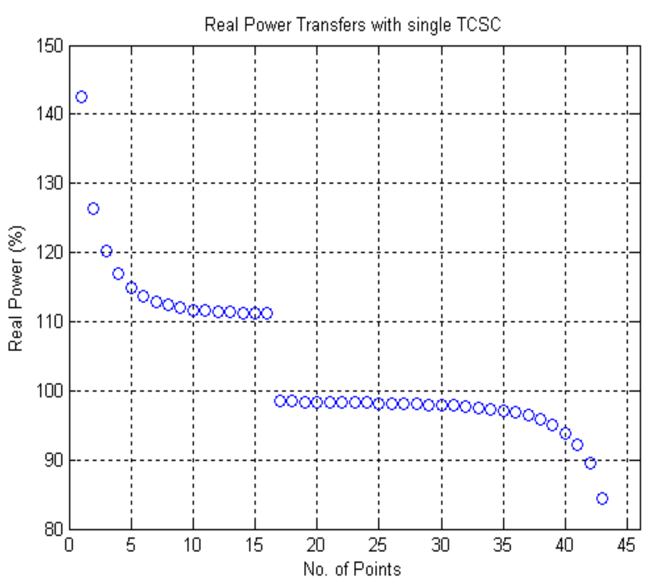

Fig. 7: Real Power Transfer with Single TCSC

Fig. 8 clearly shows the advantage of Split TCSC which clearly make us realize that real power transferred during the implementation of split TCSC improvised when compared with single TCSC results.

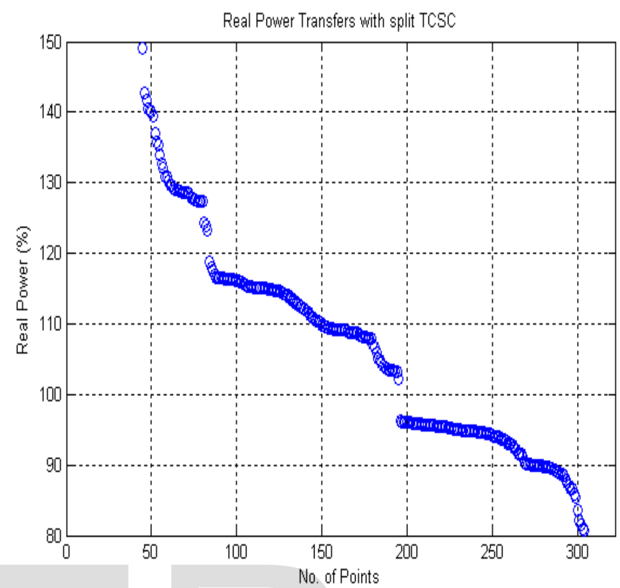

Fig.8: Real Power Transfers with Split TCSC for various firing steps

5 Conclusions

This paper presents the benefits of Split TCSC in place of Single TCSC for fine tuning of the line reactance to control smooth power flow between lines. Newton-Raphson load flow algorithm is used solve power flow problems in power system with thyristor controlled series capacitor (TCSC). The paper describes the incapability of single TCSC at critical region and showed the eminence of placing split TCSC for fine tuning the line reactance in IEEE 30-bus system. By implementing split TCSC in place of single TCSC following benefits are pointed:

1. For a particular values of L and C, maximum improvement in the active power flow occurs when Split TCSC is placed line 41, i.e., between the buses 6 and 28.
2. Fine tuning of TCSC reactance is possible with Split TCSC compared to Single TCSC, with allows fine control of power flow in the transmission lines.
3. Maximum real power flow transfer in the transmission lines can also improved by the use of Split TCSC rather than Single TCSC.
4. More number of firing points are possible with Split TCSC compared to single TCSC.
5. Huge elapse of reactance near by resonance region with single TCSC can be overcome by using split TCSC in place of single TCSC.

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BIOGRAPHIES

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