Analysis of Single and Multi Resonance Point in Reactance Characteristics of TCSC Device

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Abstract: *It was always recognized that ac power transmission over long lines was primarily limited by the series reactive impedance of the line. Thyristor controlled series compensator (TCSC) device is a series compensator to govern the power flow by compensating the reactance of the transmission line. This paper presents a conceptual study to adopt an optimum value for the capacitor and inductor of a TCSC device. Degree of Series compensation (K) brings an idea of selecting the TCSC capacitor. The Reactance characteristic curve is analyzed with resonant point for* ***different values of 'ω' which defines the square root of*** *ratio between capacitive and inductive reactance. The study is helpful in selecting an appropriate value for TCSC inductor which has influence on multi resonance point in TCSC device.*

Key Words: FACTS, TCSC, Reactance Characteristics Curves, Resonance Points.

1. INTRODUCTION

Flexible AC Transmission System (FACTS) is an emerging technology which improve power transfer scenario around the world. It improves the power transfer capability of existing transmission system with enhances reliability and security of the system. Also achieve better controllability with stability in power transmission networks. In place of building new transmission line, installing FACTS devices in existing networks is more economical. Due to these advantages, FACTS technology is now adopted by many countries like Brazil, China, India etc.. Installing of FACTS devices in developing nation like India where power demand rate is very high and increasing constantly, is very helpful to improve transmission system with great economy. [1]

FACTS devices can be connected to a transmission networks in many ways, such as in series, shunt, or a combination of series and shunt. Like, thyristor controlled series capacitor (TCSC) and static synchronous series compensator (SSSC) are connected in series; the static VAR compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt and unified power flow controller (UPFC) are connected in a series and shunt combination. Series FACTS devices increase stability and Shunt FACTS devices provide reactive power compensation.[2]

2. TCSC Device

Thyristor-controlled series capacitors (TCSC) is also a type of series compensator, can provide many benefits for a power system including controlling power flow in the line, damping power oscillations and mitigating sub -synchronous resonance. The TCSC concept is that it uses an extremely simple main circuit. The capacitor is inserted directly in series with the transmission line and the thyristor-controlled inductor is mounted directly in parallel with the capacitor. Thus no interfacing equipment like e.g. high voltage transformers is required. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation.[2-3]

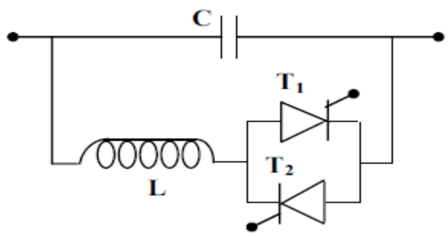

Fig -1: Basic TCSC Scheme

World's first 3 phase, 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 on site observations that it can provide series compensation without causing the same risk for sub synchronous resonance (SSR) as a fixed series capacitor. World's first TCSC for subsynchronous resonance (SSR) mitigation was installed in Stode, Sweden in 1998, by ABB.[3-4]

In India FACTS has received much attention in the last two decades. The first FACTS device installed in India is Thyristor Controlled Series Capacitor (TCSC) with Fixed Series Compensation (FSC) at 400 kV transmission line between Kanpur (U.P) and Ballabgarh (Haryana) in the Northern Grid. Some more existing FACTS project which work successfully in India are, Ranchi-Sipat 400 kV , 376 Km transmission line with 40% FSC at Ranchi end, Raipur-

Rourkela 400 kV, ,412 Km transmission line with FSC-TCSC installed at Raipur end[4].

2.1 OPERATION OF TCSC

The basic operation of TCSC can be easily explained from circuit analysis. It consists of a series compensating capacitor shunted by a Thyristor controlled reactor (TCR). TCR is a variable inductive reactor X_L controlled by firing angle α.

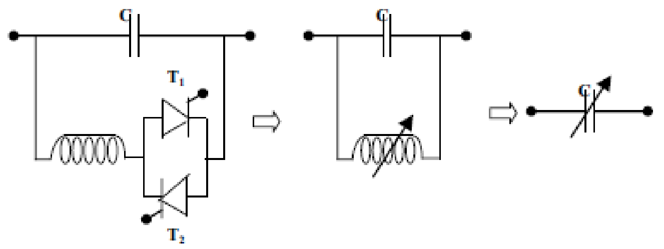

Fig -2: Equivalent circuit of TCSC

Here variation of X_L with respect to α is given by

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \quad (1)$$

$$X_C = \frac{1}{2\pi f c} \quad (2)$$

For the variation of α from 0° to 90°, X_L (α) varies from actual reactance (X_L) to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance, as shown in Fig.-2, is possible across the TCSC which modify the transmission line impedance. Effective TCSC reactance X_{TCSC} with respect to alpha (α) can be given as-[3-4].

$$X_{TCSC}(\alpha) = -X_C + C_1(2(\pi-\alpha) + \sin(2(\pi-\alpha))) - C_2\cos^2(\pi-\alpha)(\omega\tan(\omega(\pi-\alpha)) - \tan(\pi-\alpha)) \quad (3)$$

Where,

$$C_1 = \frac{X_C + X_{LC}}{\pi} \quad (4)$$

$$C_2 = 4\frac{X^2_{LC}}{X_L \pi}$$

$$X_{LC} = \frac{X_C X_L}{X_C - X_L} \quad (5)$$

$$\omega = \sqrt{\frac{X_C}{X_L}} \quad (6)$$

2.2 TCSC REACTANCE CHARACTERISTIC

Fig.-3 shows TCSC Reactance Characteristic curve of TCSC Device. It is drawn between effective reactance of TCSC and firing angle α [3]. The effective reactance of TCSC operates in three region, inductive region, capacitive region and resonance region as shown in Fig-3

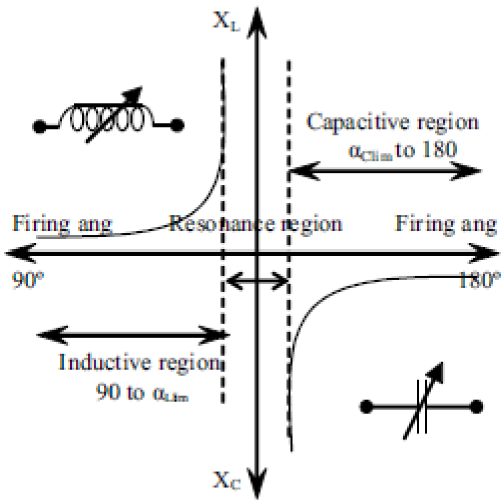

Fig-3 Reactance Vs Firing Angle Characteristics Curve

2.3 RELATION BETWEEN THE TCSC RESONANT POINT AND X_C , X_L

From equation 3, it shows the relation between ω and X_{TCSC}(α). The effective reactance X_{TCSC}(α) would be infinity when,

$$\omega(\pi-\alpha) = (2m \pm 1)\frac{\pi}{2}; \quad (m = 1,2,3....) \quad (7)$$

It is clear from equation (7), That TCSC may appear multiple resonant points in 90° to 180° of firing angle(α). However, only one resonant point, namely one capacitive range and one inductive range is practically allowable. In this paper efforts has been made to obtain reactance characteristics of TCSC for various values of, Capacitor, Inductor & ω. Multiple resonant point will reduce the the operating range of the TCSC. Thus some measures has to be taken to ensure only one resonant point between 90° to 180° of firing angle(α).

3.ANALYSIS OF SINGLE RESONANT POINT REACTANCE CHARATCRISTICS

For a practical TCSC, the compensation capacitance depends on the requirement of power system in which the TCSC is installed. Once the capacitance of compensation capacitor is fixed, the main factor influencing resonant point of TCSC is the reactance X_L . To verify this theoretical analysis, the simulation has been done in Scilab by considering Kanpur- Ballabhgarh TCSC capacitor; C=306 μF and for different values of inductance. Fig-4 and Fig-5 shows resonance characteristics of TCSC for C=306 μF, L=7.6 mH and C=306 μF and L=8.5 mH respectively.

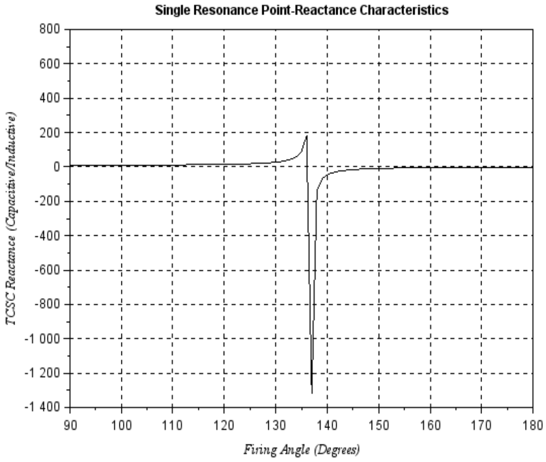

Fig-4: C=306µF and L=7.6 mH

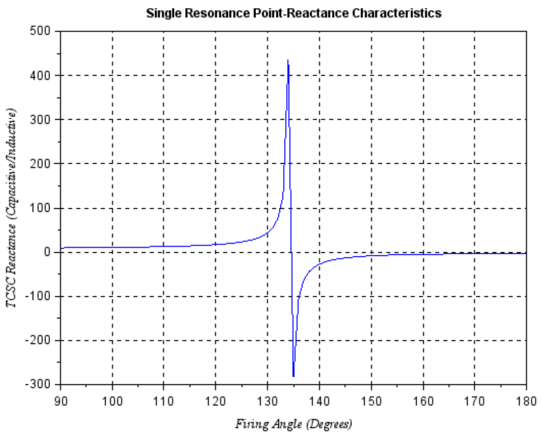

Fig-5: C=306µF and L=8.5 mH

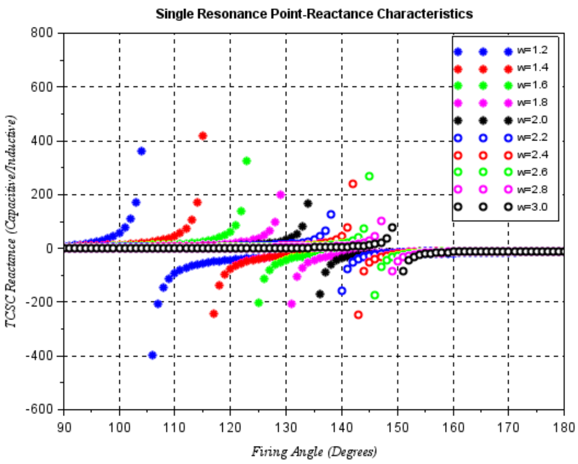

Fig-6: Single Resonance Point Reactance Characteristics curve for ω=1.2 to 3.0

From equation (7) and Fig-4,5 & 6 it is clear that factor ω decides the range of inductive and capacitive region in TCSC and operating range of TCSC. In many literature authors refereed that factor ω should be less than 3[3-4].

$$\omega = \sqrt{\frac{X_C}{X_L}} < 3 \qquad (8)$$

TABLE -1

SHIFT IN RESONANCE REGION FOR VARIOUS VALUES OF ω

ω = sqrt(X_C/X_L)	Resonance Region Between the firing Angles(Degress)	Capacitive Region Between the firing angles (Degrees)
1.2	105-106	106-180
1.4	115-116	116-180
1.6	122-125	125-180
1.8	129-130	130-180
2.0	134-135	135-180
2.2	138-140	140-180
2.4	141-142	142-180
2.6	145-146	146-180
2.8	148-149	149-180
3.0	149-151	151-180

Analyzing the factor ω from 1.2 to 3, resonance region shifts from its position and span of capacitive region shrinks. Table -1 shows occurrence of resonance and capacitive region between 90° to 180° of firing angles on the TCSC for different values of ω. Because of shift in resonance point, operating area of inductive region and capacitive region varies. For ω=1.2, capacitive region is larger and for ω=3 the capacitive region shrinks to small.

4.ANALYSIS OF MULTI RESONANT POINT REACTANCE CHARATCRISTICS

The various values of ω are considered while analyzing the multi resonant point reactance characteristic of TCSC. From simulation result it is found that, when ω is greater than 3 (ω>3) multi resonant point occurs on reactance characteristic curve. Fig-7 shows the reactance characteristics curve when ω=4.2, it is clear that for ω>3, multi resonance point occurs on reactance characteristics curve. There are two points where the resonance has been observed i.e. firing angle 115° - 117° and 157°-159°. Fig-8 shows multi resonance point in reactance curve, for ω=3.2 to 5.2 ,between the firing angle 90° to 180°, two resonance point occurred which reduces the span of the TCSC operation. Hence to operate TCSC in single Resonance Point with larger span 'ω' should be less than 3 [4].Table -2 shows occurrence of resonance between 90° to 180° of firing angles on the TCSC for different values of ω which greater than 3.

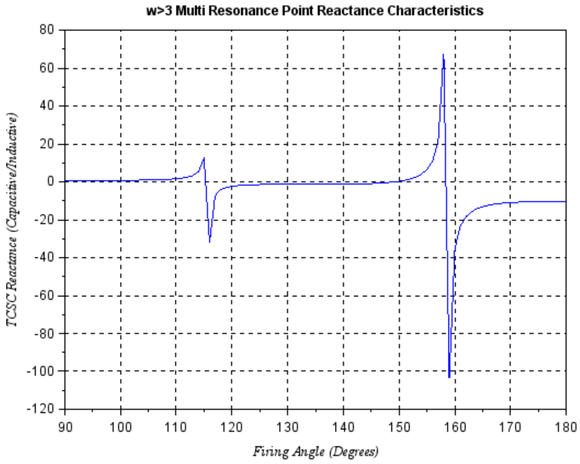

Fig-7: Multi Resonance Point Reactance Characteristics curve for ω=4.2

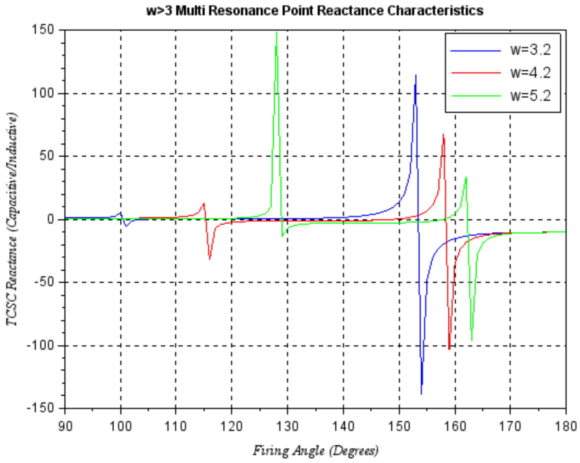

Fig-8: Multi Resonance Point Reactance Characteristics curve for ω=3.2 to 5.2

TABLE -2
MULTI RESONANCE POINT FOR VARIOUS VALUES OF 'ω' GREATER THAN 3

$\omega = \sqrt{X_C/X_L}$	Multi Resonance Region Between the firing Angles(Degrees)	
	I	II
3.2	100-101	152-154
4.2	115-116	158-159
5.2	127-129	161-162

5. ANALYSIS OF TCSC REACTANCE CHARATCRISTICS FOR $X_C = X_L$, $X_C < X_L$ ($\omega \leq 1$)

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 capacitive region is possible. Thus $\omega \leq 1$ are not permitted to get combined effect of inductive and capacitive region in TCSC operation[3].

6. CONCLUSION

This paper discusses about the operation, reactance characteristic and resonance condition of TCSC. It investigates the condition of single and multi resonance points for different values of 'ω'. From the report of resonance behavior, it is concluded that 'ω' should be optimum between 1.2 to 3 to select an appropriate value of inductor and capacitor.This study focus on an idea for selecting the TCSC parameters like inductor, capacitor as per the requirement of degree compensation. Above study is based on consideration of degree of series compensation and 'ω', but not considering the thermal loading of the transmission line, maximum allowable, current limit.

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