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Review of Thyristor Control Series Capacitor Devices installed in India

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Abstract — *Power System in India spreads over five regions namely Eastern, Western, Northern, Southern and North-Eastern. The paper focuses on detailed study of the thyristor controlled series capacitors (TCSC) installed in India on 400 kV transmission lines. Rourkela-Raipur 400 kV double circuit link between Eastern and Western Regions is planned to operate both region in synchronization. Purnea – Muzaffarpur and Muzaffarpur – Gorakhpur 400 kV Double circuit are also using TCSC. Power Transfer capability of 400 kV long transmission line is restricted by the stability limit which is less compared to the thermal capability of the line. Series compensation in the transmission lines have been successfully employed in electric power networks. With the beginning of thyristor control, the idea of series compensation has been expanded and its utility has been increased further. Using series compensation, increase in the transfer capability of existing power transmission systems can be achieved at a lower investment cost. Installation time can also be saved compared to the building of additional new lines. By series compensation systems using TCSC, additional benefits like dynamic power flow control, prospect for power oscillation damping, as well as damping of sub-synchronous resonance (SSR) can be obtained.*

Keywords- *TCSC, Series Compensation, Power oscillation damping (POD), Subsynchronous resonance (SSR), Inter-area oscillations*

I. INTRODUCTION

A Power Grid Corporation of India has bought two Thyristor Controlled Series Capacitors (TCSC) from ABB. The banks of the TCSC is installed on the Rourkela-Raipur double circuit 400 kV power transmission inter connector between the Eastern and Western regions of the grid in 2004. The length of the transmission line aggregates to 412 km.[1].Also two Thyristor Controlled Series Capacitors (TCSC) from Siemens which is installed in Purnea – Muzaffarpur 400kV D/c [Quad] (242 km) at Purnea end and Two TCSC on Muzaffarpur – Gorakhpur 400kV D/c [Quad] (233 km) at Gorakhpur end from Siemens.

Over the course of time, the inter-regional concept of operation and planning has resulted in good outcomes and all the five regional grids are now in a position to operate in an unified mode. Along with this, a number of prime factors like unbalanced growth of different regions and optimal utilization of energy resources etc. have demanded unification of regional grids.To improve the power transfer capacity and maintain system stability, fixed series compensation was proposed on Rourkala – Raipur 400kV D/c line.A low frequency,poorly damped, inter-area mode of oscillations was observed during contingent conditions. To eliminate the problem of sustained low frequency oscillations, Thyristor Control Series Compensation (TCSC) was installed on the 400kV line has been planned.[2]

Based on the studies carried out by POWERGRID,40% of Fixed Series Compensation along with 5-15% variable through TCSC mechanism was planned at Raipur end on each of the two interconnectors,same is the case for Purnea and Gorakhpur end.

To damp out Low frequency inter-area oscillations (less than 1 Hz) during certain contingency conditions in the Eastern-Western Grid, the TCSC reactance is being controlled within its operating range (5-15%) through a Power Oscillation Damping (POD) controller. This POD controls the boost factor and stabilizes the oscillation of active power, thereby damping the oscillation. Control strategy named Phasor Estimation Technique is applied to enhance TCSC damping performance.[3]

II. TCSC

Thyristor controlled series capacitor (TCSC) systems comes under the type of device commonly known as a FACTS device, which is abbreviation for Flexible AC Transmission Systems. FACTS cover power electronics based systems used for AC power transmission. FACTS solutions will be particularly reasonable in applications requiring one or more of the following qualities like Ability for frequent variations in output, Rapid dynamic response, Smooth adjustable output. Following benefits can be attained in an AC system using FACTS device such as Improved power transmission capability,Improved system stability, Improved power quality and Minimized environmental impact. FACTS devices can be inserted into transmission system in series, in shunt, and both in shunt and series. Essential applications in power transmission involve devices such as SVC (Static Var Compensators), Fixed Series Capacitors (FSC) as well as Thyristor Controlled Series Capacitors (TCSC) and STATCOM. SVC and STATCOM systems are shunt devices and used mainly to provide dynamic reactive power support in the grid to maintain voltages. On the other hand, fixed series capacitors/TCSCs are series devices and used mainly to compensate line series reactance so that virtual reduction in electrical line length is accomplished. In this way, it would enhance the line loadability without risking system stability.

Composition of TCSC is illustrated in Fig. 3. A Thyristor Controlled Reactor (TCR) is placed in parallel with series capacitor facilitates a variable and continuous series compensation in the network. TCSC's fundamental impedance is a function of the firing angle (α) and the characteristics are shown at Fig. 4. In the study, the impedance is assumed to be variable in vernier capacitive mode, allowing continuous and rapid adjustment of the transmission line compensation level.

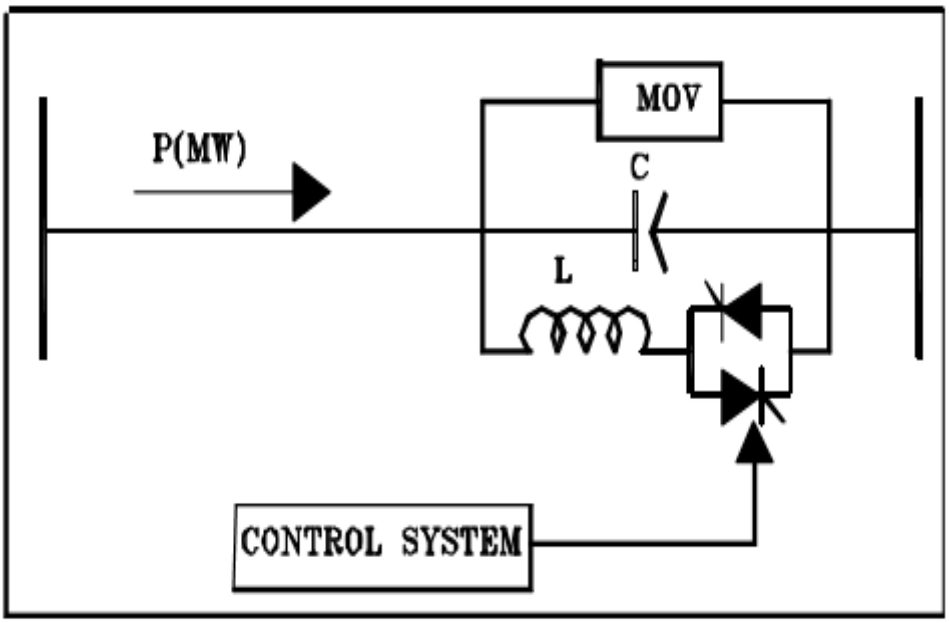

Figure:1. Composition of a typical TCSC

Due to the inherent characteristic,TCSC is capable of quick control and distribution of active power flow through several parallel transmission line to the secure transfer capability whenever required.In case of two different Networks connected by weak inter-area links(less number of transmission lines),TCSC helps in damping out active power oscillation(inter-area mode) caused by any disturbances.In this way TCSC introduces flexibility of power transfer in AC system like HVDC but at a nominal cost.A typical impedance characteristic of the TCSC is shown below.

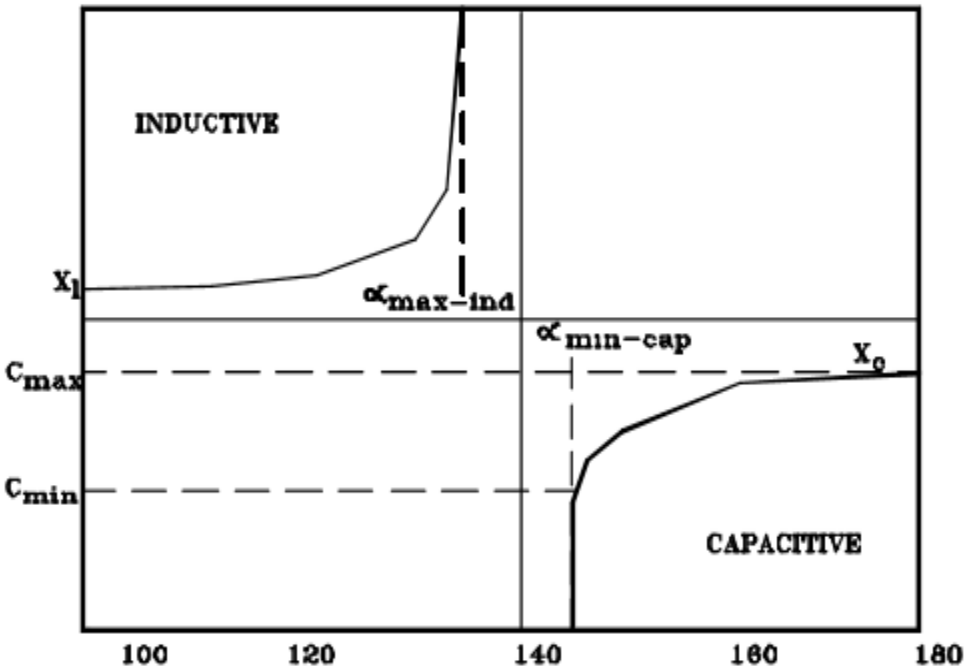

Figure:3. TCSC Impedance Characteristic

III. Installed TCSC Base

The following are the installed TCSC systems worldwide, as shown in Table below[4].

Location	Configuration	Rating	Installed (Year)	Purpose
1992	Kayenta, WAPA, US	FC plus TCSC	230 kV, 2 x 165 Mvar (TCSC module: 45 Mvar); 1,000 A	Increase power transfer; SSR (TCSC system
1993	Slatt System, BPA, US	6 TCSC modules in Series	500 kV, 208 Mvar, 2,900 A	System to demonstrate power flow control, SSR damping, stability control and fault performance
1997	Stöde, Svenska Kraftnät, Sweden	FC plus TCSC	400 kV, 493 Mvar total (TCSC 148 Mvar);1,500 A	SSR control
1999	Imperatriz, Eletronorte, Brazil		500 kV, 108 Mvar, 1,500 A	System damping
1999	Serra da Mesa, FURNAS Centrais Elétricas S.A Brazil		500 kV, 107 Mvar, 1,500 A	System damping
2002	Pingguo, State Power South Company, Guangzhou, China	2 x FC plus 2 x TCSC	500kV, TCSC 55Mvar; FSC 350Mvar, 2,000 A	System damping
2004	Serra da Mesa, Novatrans, Brazil		500 kV, 107.5 Mvar, 1,500 A	System damping
2004	Imperatriz, Novatrans, Brazil		500 kV, 107.5 Mvar, 1,500 A	System damping
2004	Chengxian, Gansu Electric Power Co. China	TCSC	220 kV, 86.7 Mvar, 1,100 A	Damping, Improving Power Transmission Capability
2004	Raipur end of , Rourkela – Raipur 400 kV D/c line; Power Grid Corporation of India, Ltd.	2 x TCSC plus 2 x FC	400 kV, 394 Mvar FC and 71 Mvar TCSC, 1,550 A	System damping
2006	Gorakhpur end of Muzaffarpur – Gorakhpur 400 kV D/c line;, Power Grid Corporation of India, Ltd.	2 x FC plus 2 xTCSC	420 kV, 716 Mvar FC and 107 Mvar TCSC	System damping
2006	Purnea end of Purnea – Muzaffarpur 400 kV D/c line, Power Grid Corporation of India, Ltd.	2 x FC plus 2 x TCSC	420 kV, 743 Mvar FC and 112 Mvar TCSC	System damping
2009	Fengtun, Northeast China Grid Co., Ltd	TCSC	500 kV, 326 Mvar, 2,330 A	System damping

While series capacitor banks have been effective in improving transient and steady state stability, the requirement to enhance the transmission capacity of lines to their designed limits has resulted in the additional requirement for damping of system oscillations. A TCSC adds another controllability dimension, as thyristors are used to dynamically modulate the capacitor reactance provided by the inserted series capacitors. This is primarily used to provide damping of possible low frequency electro-mechanical oscillations. Often the TCSC is here combined with fixed series compensation banks in order to increase the transient stability in a cost effective way. The installed TCSCs are described below.

Installed TCSC System in India

• Two TCSC on Rourkela – Raipur 400kV D/c (412 km) at Raipur end
• Two TCSC on Purnea – Muzaffarpur 400kV D/c [Quad] (242 km) at Purnea end
• Two TCSC on Muzaffarpur – Gorakhpur 400kV D/c [Quad] (233 km) at Gorakhpur end
The single line diagram of the TCSC installations is shown in Figure below

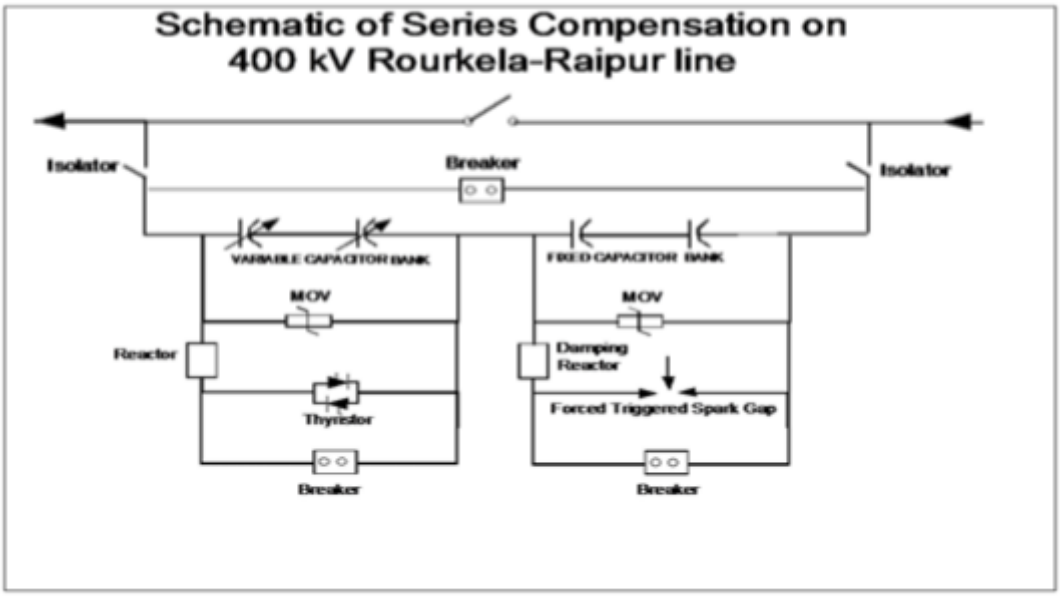

FIGURE 3:SINGLE LINE DIAGRAM OF THE TCSC INSTALLATIONS

IV. TCSC Raipur – Rourkela TCSC System Data

The location of the TCSC 400kV Rourkela- Raipur D/c is situated in Raipur, Chattisgarh.The Owner of the system is Power Grid Corporation of India and the Manufacturer is ABB.The TCSC system has been commercially operated from 2004.The main function of the TCSC system is Damping of inter-area low frequency oscillations.The power frequency of the system is 50 Hz.The line to line rms system rated voltage is 400kV and maximum system operating voltage is 420kV.The short circuit current at nominal voltage is 40kA.The effective Degree of compensation due to TCSC is 40% for Fixed Capacitor(FC) and 5%to15% for TCSC. The rated reactive power of TCSC is 59.1 MVAr and the rated TCSC voltage 12.7 kVrms.The rated Current for TCSC is 1550 A.

The Capacitive reactance (Xc) is 6.83 ohms/ph and the effective capacitive reactance (Xeff) is 1.2 p.u The Maximum effective capacitive reactance is 20.49 ohms.The Inductive reactance in TSR mode (XTSR) is 1.3 Ohms.The Capacitance (series capacitor) is 6.83 Ohms.The Capacitor bank arrangement is combination of Series & Parallel.About the equipment the capacitance for the Fixed Series Capacitor(FSC) is 58.19 µF and the capacitance for TCSC 133.16 µF.The Thyristor valve is 100mm device where 14 thyristor are placed in series.The Reactor inductance (TCR) is 3480 uH.The inter area damping mode is taken care by the system and the performance of the system is being evaluated by the Field Test[4].

V. TCSC Purnea – Muzaffarpur TCSC System Data

The location of the TCSC 400kV Purnea- Muzaffarpur D/c is situated in Purnea, Bihar.The Owner of the system is Power Grid Corporation of India and the Manufacturer is Siemens.The TCSC system has been commercially operated from 2006.The main function of the TCSC system is Damping of inter-area low frequency oscillations.The power frequency of the system is 50 Hz.The line to line rms system rated voltage is 400kV and maximum system operating voltage is 420kV.The short circuit current at nominal voltage is 20kA.The effective Degree of compensation 5%to15% for TCSC. The rated reactive power of TCSC is 140.4 MVAr and the rated TCSC voltage 11.9 kV. The rated Current for TCSC is 3931 A.

The Capacitive reactance (Xc) is 3.03 ohms – 5% and the effective capacitive reactance (Xeff) is 3.64 ohms – 6%. The Maximum effective capacitive reactance is 9.09 ohms – 15%. About the equipment the capacitance Total number of Capacitor units/phase -76 kVAr rating per capacitor – 616 kVAr Capacitor bank arrangement Number of capacitors in series and parallel - Series unit per leg – 1 Series Unit total -2 Parallel unit per leg -19 Parallel units total-38.The Thyristor valve is 100mm device where 11 thyristor are placed in series.The Reactor inductance (TCR) is 1.5 mH.The inter area damping mode is taken care by the system.[4]

VI. TCSC Muzaffarpur – Gorakhpur TCSC System Data

The location of the TCSC 400kV Muzaffarpur - Gorakhpur D/c is situated in Gorakhpur, UttarPradesh.The Owner of the system is Power Grid Corporation of India and the Manufacturer is Siemens.The TCSC system has been commercially operated from 2006.The main function of the TCSC system is Damping of inter-area low frequency oscillations.The power frequency of the system is 50 Hz.The line to line rms system rated voltage is 400kV and maximum system operating voltage is 420kV.The short circuit current at nominal voltage is 20kA.The effective Degree of compensation 5%to15% for TCSC. The rated reactive power of TCSC is 135.2 MVAr and the rated TCSC voltage 11.5 kV. The rated Current for TCSC is 3929 A.

The Capacitive reactance (Xc) is 3.03 o 2.92 ohms – 5% and the effective capacitive reactance (Xeff) is 3.5 ohms – 6%.The Maximum effective capacitive reactance is 8.76 ohms – 15%.About the equipment the capacitance Total number of Capacitor units/phase -76 kVA rating per capacitor – 593 kVAr Capacitor bank arrangement Number of capacitors in series and parallel - Series unit per leg – 1 Series Unit total -2 Parallel unit per leg -19 Parallel units total-38.The Thyristor valve is 100mm device where 11 thyristor are placed in series.The Reactor inductance (TCR) is 1.5 mH.The inter area damping mode is taken care by the system[4].

VII. Conclusion

This paper presents a brief study of Rourkela-Raipur, Purnea – Muzaffarpur, Muzaffarpur – Gorakhpur 400kV D/c transmission line and emphasis on various governing factors have been explained.Rourkela-Raipur section requires provision of 40% fixed series compensation and TCSC with the range of 5%-15% compensation.The Series Capacitor, compensate the inductive reactance of transmission line, thereby making virtual reduction in line length and enhances the power transfer capacity. Series compensation is a tool for utilization of existing transmission infrastructure optimally. Being series element, adequate protection is required which is achieved by installation of ZnO varistor (MOV),forced trigger spark gap and bypass switch. Besides for variable series compensation (TCSC), thyristor controlled reactor(TCR) is also required to provide necessary capacitive boost for control purpose. Further,to damp out the low frequency inter-area oscillation.Power Oscillation Damper(POD) is required whose basic principal of operation is highlighted.

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