

STUDY OF THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC) AS A USEFUL FACTS DEVICE

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Abstract

For transmission of large amounts of electric power, AC in the overwhelming majority of cases is the established as well as the most cost effective option at hand. In cases of long distance transmission, as in interconnection of power systems, care has to be taken for safeguarding of synchronism as well as stable system voltages in the interconnection, particularly for extreme load conditions and in conjunction with system faults. Use of Thyristor Controlled Series Capacitor (TCSC) as Flexible AC Transmission System (FACTS) device brings a number of benefits for the user of the grid, all contributing to an increase of the power transmission capability of new as well as existing transmission lines. These benefits include improvement in system stability, voltage regulation, reactive power balance, load sharing between parallel lines and reduction in transmission losses.

Key Words: Thyristor Controlled Series Capacitor; Series Compensation; FACTS; SSR.

1. Introduction

Series compensation has been utilized for many years with excellent results in AC power transmission in a number of countries all over the world. The usefulness of the concept can be demonstrated by well-known expressions Eq. (1) and Eq. (2) relating to active power transfer and voltage [1]:

$$P = V_1 V_2 \sin \Psi / X \quad (1)$$

$$V = f(P, Q) \quad (2)$$

Here, V_1 and V_2 denote the voltages at either end of the interconnection, whereas Ψ denotes the angular difference of the said voltages. X is the reactance of the transmission circuit, while P and Q denote the active and reactive power flow. From Eq. (1) it is evident that the flow of active power can be increased by decreasing the effective series reactance of the line. Similarly it is demonstrated that by introducing a capacitive reactance in the denominator of Eq. (1), it is possible to achieve a decrease of the angular separation with power transmission capability unaffected, i.e. an increase of the angular stability of the link. The influencing of transmission reactance by means of series compensation also opens up for optimizing of load sharing between parallel circuits, thereby bringing about an increase in overall power transmission capacity again. Likewise a valuable feature, active losses associated with power transmission can be decreased, as well. From Eq. (2) it is seen that the voltage of a transmission circuit depends of the flow of active as well as reactive power. The explicit relationship between the quantities in the formula is not simple. Closer analysis reveals, however, that the reactive power contribution from a capacitive element in series with the line acts to improve the reactive power balance of the circuit, and thereby to bring about a stabilization of the transmission voltage. It can further be shown that this reactive power contribution is instantaneous and of a self regulatory nature, i.e. it increases

when the line load increases, and vice versa. It consequently contributes to voltage stability in a truly dynamic fashion. This makes series compensation a highly effective means for up keeping or even increasing voltage stability in a heavily loaded transmission circuit. And likewise, it allows additional power transmission over the circuit without upsetting voltage stability. With the reactance of the capacitive element, i.e. the series capacitor equal to X_C and the inductive reactance of the line equal to X_L , we can define the degree of series compensation, k :

$$k = X_C / X_L \quad (3)$$

2. TCSC for Power Transmission

2.1. Circuit

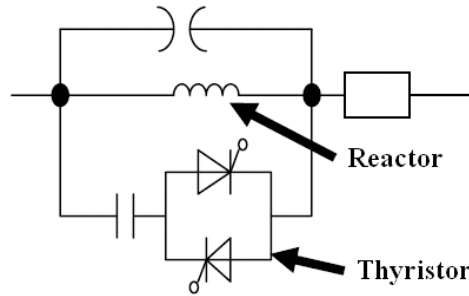


Fig. 1 Simple diagram of TCSC

Figure 1 shows the simple diagram of TCSC comprised of a series capacitor bank, shunted by a Thyristor Controlled Reactor (TCR), to provide a smoothly variable series capacitive reactance. It is a one-port circuit in series with transmission line; it uses natural commutation; its switching frequency is low; it contains insignificant energy storage and has no DC port. Insertion of a capacitive reactance in series with the line's inherent inductive reactance lowers the total, effective impedance of the line and thus virtually reduces its length. As a result, both angular and voltage stability gets improved.

2.2. Control Mechanism

Research on control strategies for TCSC can be traced back to 1966 when Kimbark [2] analyzed the improvement in transient stability of power systems by using switched series capacitors. This was a very simple control; the maximum amount of compensation was inserted at the same time that the faulted line was switched out. Ramarao *et al.*[3] proposed an optimal control of the capacitance. Pontryagin's maximum principle was used to obtain bang-bang control. It was one of the earliest closed-loop control systems for series compensation.

With TCSC, it is possible to vary the degree of compensation k at mains frequency (50 Hz) with rapidity limited only by the speed of response of the electronic scheme used in the TCSC. This opens up for applications previously not encountered in conjunction with series compensation, such as post-contingency power flow control and damping of active power oscillations. By referring to Eq. (1), it is readily seen that the introducing of a periodic modulation of the line reactance in the denominator of a suitably low frequency (usually less than 1 Hz for inter-area power oscillations), it is possible to counter-act and subsequently damp out active power oscillations. Since it is not infrequent to encounter particularly active power oscillations as a limiting factor on power transmission capacity of radial interconnecting ties, the TCSC concept is very useful as a tool for extending the possibilities for AC power interconnection between regions, both as far as amounts of power and geographical distances are concerned.

2.3. Impacts

2.3.1. Balancing of load flows

This enables the load flow on parallel circuits and different voltage levels to be optimized, with a minimum of power wheeling, the best possible utilization of the lines, and a minimizing of overall system losses at the same time.

2.3.2. *Increasing of first swing stability, power oscillation damping, and voltage stability*

This enables a maximizing of system availability as well as of power transmission capability over existing as well as new lines. Thus, more power can be transmitted over fewer lines, with a saving of money as well as of environmental impact of the transmission link.

2.3.3. *Mitigation of sub synchronous resonance risk*

Sub synchronous resonance (SSR) is a phenomenon which can be associated with series compensation under certain adverse conditions. The elimination of the risk of SSR even for the most onerous conditions means that the series compensation concept can be utilized in situations where it would otherwise not have been undertaken, thereby widening the usefulness of series compensation.

2.3.4. *Power system interconnection*

Interconnecting of power systems is becoming increasingly widespread as part of power exchange between countries as well as regions within countries in many parts of the world. Such are found in the Nordic countries, Argentina, and Brazil.

3. Practical Applications of TCSC

By the end of year 2004, seven TCSCs have been installed worldwide. In Asia, three TCSC came into operation; two in China and one in India, bringing Asia into the forefront of the advanced FACTS technology. Table 1 shows the complete list of TCSC installed worldwide as of December 2004 [4].

Table 1: Complete list of TCSC installation

Year	Country	KV	Purpose	Place
1992	USA	230	To increase power transfer capability	Kayenta substation, Arizona
1993	USA	500	Controlling line power flow and increased loading	C.J.Slatt substation, Northern Oregon
1998	Sweden	400	Sub Synchronous Resonance mitigation	Stöde
1999	Brazil	500	To damp inter-area low freq (0.2 Hz) oscillation	Imperatriz and Sarra de Mesa
2002	China	500	Stability improvement, low frequency oscillation mitigation	Pinguo substation, State power south company, Guangzhou
2004	India	400	Compensation, Damping interregional power oscillation	Raipur substation
2004	China	220	Increase Stability margin, suppress low frequency oscillation	North-West China Power System

4. Case Studies and TCSC for Bangladesh

4.1. Case Study 1: Raipur substation, India

Power Grid Corporation of India Ltd (PGCIL) installed two Thyristor Controlled Series Capacitors (TCSC) [5]. The banks were installed on the Rourkela-Raipur double circuit 400 kV power transmission interconnector between the Eastern and Western regions of the grid. The length of the interconnector amounts to 412 km. The main purpose of this major AC interconnector is to enable export of surplus energy from the Eastern to the Western regions of India during normal operating conditions, and also during contingencies. The TCSC are located at the Raipur end of the lines. The TCSC enable damping of inter-area power oscillations between the regions, which would otherwise have constituted a limitation on power transfer over the interconnector. Dynamic simulations performed during the design stage, and subsequently confirmed at the commissioning and testing stage, have proved the effectiveness of the Raipur TCSC as power oscillation dampers. Furthermore, system studies performed showed no risk for Sub-Synchronous Resonance (SSR) in the Indian network. As a solution to these inter-area low frequency power swings, the studies proposed two fixed Series Capacitors, each rated at 40% degree of compensation of the Rourkela-Raipur line, and two TCSCs, each rated at 5% degree of compensation of the Rourkela-Raipur line. For power oscillation damping (POD), by control of the boost factor, the TCSCs introduce a component of modulation of the effective reactance of the power lines. By suitable system control, this modulation of reactance counteracts the oscillation of active power, thereby quickly damping it out. The Rourkela- Raipur TCSCs have proven effective as power oscillation dampers.

4.2. Case Study 2: Imperatriz, Brazil

Since spring of 1999, Brazil has been operating a Thyristor-controlled Series Capacitor (TCSC) and five fixed Series Capacitors in the 500 kV interconnector between its northern and southern power systems [5]. All in all, about 1.100 Mvar of series capacitors have been installed. The TCSC is located at Imperatriz at the northern end of the power corridor connecting the two systems which were previously not interconnected. Feasibility studies had been performed regarding the interconnection of the two systems, and a decision was made to go ahead and build the transmission corridor. Both AC and DC alternatives were assessed, and decided in favor of the AC option. It consists of a single 500 kV compact circuit (subsequently doubled), more than 1.000 km long and series compensated in several places along the line. Operation began in 1998. The power transmission capability of the corridor is 1.300 MW. The TCSC at Imperatriz, the first of its kind to be installed in Latin America, has the task of damping low-frequency inter-area power oscillations between the power systems on either side of the interconnection. These oscillations (0,2 Hz) would otherwise have constituted a hazard to power system stability and thereby to power transmission capability. The TCSC efficiently eliminates this obstacle to power transmission.

4.3. TCSC for the Improvement of Existing Power System of Bangladesh

Bangladesh's installed electric generating capacity in 2009 was 4000 MW, of which 94% was thermal (mainly natural-gas-fired), and the remainder hydroelectric, at 18 power stations. The Padma-Jamuna-Meghna river system divides Bangladesh into two zones, East and West [6]. The East contains nearly all of the country's electric generating capacity, while the West, with almost no natural resources, must import power from the East. Electricity interconnection from the East to the West was accomplished in 1982 by a new, 230-kilovolt (kV) power transmission line. The vast majority of Bangladesh's electricity consumption takes place in the East, with the entire region west of the Jamuna River accounting for only 22% of the total. Greater Dhaka alone consumes around half of Bangladeshi electricity.

Series compensation can be a useful tool for the power interconnection corridors between East and West Zones of Bangladesh. Analysis and survey by experts followed by proper placement of TCSC in the power grid of Bangladesh will improve the power transmission capacity as well as steady-state and dynamic stability of the long AC power transmission system. Bangladesh is also going to buy 500 MW power from different power plants of India. [7]. The power will be transmitted through a 400 KV switching station and a 400 KV single circuit line. Power Grid Corporation of India Ltd (PGCI) will also construct a 400KV double circuit line stretching from India's Bherampur to Bheramara in Bangladesh. If Two TCSC are installed on the double circuit 400 kV power transmission interconnector between the sending and receiving end of the grid, it will enable surplus energy during normal operating conditions, and also during contingencies.

5. Conclusion

With the history of more than three decades and widespread research and development, FACTS controllers are now considered a proven and mature technology. The recent introduction of TCSC has further widened the scope and added new valuable benefits. This paper reveals an overview of TCSC as one the best proposed devices in FACTS family, its applications and the prospects of TCSC as an effective power system improvement tool for Bangladesh.

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