ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 2, Issue 10, October 2013

Optimization Location of TCSC to control Power Swing

Sonora Dixit, Rajkumar Jhapte

***Abstract*— Flexible Alternating Current Transmission Systems (FACTS) devices can be used to minimize transmission system power loss, and power flow control flexibility and rapidity. FACTS devices can provide strategic benefits for transmission system management through better utilization of existing transmission facilities, increasing system capacity and reliability, enhancing system stabilities, as well as enabling ecological benefits. Though FACTS controllers offer many advantages, their installation cost is very high. Hence the optimal placement and the optimal parameter settings of these devices in the power system are of important issues. This paper presents the optimal location and the optimal parameter setting of TCSC considering the active power losses minimization in the power network. The results are presented in the paper together with appropriate discussion. This paper proposes a comparative analysis for the optimal location of TCSC for the active power loss in transmission line using PSCAD.**

***Index Terms*— Thyristor Controlled Series Capacitor (TCSC), Power flow, harmonics, PSCAD.**

I. Introduction

The generated power from the electric power plant is distributed through the transmission, sub transmission, and distribution lines to the consumer. Due to the installation of capacitor, the improvement of voltage profile and system losses are reduced which depends on how capacitors are placed and operated in the system that serves a variety of load [1]. FACTS provide dynamic control of the power transfer parameters like transmission voltage, line impedance and phase angle, this plays the major thrust in power electronics based technology. Due to the usage of FACTs devices increased flexibility, lower operation and maintenance costs with less environmental externalities are obtained [2]. In the radial distribution system, the voltage profile improvement and the energy losses are reduced by the installation of capacitors at suitable locations. In the distribution networks it is concluded that 13% is I^2R losses from the total power generation [3].

In this paper TCSC is used because it offers flexible control with higher response rate than the variable series capacitor on lines impedance. Other uses can be about increase the power transfer capability, improve transient stability, reduce transmission losses and damp out power system oscillations. TCSC should be properly installed in the network with appropriate parameters for achieving the above mentioned benefits. For this reason, some performance indices must be satisfied. The active power loss reduction, the stability margin improvement, the power transmission capacity increasing and the power blackout prevention are the factors that can be considered in the optimal installation and the optimal parameter of TCSC. [4] Therefore, PSCAD software should incorporate with TCSC considering one or all of the above mentioned factors. A PSCAD to solve power flow problems in power system with thyristor controlled series capacitor (TCSC) was proposed. A real power flow performance index sensitivity to obtain the optimal placement of TCSC was suggested by reference [2]. This paper presents to find out the optimal location and parameter setting of the TCSC with the consideration of active power loss reduction in the power system.

TCSCs have many benefits for AC transmission systems such as improved efficiency [5], controlled power flow [6], enhanced transient stability [7], improved power quality [8] and power transfer capability, as well as damping sub-synchronous resonances [9]. To achieve these advantages, proper location for controlling TCSC are required. Several strategies have been proposed and used for controlling TCSC in power system utilities [10]. In compensated transmission lines using TCSC, harmonic currents and voltages depend on the size and location of the compensator. Therefore, it is important to consider the harmonic performance when designing TCSCs. Voltage and current harmonics of TCSC versus location distance of TCSC are computed and analyzed. PSCAD facilities are used to simulate a sample system with a designed TCSC [11].

In order to meet the high demand for power transmission capacity, some power companies have installed series capacitors on power transmission lines. This allows the impedance of the line to be lowered, thus yielding increased transmission capability. The series capacitor makes sense because it's simple and could be installed for 15 to 30% of the cost of installing a new transmission line, and it can provide the benefits of increased system stability, reduced system losses, and better voltage regulation [12]. TCSC is able to directly schedule the real power flow control by selected line and allow the system to operate closer to the line limits. More importantly because of its rapid and flexible regulation ability, it can improve transient stability to and dynamic performance of the power systems [13]. The objective of this paper is to study the impact of TCSC on enhancing power system stability as well as location of TCSC. Section (II) and (III) of this paper gives description about FACT devices and TCSC while sections (IV) gives

TCSC Simulation model Description of power system. The rest of the sections are organized as follows: in section (V) optimization of power flow by TCSC location is presented Section (VI) Relation between TCSC optimization and distance is shown. The simulation and results are presented in section (VII). Finally conclusions are discussed in section (VIII)

II. FLEXIBLE AC TRANSMISSION SYSTEM(FACTS)

A. FACTS

FACTS controllers are used which is classified as series and shunt. Transmission or distribution system parameters are modified by using series compensation and the equivalent impedance of the load can be changed by shunt compensation technique. In both the cases, FACTS controls the reactive power flows through the system and improves the overall performance of ac power system. Series controllers increase the power handling capacity where as shunt controllers improve the voltage at a particular location. The series compensation improves the power transmission capability of the lines which is an economic method [14],[15].

Expressions Eq. (1) and Eq. (2) relating to active power transfer and voltage [16]:

$$P = V_1V_2 \sin(\psi/X) \quad (1)$$

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

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. From Eq. (2) it is seen that the voltage of a transmission circuit depends of the flow of active as well as reactive power. 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:

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

B. Five regional grids in India.

TABLE I
All india installed capacity

North	(N)	53.9 GW
East	(E)	26.3 GW
South	(S)	52.7 GW
West	(W)	64.4 GW
North-East	(N-E)	2.4 GW
Total		200 GW

In India, installation of TCSC with system voltage 400 kv in service year 2004, is for the application purpose of compensation, damping inter-regional,and power oscillation. In India, installation of TCSC with system voltage 400 kv in service year 2006 is to improve transmission performance and the reliability of over head line.

III. TCSC

A. Thyristor controlled series compensator (TCSC)

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 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 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. TCSC consists of series compensating capacitor shunted by thyristor controlled reactor. It is modeled as a controllable reactance, inserted in series with the transmission line to adjust the line impedance and thereby control the power flow [17]. Fig.1 shows the single line diagram of transmission line with TCSC.

$$X_{ij\,new} = X_{ij} + X_{TCSC} \quad (4)$$

where,

$X_{ij\,new}$ — Reactance after the location of TCSC,
X_{ij} — Reactance of the transmission line,
X_{TCSC} — Reactance of the TCSC.

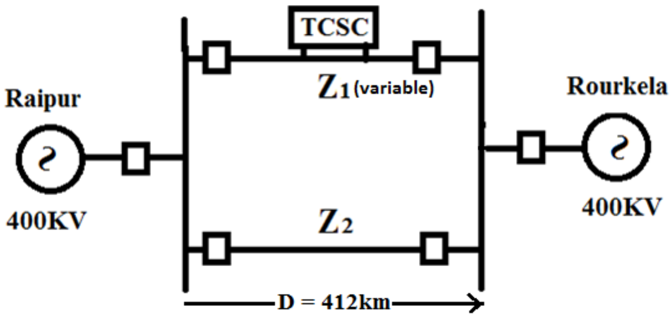

Fig. 1. Single Line Diagram of Transmission line with TCSC

B. Impacts

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. 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.

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 difficult 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.

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.

The main drawbacks of TCSC are the nonlinear effects on system stability, discrete (non-continuous) impedance and harmonics injection. It is known that harmonic currents and the resulting harmonic voltages can be magnified considerably causing all sorts of operational problems. Especially if a resonance occurs at one of the harmonic frequencies. For this reason, a recommended limit of 1% for each harmonic voltage is set and used in power systems above 138 kV [18]

IV. TCSC SIMULATION MODEL DESCRIPTION

A. Simulation Model of TCSC

The transmission line connected between buses i and j represented by lumped π-equivalent parameters. For providing series compensation in the most sensitive line the TCSC can be taken as static capacitive reactance –jXc. TCSC helps to enhance the power transfer capability by providing series compensation in system. If X_{ij} and R_{ij} are the reactance and resistance of the line i-j, respectively. Then effective reactance of the line is given as [14]: $X_{ij,eff} = X_{ij} - X_C$

$$X_{ij,eff} = (1 - k)\, X_{ij} \tag{5}$$

where k is the degree of compensation whose value lies between 0 and 1.

$$P_{ij}^c = V_i^2 G_{ij,eff} - V_i V_j [G_{ij,eff}\cos(\delta_{ij}) + B_{ij,eff}\sin(\delta_{ij})] \tag{6}$$

$$Q_{ij}^c = -V_i^2 (B_{ij,eff} + B_{sh}) - V_i V_j [G_{ij,eff}\sin(\delta_{ij}) - B_{ij,eff}\cos(\delta_{ij})] \tag{7}$$

$$P_{ji}^c = V_j^2 G_{ij,eff} - V_i V_j [G_{ij,eff}\cos(\delta_{ij}) - B_{ij,eff}\sin(\delta_{ij})] \tag{8}$$

$$Q_{ji}^c = -V_j^2 \left(B_{ij,eff} + B_{sh}\right) + V_i V_j [G_{ij,eff}\sin(\delta_{ij}) + B_{ij,eff}\cos(\delta_{ij})] \tag{9}$$

Where, $\delta_{ij} = \delta_i - \delta_j$,

$$G_{ij,eff} = \frac{R_{ij}}{R_{ij}^2 + (X_{ij} - X_c)^2} \quad \text{and} \quad B_{ij,eff} = \frac{-(X_{ij} - X_c)}{R_{ij}^2 + (X_{ij} - X_c)^2}$$

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2 + X_{ij}^2)^2}$$

B. Optimal Location of TCSC

The sensitivity analysis criterion has been considered for the optimal placement of TCSC device in the transmission network. This method based on the sensitivity of total system reactive power loss (Q_L) with respect to the control parameter of TCSC. Placing TCSC between buses i and j, the net line series reactance X_{ij} becomes variable. The sensitivity index for ij[th] line can be given as [19]

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)]\frac{R_{ij}^2 - X_{ij}^2}{(R_{ij}^2 + X_{ij}^2)^2} \tag{10}$$

The TCSC should be installed in a line whose loss index a_{ij} value is most positive one.

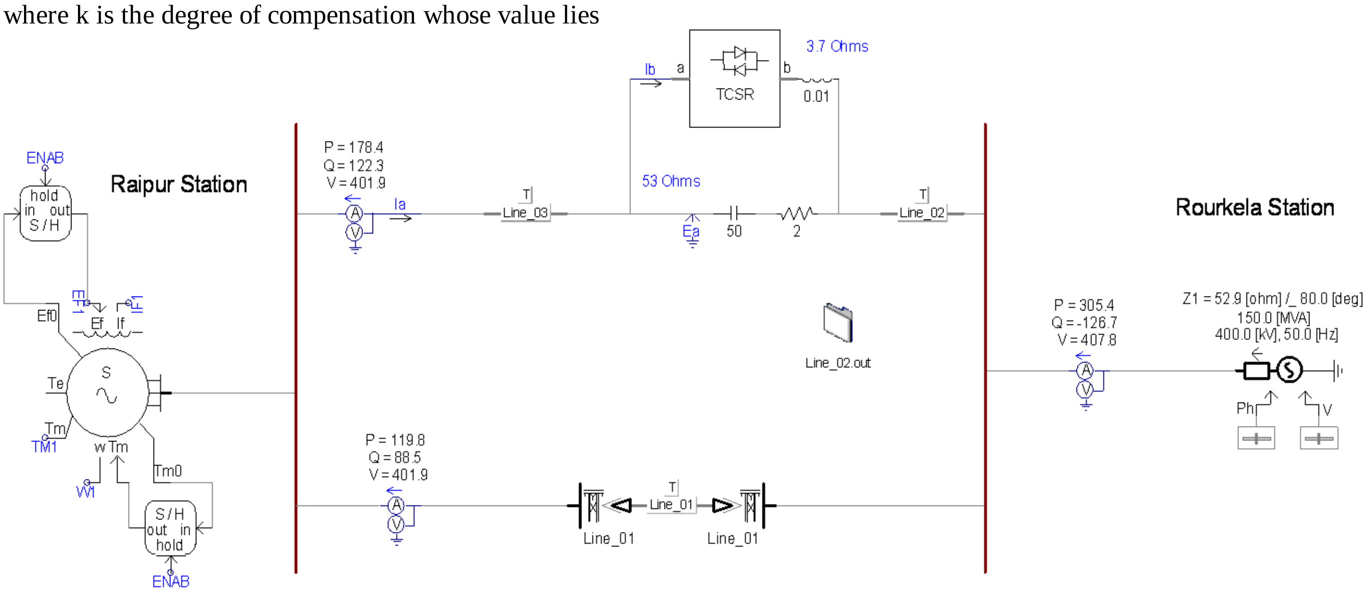

Fig. 2. TCSC Simulation Model

C. TCSC Implementation

In order to simulate the performance of TCSC and illustrate its effects on transmission line loadability and power quality, the 400 kV, 412 km line located in the Eastern and Western grids of India is considered [6]. System diagram and line parameters are illustrated in Fig. 3 and Table II. The main purpose of using TCSC is to reach the maximum power transfer (P_{max}^{L1}) of the transmission line (e.g., 100% compensated).

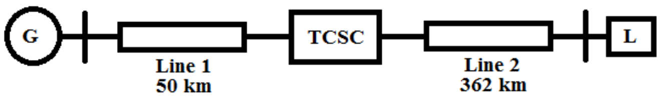

Fig. 3. The 400 kV, 412 km line used for simulations

The quotient between the resonance frequency of TCSC $\omega_r = 1/\sqrt{LC}$ and the network frequency (ω) is

$$\lambda = \frac{\omega_r}{\omega} = \sqrt{Xc/X_L} \quad (11)$$

where X_C and X_L are bank capacitance and thyristor branch reactance, respectively. The fundamental component of TCSC voltage [20] is used to measure the equivalent device impedance.

$$|X_1| = \left|\frac{V}{I\ line}\right| = -\frac{1}{\omega r} + \frac{K}{C\omega\pi}(\delta + \sin(\delta)) - \frac{4K\cos^2(\frac{\delta}{2})}{\omega\pi(\lambda^2-1)} \left(\lambda \tan\left(\lambda\frac{\delta}{2}\right) - \tan\left(\frac{\delta}{2}\right)\right) \quad (12)$$

Where, $K = \omega r^2/(\omega r^2 - \omega^2)$

TABLE II
Transmission line parameters for the 400 kV, 412km line (Fig. 3) located between Raipur and Rourkela

Nominal voltage(kv)	400
Highest voltage(kv)	420
Resistance(pu/km)	1.862×10^{-5}
Reactance(pu/km)	2.075×10^{-4}
Susceptance(pu/km)	5.55×10^{-3}
Surge impedance loading(MW)	515

V. OPTIMIZATION OF POWER FLOW BY TCSC LOCATION

A. Problem formulation

The following performance index is selected to find out the optimal location and the optimal parameter setting of the TCSC in the power network to minimize the loss of the power system:

$$\min F = \sum_{K=1}^{n} P_{LK} \quad (13)$$

Subject to the following equality constraints:

$$P_{gi} - P_{di} - \sum_{j=1}^{N} V_i V_j Y_{ij} (\vec{x}_{tcsc}) \cos(\delta_{ij} + \gamma_j - \gamma_i) = 0 \quad (14)$$

$$Q_{gi} - Q_{di} - \sum_{j=1}^{N} V_i V_j Y_{ij} (\vec{x}_{tcsc}) \sin(\delta_{ij} + \gamma_j - \gamma_i) = 0 \quad (15)$$

and following inequality constraints:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad \forall i \in NG \quad (16)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \quad \forall i \in NG \quad (17)$$

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad \forall i \in NG \quad (18)$$

$$V_i^{min} \le V_i \le V_i^{max} \quad \forall i \in N \quad (19)$$

$$\delta_{ij}^{min} \le \delta_{ij} \le \delta_{ij}^{max} \quad \forall i \in N \quad (20)$$

$$x_{tcsc}^{min} \le x_{tcsc} \le x_{tcsc}^{max} \quad (21)$$

$$\alpha^{min} \le \alpha \le \alpha^{max} \quad (22)$$

Where:
F is the objective function.
P_{LK} is the active power loss in the K^{th} line.
n is the number of lines in the system.
N is the set of buses indices.
NG is the set of generation bus indices.
Y_{ij} and θ_{ij} are the magnitude and phase angle of element in admittance matrix.
P_{gi} and Q_{gi} are the active and reactive power generation at bus i .
P_{di} and Q_{di} are the active and reactive power load at bus i.
V_i is the voltage magnitude at bus i .
θ_{ij} is the power angle.
x_{tcsc} is the reactance of TCSC as a function of α.
α is the thyristor firing angle.

B. Optimal Location of TCSC Based On Real Power Loss

The static conditions are considered here for the placement of FACTS devices in the power system. The objectives for device placement may be one of the following: 1.Reduction in the real power loss of a particular line. 2.Reduction in the total system real power loss 3.Reduction in the total system reactive power loss. 4.Maximum relief of congestion in the system. For the first objective the line with the maximum power loss may be considered for placement of TCSC. Methods based on the sensitivity approach may be used for the next three objectives. If the objective of FACTS device placement is to provide maximum relief of congestion, the devices may be placed in the most congested lines or, alternatively, in locations determined by trial-and-error.[21]

C. Case Study 1: Raipur substation, India

Power Grid Corporation of India Ltd (PGCIL) installed two Thyristor Controlled Series Capacitors (TCSC) [22]. 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 o f 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.

VI. RELATION BETWEEN TCSC OPTIMIZATION AND DISTANCE

The results before and after installation of FACTs devices (TCSC) in transmission line between Raipur and Rourkela are shown in Fig.4,5,6,7 and Table III.

TABLE III
TCSC location

S.N	TCSC location in km from	P power measured at Raipur (MW)		Q power measured at Raipur (Mvar)	
		Line 1	Line 2	Line 1	Line 2

	Raipur	(P1)	(P2)	(Q1)	(Q2)
1	0km	178.4	119.8	122.3	88.5
2	50km	185.2	118.2	112.4	89.56
3	100km	185.3	118.4	104.8	91.81
4	200km	183.9	119.2	87.92	96.38
5	300km	180.6	120.4	69.67	100.8
6	400km	174.5	122.2	53.06	104.6
7	412km	169.5	123.6	57.06	105

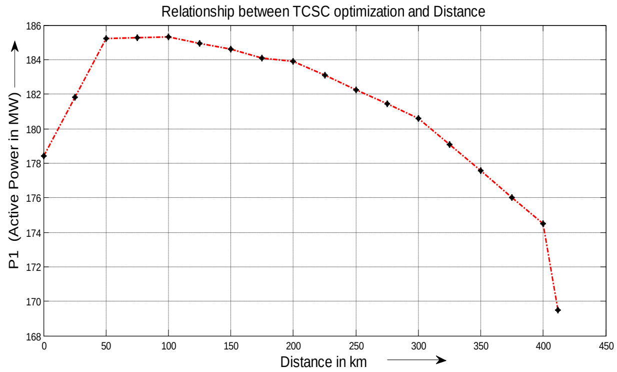

Fig. 4. Active power with TCSC

Fig.4 shows the relationship between active power with TCSC at different location.

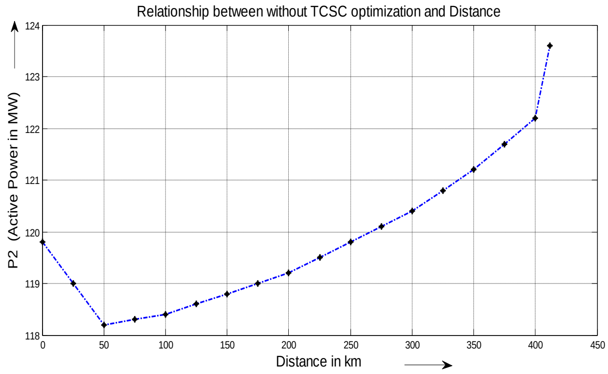

Fig. 5. Active power without TCSC

Fig.5 shows the relationship between active power without TCSC at different location.

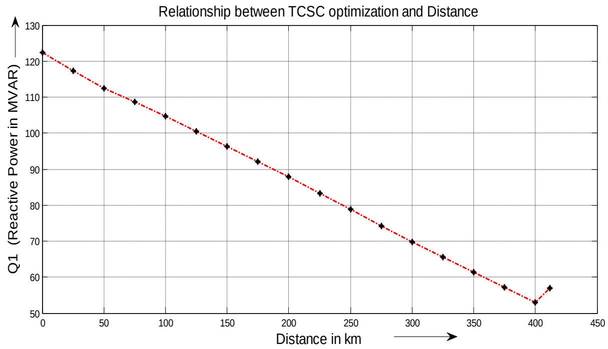

Fig. 6. Reactive power with TCSC

Fig.6 shows the relationship between reactive power with TCSC at different location.

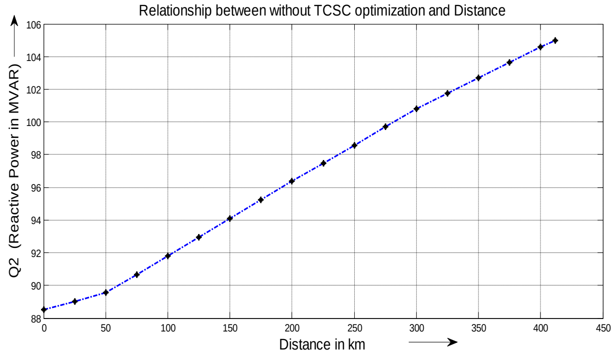

Fig. 7. Reactive power without TCSC

Fig.7 shows the relationship between reactive power without TCSC at different location.

VII. SIMULATION AND RESULTS

A. *TCSC at 0km from Raipur*

Active power transmitted from the transmission line when TCSC is installed at Raipur station is 178.4 MW. i.e 0 km away from the Raipur is shown in Fig.8.

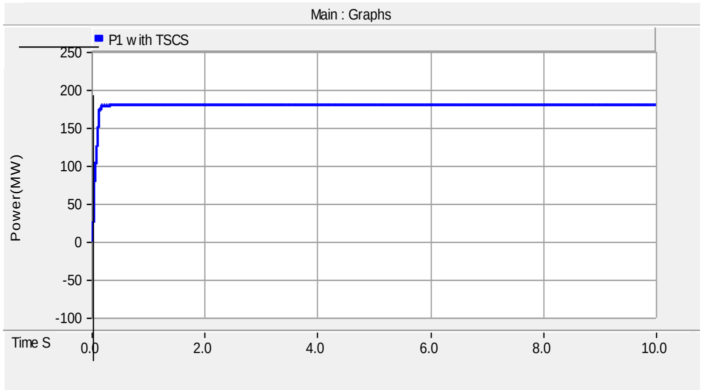

Fig. 8. Active power with TCSC at 0 km

B. *TCSC at 50km from Raipur*

Active power transmitted from the transmission line when TCSC is installed at 50 km away from Raipur station is 185.2 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 3.811% increase in active power flow when TCSC is located at 50 km is shown in Fig.9.

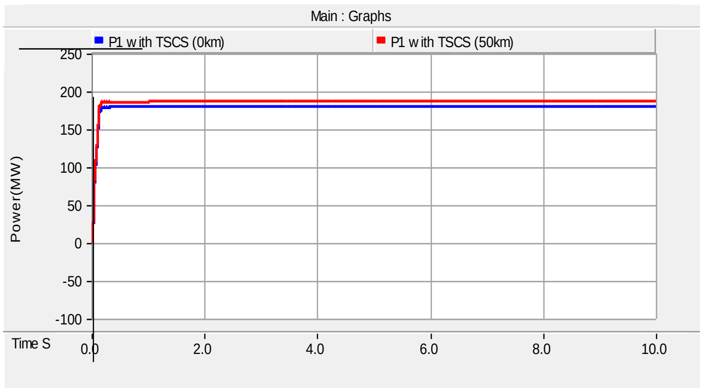

Fig. 9. Active power with TCSC at 0 and 50 km

C. TCSC at 100km from Raipur

Active power transmitted from the transmission line when TCSC is installed at 100 km away from Raipur station is 185.3 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 3.86% increase in active power flow when TCSC is located at 100 km is shown in Fig.10.

D. TCSC at 200km from Raipur

Active power transmitted from the transmission line when TCSC is installed at 200 km away from Raipur station is 183.9 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 3.082% increase in active power flow when TCSC is located at 200 km is shown in Fig.11.

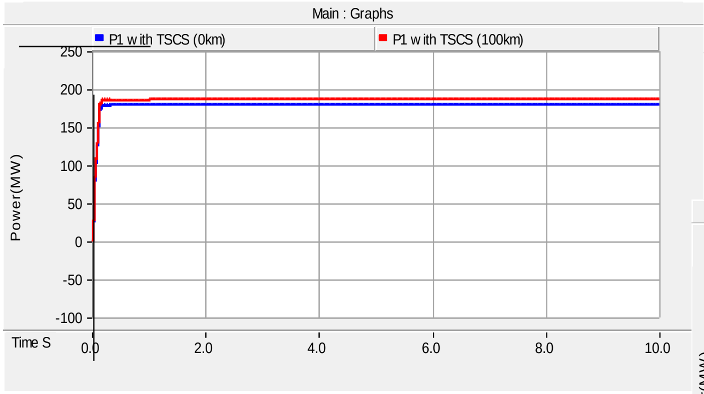

Fig. 10. Active power with TCSC at 0 and 100 km

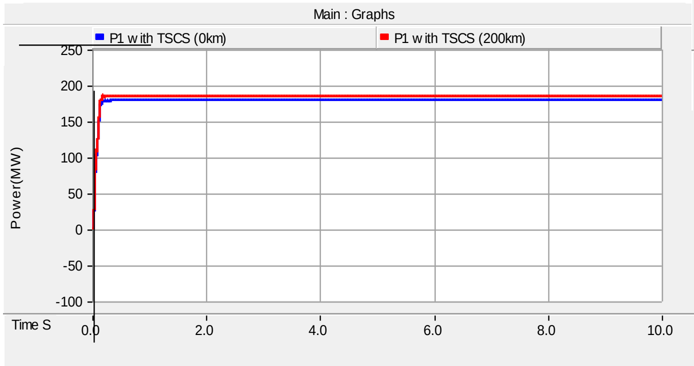

Fig. 11. Active power with TCSC at 0 and 200 km

E. TCSC at 300km from Raipur

Active power transmitted from the transmission line when TCSC is installed at 300 km away from Raipur station is 180.6 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 1.233% increase in active power flow when TCSC is located at 300 km is shown in Fig.12.

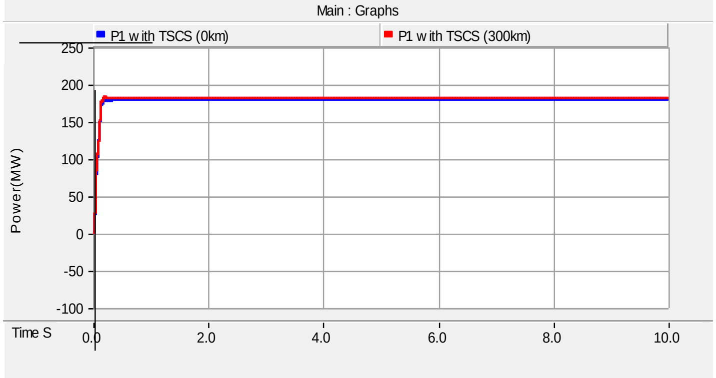

Fig. 12. Active power with TCSC at 0 and 300 km

F. TCSC at 400km from Raipur

Active power transmitted from the transmission line when TCSC is installed at 400 km away from Raipur station is 174.5 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 2.1865% decrease in active power flow when TCSC is located at 400 km is shown in Fig.13.

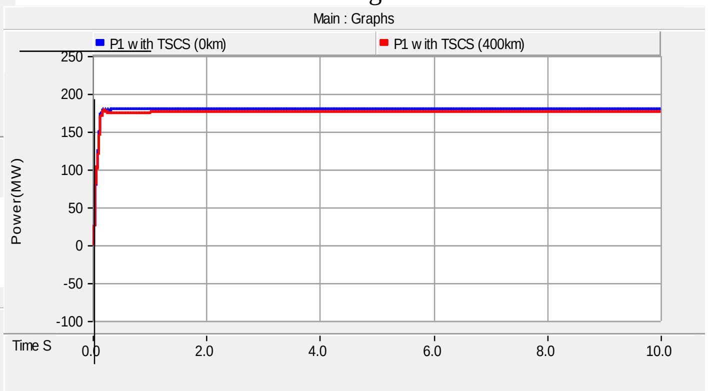

Fig. 13. Active power with TCSC at 0 and 400 km

G. TCSC at 412km from Raipur

Active power transmitted from the transmission line when TCSC is installed at 412 km away from Raipur station is 169.5 MW. Comparing this Active power with the active power flow when TCSC is installed at Raipur station, there is 4.989% decrease in active power flow when TCSC is located at 400 km is shown in Fig.14.

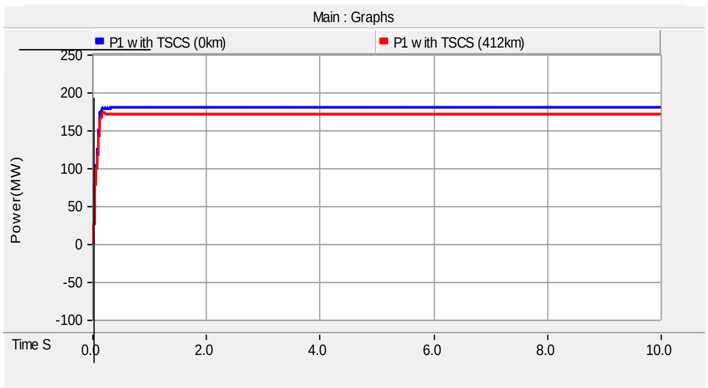

Fig. 14. Active power with TCSC at 0 and 412 km

Analyzing all the waveform showing the response of active power at different location of TCSC, 100 km from the

Raipur Station is the best place to locate the TCSC. This result is shown in different graph. With TCSC at 100 km, the power transfer capability increases with the percentage increase in 3.86%. Best optimization of TCSC is at 100 km away from Raipur. It is clear from above figures that the proposed TCSC controller damp and suppresses the oscillations and provides good damping characteristics by stabilizing system much faster, which in turn enhances system stability.

VIII. CONCLUSION

The capability of the optimal installation of TCSC for minimizing the active power losses in power system has been investigated in this paper. For the problem under consideration PSCAD has been successfully applied. It is possible for utility to place TCSC in the transmission line such that proper power planning can be achieved with minimum system losses. It can easily find out the optimal location and the best parameters of the TCSC, including high-quality solution, stable convergence characteristics, and good computation efficiency. Therefore Optimization shows at 100 km and the power transfer capability increases with 3.86%

The main conclusions of the paper are: i) The time of convergence is less. ii) The placement of Facts devices enhances system and mitigates real power loss. iii) The simple and direct method of placing TCSC in the lines having maximum power loss has shown effective results in loss reduction and enhancing the power transfer capability of the transmission lines. This is performed by proper selection of TCSC elements (capacitance and inductance). Finally, a TCSC is designed, modeled, simulated and analyzed.

This paper deals with the application of PSCAD for the optimal allocation and sizing of a Thyristor Controlled Series Capacitor (TCSC) in a power system. The criterion which is used to find the solutions to optimize the voltage profile of the system and the TCSC size such that voltage deviations at each bus do not exceed a predefined set value.

REFERENCES

[1] M.Geethanjali, S.Devi "Optimal Location and Sizing ofThyristor Controlled Series Capacitor in Radial Distribution Systems Using Particle Swarm Optimization and DifferentialEvolutionTechniques" 2013 International Conference on Power, Energy and Control (ICPEC)

[2] K.S. Verma, S.N. Singh and H. O. Gupta, " FACTS devices location for enhancement of total transfer capability", IEEE Power Engineering Society Winter Meeting, Vol. 2, pp. 522 – 527, 28 Jan.-1 Feb. 2001.

[3] H.N. Ng, M.M.A. Salama, A.Y. Chikhani, Classification of capacitor allocation techniques , IEEE Transactions on Power Delivery 15 (January (1)) (2000)387–392.

[4] Ghamgeen I. Rashed, Yuanzhang Sun, H. I. Shaheen " Optimal Location of Thyristor Controlled Series Compensation in a Power System Based on Differential Evolution Algorithm Considering Transmission Loss Reduction " Proceedings of the 8th World Congress on Intelligent Control and Automation June 21-25 2011

[5] Kimbark, E. W. (1966). "Improvements of system stability by switched series capacitors". IEEE Trans. on PAS,85(2), 180-188.

[6] Kingston, R., Holmberg, N., Kotek, J. & Baghzouz, Y. "Series capacitor placement on transmission lines with slightly distorted currents". IEEE Power Eng. Society, Chicago, USA, 221-226 (1994).

[7] Dolan, P. S., Smith, J. R. & Mittelstand, W. A. "A study of TCSC optimal damping control parameters for different operating conditions". IEEE Tran. on Power System, 10(4), 1972-1978 (1995).

[8] Tenorio, A. R. M. & Daconti, J. R. (1998). "Voltage sag mitigation by means of thyristor controlled series capacitors". IEEE/PEC Athens, Greece Conf., 572-576.

[9] Perkins, B. K. & Iravani, M. R. (1997). "Dynamic modeling of TCSC with application to SSR analysis". IEEE Tran. on Power System, 12(4), 1619-1626.

[10] Escobar, G., Stankovic, A. M., Mattavelli, P. & Ortega, A. (2001). "A comparative study of three nonlinear controllers for TCSC". IEEE Power Tec. Conf., Porto, Portugal, 422-423.

[11] A. Kazemi, S. M. Mousavi Badejani And M. A. S. Masoum "Analysis and control of voltage harmonics generated by thyristor controlled series capacitors" Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 30, No. B2 Printed in The Islamic Republic of Iran, 2006 © Shiraz University

[12] N.Srikanth, Atejasri "Enhancing power system stability by using Thyristor Controlled Series Compensator " International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 5, September- October 2012, pp.1817-1824

[13] C. Gama and R. Tenorio, "Improvements for power system performance: Modeling, analysis and benefits of TCSC's," in Proc. IEEE/Power Eng .Soc . Winter Meeting, Singapore, January 2000.

[14] N. G. Hingorani and L. Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", IEEE Press,

[15] R. M. Mathur and R.K. Varma, "Thyristor based FACTS controllers for Electrical transmission systems", John Wiley & Sons Inc.

[16] Grünbaum R. and Pernot J. "Thyristor-controlled series compensation: a state of the art approach for optimization of transmission over power links" . 1st international forum on innovations in power links, Paris, France 29 March, 2001.

[17] S. Nagalakshmi, N. Kamaraj, "Secured loadabilityenhancement with TCSC in transmission system using computational intelligence techniques for pool and hybrid model", Applied Soft Computing 11(2011) 4748–4756.

[18] IEEE Std. 519, (1999) IEEE Recommended Practices and Requirements for Harmonic Control in Electric power systems, IEEE Press.

[19] H. Besharat, and S.A. Taher, "Congestion management by determining optimal location of TCSC in deregulated power systems", Electrical Power and Energy Systems 50, 563-568, June 2008

[20] Christl, N., Hedin, R., Sadek, K. & Mckenna, S. M. (1992). "Advanced series compensation (ASC) with thyristor controlled impedance". Cigre, Paris, France, 14/37/38-05.

[21] Julluri Namratha Manohar, Amarnath Jinka, Vemuri Poornachandra Rao, "Optimization of Loss Minimization Using FACTS in Deregulated Power Systems Innovative Systems Design and Engineering" ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online) Vol 3, No 3, 2012

[22] www.abb.com, 2010.

Sonora Dixit presently pursuing her M.E in power system engineering from Shri Shankaracharya College of Engineering & Technology.

Rajkumar Jhapte presently working as Sr. Asst. Professor, Department (Electrical) in Shri Shankaracharya College of Engineering & Technology, IEEE Faculty membership. He is M.E in Power System , having 2 years Industrial Experience Commissioning and maintainance of EOT Drives, Electronic And Power control Company Bhilai and 7 years in teaching.