Optimal Placement of TCSC by Sensitivity Methods Using PSAT

Sunil N. Malival[1] K.C. Chande[2] Rahil S. Parikh[3]
[1,2,3]PG Student
[1,2,3]Gujarat Technological University, Ahmedabad, Gujarat, India

Abstract--- The increase in power demand has forced the power system to operate closer to its stability limit. Voltage instability and line overloading have become challenging problems due to the strengthening of power system by various means. The nature of voltage stability can be analyzed by the production, transmission and consumption of reactive power. One of the major causes of voltage instability is the reactive power unbalancing which occurs in stressed condition of power system. And also in deregulated electricity market, it may always not be possible to dispatch all of the contracted power transactions due to congestion of the transmission corridors. The ongoing power system restructuring requires an opening of unused potentials of transmission system due to environmental, right-of-way and cost problems which are major hurdles for power transmission network expansion. So Flexible AC transmission system (FACTS) devices play an important role in improving the performance of a power system by improving the voltage profile and removing the congestion in the transmission lines, but these devices are very costly and hence need to be placed optimally in power system. FACTS device like thyristor controlled series compensator (TCSC) can be employed to reduce the flows in heavily loaded lines, resulting in a low system loss and improved stability of network. In this paper, a method based on real power performance index and reduction of total system VAR power losses has been proposed to decide the optimal location of TCSC. The effectiveness of the proposed method is demonstrated on IEEE 6-bus power system.

I. INTRODUCTION

The increasing industrialization, urbanization of life style has lead to increasing reliance on the electrical energy. This has resulted into rapid growth of power systems. This rapid growth has resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and affect the economy of any country. In contrast to the rapid changes in technologies and the power required by these technologies, transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits due to the fact that the delivery of power have been increasing. If the exchanges were not controlled, some lines located on particular paths may become overloaded, this phenomenon is called congestion.[1] Also the another main cause is voltage collapse which may be due to the inability of the power system to supply the reactive power or an undue absorption of the reactive power by the system itself. Voltage stability concerned with the ability of a power system to maintain tolerable voltages at all buses in the system under normal conditions.[7]

In a competitive electricity market, congestion occurs when the transmission network is unable to accommodate all of the desired transactions due to a violation of system operating limits. Congestion does occur in both electrically bundled and unbundled systems but the management in the bundled system is relatively simple as generation, transmission, and in some cases, distribution systems are managed by one utility. The management of congestion is somewhat more complex in competitive power markets and leads to several disputes. In the present day competitive power market, each utility manages the congestion in the system using its own rules and guidelines utilizing a certain physical or financial mechanism. The limitations of a power transmission network arising from environmental, right-of-way and cost problems are fundamental to both bundled and unbundled power systems. Patterns of generation that result in heavy flows tends to incur greater losses, and to threaten stability and security, ultimately make certain generation patterns economically undesirable. Hence, there is an interest in better utilization of available power system capacities by installing new devices such as Flexible AC Transmission Systems (FACTS). FACTS devices by controlling the power flows in the network without generation rescheduling or topological changes can improve the performance considerably. The insertion of such devices in electrical systems seems to be a promising strategy to decrease the transmission congestion and to increase available transfer capability. Using controllable components such as controllable series capacitors line flows can be changed in such a way that thermal limits are not violated, losses minimized, stability margins increased, contractual requirement fulfilled etc, without violating specific power dispatch. The increased interest in these devices is essentially due to two reasons. Firstly, the recent development in high power electronics has made these devices cost effective and secondly, increased loading of power systems, combined with deregulation of power industry, motivates the use of power flow control as a very cost effective means of dispatching specified power transactions. It is important to ascertain the location for placement of these devices because of their considerable costs. There are several methods for finding optimal locations of FACTS devices in both vertically integrated and unbundled power systems.[2] This paper presents the comparative analysis of methodologies based on real power Performance Index and reduction of total system VAR power losses for proper location of TCSC for congestion management and improving voltage profile in the deregulated electricity markets. The effectiveness of the proposed method is demonstrated on IEEE 6-bus power system.

II. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

The FACTS is a generic term representing the application of power electronics based solutions to AC power system. These systems can provide compensation in series or shunt or a combination of both series and shunt. The FACTS can attempt the compensation by modifying impedance, voltage or phase angle. FACTS devices can be connected to a transmission line in various ways, such as in series with the power system (series compensation), in shunt with the power system (shunt compensation), or both in series and shunt.[1]

A. Series Facts Devices

The series Compensator could be variable impedance, such as capacitor, reactor, etc. or a power electronics based variable source of main frequency to serve the desired need. Various Series connected FACTS devices are;

- Static Synchronous Series Compensator (SSSC)
- Thyristor Controlled Series Capacitor (TCSC)
- Thyristor Switched Series Capacitor (TSSC)
- Thyristor Controlled Series Reactor (TCSR)
- Thyristor Switched Series Reactor (TSSR)

B. Shunt Facts Devices

Shunt Controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt Controllers inject current into the system at the point of connection. Various shunt connected controllers are;

- Static Synchronous Series Compensator (STATCOM)
- Static VAR Compensator (SVC)
- Thyristor Controlled Reactor (TCR)
- Thyristor Switched Capacitor (TCS)

C. Combined Shunt-Series Facts Devices

This may be a combination of separate shunt and series controllers, which are controlled in a coordinated manner or a Unified Power Flow Controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with shunt part of controller and voltage with the series part of controller. Various combined series shunt Controllers are: Various combined series shunt Controllers are;

- Unified Power Flow Controller
- Thyristor Controlled Phase Shifter

III. CHARACTERISTICS OF TCSC

Thyristor Controlled Series Capacitor (TCSC) is a series compensator which increases transmission line capacity by decreasing lines' series impedances and increase network reliability. 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 for example high voltage transformers is required. The bi-directional thyristor valve is fired with an angle α ranging between 90° and 180° with respect to the capacitor voltage. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation. Series compensation will;

- Increase power transmission capability.
- Improve system stability.
- Reduce system losses.
- Improve voltage profile of the lines.
- Optimize power flow between parallel lines.

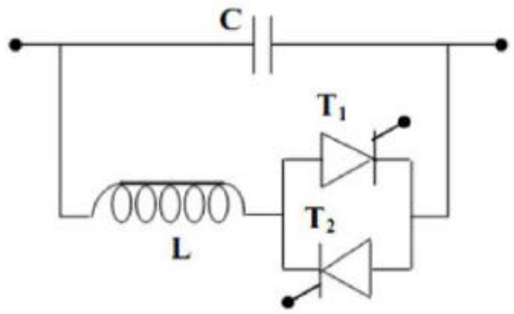

Fig. 1: Schematic diagram of TCSC

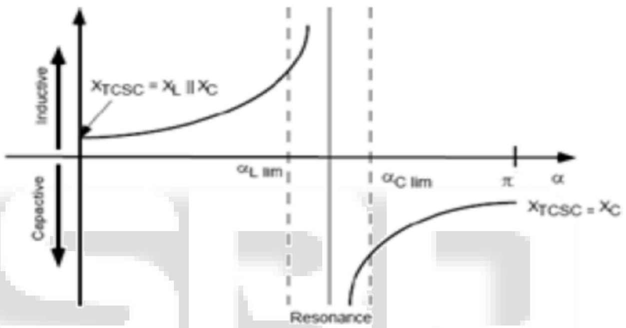

Fig. 2: Variation of impedance in case of TCSC

Fig.2 shows the impedance characteristics curve of a TCSC device. It is drawn between effective reactance of TCSC and firing angle α. The effective reactance of TCSC starts increasing from XL value to till occurrence of parallel resonance condition XL(α)=XC, theoretically XTCSC is infinity. This region is inductive region. Further increasing of XL(α) gives capacitive region, Starts decreasing from infinity point to minimum value of capacitive reactance XC. Thus, impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).[1]

- $90 < \propto < \propto_{Llim}$ ………………..Inductive Region
- $\propto_{Clim} < \propto < 180$………………Capacitive Region
- $\propto_{Llim} < \propto < \propto_{Clim}$………………Resonance Region

While selecting inductance, Xl should be sufficiently smaller than that of the capacitor Xc . Since to get both effective inductive and capacitive reactance across the device. Suppose if Xc is smaller than the Xl ,then only capacitive region is possible in impedance characteristics. In any shunt network, the effective value of reactance follows the lesser reactance present in the branch. So only one capacitive reactance region will appears. Also Xl should not be equal to Xc value; or else a resonance develops that result in infinite impedance an unacceptable condition and transmission line would be an open circuit. The impedance of TCSC circuit is that for a parallel LC circuit and is given by;

The impedance of TCSC circuit is that for a parallel LC circuit and is given by;

$X_{TCSC}(\alpha) = \frac{Xc\ Xl\ (\alpha)}{Xl(\alpha)-Xc}$……………………(1)

Where $X(\alpha) = Xl.\frac{\pi}{\pi-2\alpha-sin\alpha}$…………(2)

α=firing angle

Xl=Inductive reactance

Xl(α)=Effective reactance of the inductor at firing angle α

& is limited thus;

$Xl \leq Xl(\alpha) \leq \infty$………………………(3)

IV. METHODS FOR OPTIMAL LOCATION OF TCSC

A. Reduction of total system reactive power loss (aij):[2]

A method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. The reactive power loss sensitivity factors with respect to these control variables may be given as follows:

1. Loss sensitivity with respect to control parameter Xij of TCSC placed between buses i and j,

$a_{ij}=\frac{\partial Q_L}{\partial X_{ij}}$……………………………………….. (1)

These factors can be computed for a base case power flow solution.

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

B. Real power flow performance index sensitivity indices:[2]

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index, as given below.

$PI=\sum_{m=1}^{NL}\frac{Wm}{2n}\left(\frac{PLm}{PLm^{max}}^{2n}\right)$ ……………….................(1)

where PLm is the real power flow and max PLm is the rated capacity of line-m, n is the exponent and m w a real non-negative weighting coefficient which may be used to reflect the importance of lines. PI will be small when all the lines are within their limits and reach a high value when there are overloads. Thus, it provides a good measure of severity of the line overloads for given state of the power system. Most of the works on contingency selection algorithms utilize the second order performance indices which, in general, suffer from masking effects. The lack of discrimination, in which the performance index for a case with many small violations may be comparable in value to the index for a case with one huge violation, is known as masking effect. By most of the operational standards, the system with one huge violation is much more severe than that with many small violations. Masking effect to some extent can be avoided using higher order performance indices, that is n > 1. However, in this study, the value of exponent has been taken as 2 and Wi =1.

The real power flow PI sensitivity factors with respect to the parameters of TCSC can be defined as

$b_k = \frac{\partial PI}{\partial x_{ck}}\Big|x_{ck} = 0$………………………………(2)

The sensitivity of PI with respect to TCSC parameter connected between bus-i and bus-j can be written as

$\frac{\partial PI}{\partial x_{ck}} = \sum W_m * P_{LM}{}^3\left(\frac{1}{PLm^{max}}\right)^4\frac{\partial P_{LM}}{\partial x_{ck}}$……………..(3)

The real power flow in a line-m can be represented in terms of real power injections using DC power flow equations where s is slack bus, as

$$P_{LM} = \begin{cases}\sum_{\substack{n=1\\n\neq s}}^{N} S_{mn}P_n & for\ m \neq k\\ \sum_{\substack{n=1\\n\neq s}}^{N} S_{mn}P_n + P_j & for\ m = k\end{cases}$$ …………..(4)

Using equation (4), the following relationship can be derived,

$$\frac{\partial P_{LM}}{\partial x_{ck}} = \begin{cases} S_{mi}\frac{\partial Pi}{\partial x_{ck}} + S_{mj}\frac{\partial Pj}{\partial x_{ck}} for\ m \neq k\\ S_{mi}\frac{\partial Pi}{\partial x_{ck}} + S_{mj}\frac{\partial Pj}{\partial x_{ck}} + \frac{\partial Pj}{\partial x_{ck}} for\ m = k\end{cases}$$ …..(5)

The terms $\frac{\partial P_i}{\partial x_{ck}}\Big|x_{ck=0} = \frac{\partial P_{ic}}{\partial x_{ck}}\Big|x_{ck} = 0$ can be derived as below

$=-2\left(V_i^2 - V_iV_j\cos\delta_{ij}\right).\frac{R_{ij}X_{ij}}{[R_{ij}^2+X_{ij}^2]^2} +$

$V_j\sin\delta_{ij}\frac{R_{ij}^2-X_{ij}^2}{[R_{ij}^2+X_{ij}^2]^2}$.(6)

V. OPTIMAL PLACEMENT CONDITIONS

The TCSC device should be placed on the most sensitive line. With the sensitivity indices computed for TCSC, following criteria can be used for its optimal location.

1. In reactive power loss reduction method TCSC should be placed in a line having the most positive loss sensitivity index.
2. In real power flow performance index sensitivity indices method TCSC should be placed in a line having most negative sensitivity index.

VI. TEST SYSTEM

For the validation of the proposed FACTS's devices, TCSC have been tested on the IEEE 6 Bus test System. An IEEE 6 bus test system and this test system including 6 buses,2 generators,11 lines, and 3 loads is simulated using PSAT is presented. The generators are modelled as standard PV buses with both P and Q limits; loads are represented as constant PQ loads.

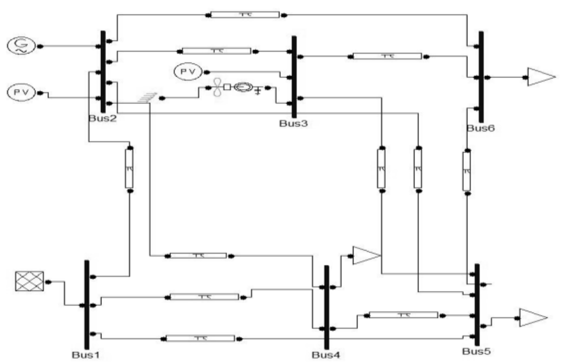

Fig. 3: IEEE 6 bus test system

VII. SIMULATION RESULTS

From table 1 the calculation of reactive power loss (aij) and real power flow performance index (bij) is calculated using eqs of aij and bij which is shown above.now according to conditions for optimal location of TCSC in which reduction of reactive power loss method higest aij is selected.so line no.7 is having higest index hence the TCSC is placed in Line no.7 which is between bus 2-6.now according to another method which is real power flow performance index the most negative value of bij is chosen for optimal placement of TCSC.so from table 1.line 10 and line 11 having most negative indices so TCSC is also placed in line 10 and line 11.and results of voltage profile,Active power flow and reactive power loss are compared after placing TCSC in line 7,line 10,line 11.

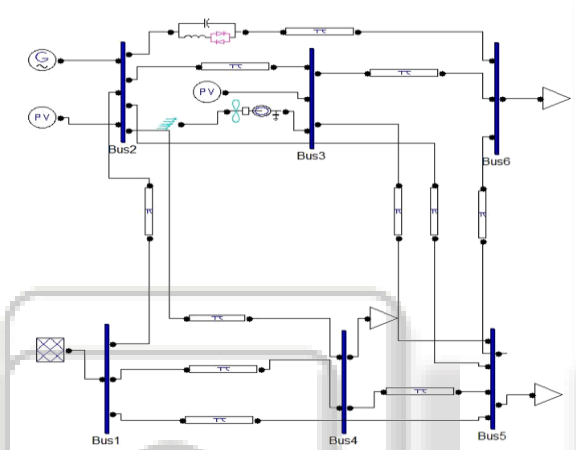

Fig. 4: IEEE 6 bus test system with TCSC

line no	From bus	To bus	aij	bij
1	1	2	3.5272	0.4408
2	1	4	3.5680	3.3440
3	1	5	3.8074	1.1302
4	2	3	3.7472	0.2101
5	2	4	3.0406	11.4048
6	2	5	3.6744	0.8443
7	2	6	**4.3211**	1.5621
8	3	5	3.4351	1.1089
9	3	6	4.1251	5.2063
10	4	5	2.7976	**-0.2424**
11	5	6	3.5011	**-0.1716**

Table 1:- Calculated Sensitivity Indices

The voltage profile for IEEE 6 bus system with and without TCSC is shown in fig 5.and considerable improvement in voltage stability is maintain.

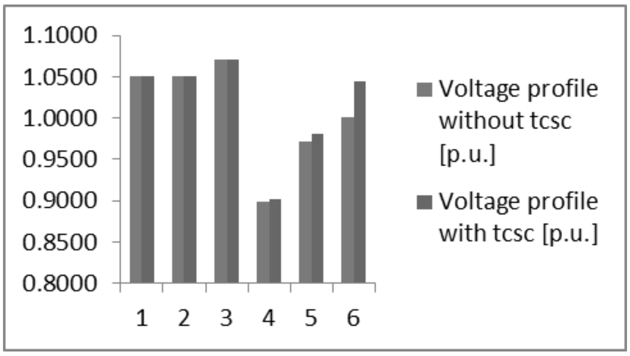

Fig. 5: Voltage Profile Comparisons

Fig shows the comparisons of Active power flow without and with TCSC at line 7,10,11.fron table 2 the active power flow in line 7 is improved as compared without and TCSC placed in line 10 and line 11.so hence line 7 is effective location of TCSC for relieving congestion.

Line	From Bus	To Bus	Active Power Flow without TCSC	Active Power Flow with TCSC at line 7	Active Power Flow with TCSC at line 10	Active Power Flow with TCSC at line 11
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
1	1	2	0.0758	-0.0732	0.0736	0.0818
2	1	4	0.4318	0.2527	0.4325	0.4287
3	1	5	-0.0901	-0.1103	-0.0914	-0.1124
4	2	3	0.2433	0.2737	0.2405	0.2524
5	2	4	-0.0251	-0.1275	-0.0267	-0.0268
6	2	5	0.0303	0.0271	0.0300	0.0264
7	2	6	0.1517	0.1951	0.1518	0.1665
8	3	5	0.6197	0.6005	0.6177	0.5912
9	3	6	0.3315	0.2880	0.3326	0.3420
10	4	5	0.3126	0.0430	0.3161	0.3196
11	5	6	0.2304	0.1555	0.2294	0.2356
total active power flow			2.3119	**1.5245**	2.3063	2.3049

Table 2: Active power flow with and without TCSC

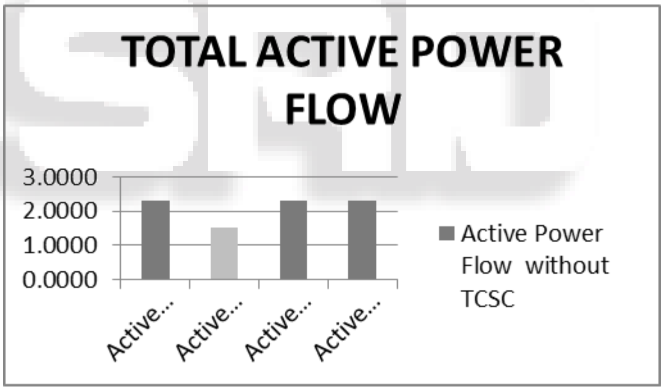

Fig. 6: Active power flow Comparisons

Line	From Bus	To Bus	Reactive power loss without tcsc	Reactive power loss with tcsc at line 7	Reactive power loss with tcsc at line 10	Reactive power loss with tcsc at line 11
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
1	1	2	-0.06394	-0.06513	-0.06403	-0.06367
2	1	4	0.031865	-0.01221	0.04424	0.03559
3	1	5	-0.05926	-0.05776	-0.0588	0.009182
4	2	3	-0.01874	-0.02213	-0.02268	-0.0079
5	2	4	-0.05557	-0.04813	0.002896	-0.05155
6	2	5	0.005256	0.004739	0.005095	0.003454
7	2	6	-0.03897	-0.03565	-0.03896	-0.03793
8	3	5	0.110633	0.102972	0.107156	0.073034
9	3	6	-0.0206	-0.03112	-0.02312	-0.01126
10	4	5	-0.03072	0.000486	-0.02685	-0.02896
11	5	6	-0.01515	-0.02471	-0.01789	-0.00717
Total Reactive Power Loss			-0.15519	**-0.18865**	-0.09295	-0.08718

Table 3: Reactive power flow with and without TCSC

Table 3 shows the comparisons of Reactive power loss without and with TCSC at line 7,10,11.from table 3 the Reactive power loss in line 7 is reduced as compared without and TCSC placed in line 10 and line 11.so hence line 7 is effective location of TCSC for improving voltage stability.

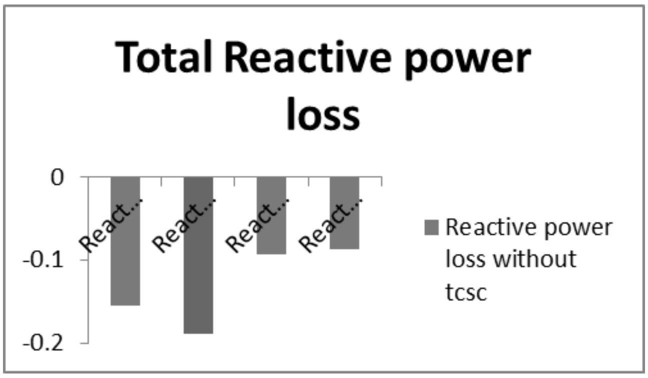

Fig. 7: Reactive power loss Comparisons

VIII. CONCLUSION

In this paper, reduction of reactive power loss and real power flow performance index or sensitivity-based method has been developed for determining the optimal location of TCSC in an electricity market. The developed method is implemented on IEEE 6 bus system and the results reveal that the proposed method is simple, reliable and efficient for the practical implementation.

REFERENCES

[1] Madhura Gad, Prachi Shinde, Prof.S.U.Kulkarni,"Optimal Location of TCSC by Sensitivity Methods," International Journal of Computational Engineering Research, Vol.2, Oct.2012.

[2]Seyed Abbas Taher, Hadi Besharat "Transmission Congestion Management by Determining Optimal Location of FACTS Devices in Deregulated Power systems," American Journal of Applied Sciences, 5 (3):242-247, ISSN 1546-9239, 2008.

[3]Md. Nasimul Islam Maruf et. al. "Study of Thyristor Controlled Series Capacitor (TCSC) as a Useful FACTS Device" International Journal of Engineering Science and Technology" Vol. 2(9), 2010, 4357-4360

[4]B.Likhitha, J.Srinivasa Rao, J.Amarnath, "Sensitivity Approach for the Effective location of TCSC in a Deregulated Electricity Market", IOSR Journal of Engineering (IOSRJEN) ISSN: 2250-3021 Volume 2, Issue 6 (June 2012), PP 09-15

[5]Abouzar samimi, Peyman Naderi "A New Method for Optimal Placement of TCSC based on Sensitivity Analysis for Congestion management," Smart Grid and Renewable Energy, 2012, 3, 10-16.

[6]N.Sambasivarao, "A Novel Method for Mitigation of Active, Reactive Power Loss and Overloading in A Restructured Power system Using TCSC", International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 10, October – 2013,ISSN: 2278-0181

[7]Renu Yadav, Sarika Varshney & Laxmi Srivastava, "Enhancement of Voltage Stability Through Optimal Placement of TCSC",International Journal of Power System Operation and Energy Management, ISSN (*PRINT*): 2231–4407, Volume-1, Issue-2, 2011

[8]N.G. Hingaroni and L. Gyugyi. "Understanding FACTS concepts and technology of flexible ac transmission systems. IEEE Press, New York, 2000.

