# Optimal Location of TCSC by Sensitivity Methods

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**Abstract -** Due to the deregulation of the electrical market, difficulty in acquiring rights-of-way to build new transmission lines, and steady increase in power demand, maintaining power system stability becomes a difficult and very challenging problem. In a competitive power market, the system is said to be congested when the volume of transactions exceeds the transfer capability of the transmission corridor.

In deregulated electricity market transmission congestion occurs when there is insufficient transmission capacity to simultaneously accommodate all constraints for transmission of a line. FACTS devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flow in the network.

A method to determine the optimal location of TCSC has been suggested in this paper. The approach is based on the sensitivity of the reduction of total system reactive power loss and real power performance index.

The proposed method has been demonstrated on 5-bus power systems.

**Keywords:** Congestion, Compensation, Deregulated Power System, Flexible AC Transmission Systems (FACTS), Optimal location, Performance Index, Thyristor Controlled Series Capacitor (TCSC), Static Modelling.

## I. Introduction

The increasing industrialization, urbanization of life style has lead to increasing dependency 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. The major problems faced by power industries in establishing the match between supply and demand are:

- Transmission & Distribution; supply the electric demand without exceeding the thermal limit.
- In large power system, stability problems causing power disruptions and blackouts leading to huge losses.

These constraints affect the quality of power delivered. However, these constraints can be suppressed by enhancing the power system control. Congestion may be alleviated through various ways. Among the technical solutions, we have system redispatch, system reconfiguration, outaging of congested lines, operation of FACTS devices and operation of transformer tap changers [10][17].

The issue of transmission congestion is more pronounced in deregulated and competitive markets and it needs a special treatment. In this environment, independent system operator (ISO) has to relieve the congestion, so that the system is maintained in secure state. To relieve the congestion ISO can use followings techniques [16],

- Out-ageing of congested lines
- Operation of transformer taps/phase shifters [9]
- Operation of FACTS devices particularly series devices
- Re-dispatching the generation amounts. By using this method, some generators back down while others increase their output. The effect of re-dispatching is that generators no longer operate at equal incremental costs.
- Curtailment of loads and the exercise of load interruption options [13]

FACTS devices are utilized as one of such technology which can reduce the transmission congestion and leads to better using of the existing grid infrastructure. Besides, using FACTS devices gives more opportunity to ISO [16].

Thyristor Controlled Series Capacitor (TCSC) is a variable impedance type FACTS device and is connected in series with the transmission line to increase the power transfer capability, improve transient stability, and reduce transmission losses[6].

This paper deals with the location aspect of the series FACTS devices, especially to manage congestion in the deregulated electricity markets. The location of FACTS devices can be based on static or dynamic performance of the system. Sensitivity factor methods are used to determine the suitable location for FACTS devices [1][2][3].

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 for congestion management in the deregulated electricity markets.

## 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.

2.1 SERIES FACTS : 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[17];

- 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)

2.2 SHUNT FACTS : 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)

2.3 COMBINED SHUNT – Series Controller: 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. Chracteristics & Static Modeling Of TCSC

3.1 CHARACTERISITCS: 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.

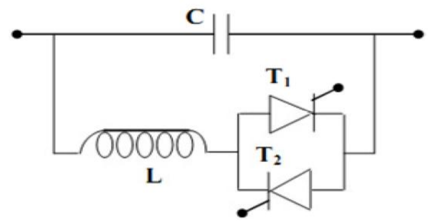


Fig 1 : Schematic diagram of TCSC

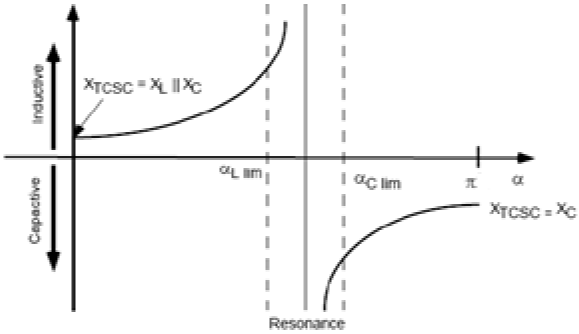


Fig 2 : Variation of impedance in case of TCSC

Fig.2 shows the impedance characteristics curve of a TCSC device [2][17]. It is drawn between effective reactance of TCSC and firing angle α. The effective reactance of TCSC starts increasing from $X_L$ value to till occurrence of parallel resonance condition $X_L(\alpha)=X_C$, theoretically $X_{TCSC}$ is infinity. This region is inductive region. Further increasing of $X_L(\alpha)$ gives capacitive region, Starts decreasing from infinity point to minimum value of capacitive reactance $X_C$. Thus, impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).

- $90 < \alpha < \alpha_{Llim}$ Inductive region
- $\alpha_{Clim} < \alpha < 180$ Capacitive region

- $\alpha_{Llim} < \alpha < \alpha_{Clim}$ Resonance region

While selecting inductance, $X_L$ 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 $X_L$ , 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 $X_L$ 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;

$$X_{TCSC}(\alpha) = \frac{X_c X_l(\alpha)}{Xl(\alpha) - Xc} \qquad (1)$$

Where

$$X_l(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - Sin\alpha} \qquad (2)$$

$\alpha$ is the firing angle ,

$X_L$ is the reactance of the inductor and $Xl(\alpha)$ is the effective reactance of the inductor at firing angle $\alpha$ and is limited thus:

$$X_L \le X_l(\alpha) \le \infty$$

3.2 STATIC MODLING : The Fig 3 shows a simple transmission line represented by its lumped pi equivalent parameters connected between bus-i and bus-j. Let complex voltage at bus-i and bus-j are $Vi < \delta i$ and $Vj < \delta j$ respectively. The real and reactive power flow from bus-i to bus-j can be written as [1],

$$P_{ij} = V_1^2 G_{ij} - V_i V_j \left[G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})\right] \qquad (3)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j \left[G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})\right] \qquad (4)$$

Where $\delta ij = \delta i - \delta j$ , similarly the real and reactive power flow from bus-j to bus-i is;

$$P_{ji} = V_j^2 G_{ij} - V_i V_j \left[G_{ij}\cos(\delta_{ij}) - B_{ij}\sin(\delta_{ij})\right] \qquad (5)$$

$$Qj_{ji} = -V_j^2 (B_{ij} + B_{sh}) + V_i V_j \left[G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})\right] \qquad (6)$$

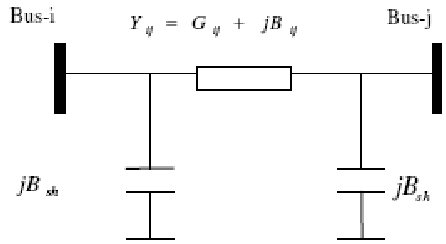


Fig 3 : Model of Transmission line

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Fig.4. During the steady state the TCSC can be considered as a static reactance -jXc . The real and reactive power flow from bus-i to bus-j, and from bus-j to bus-i of a line having series impedance and a series reactance are,

$$P_{ij}^C = V_i^2 G'_{ij} - V_i V_j \left(G'_{ij}\cos\delta_{ij} + B'_{ij}\sin\delta_{ij}\right) \qquad (7)$$

$$Q_{ij}^C = -V_i^2 \left(B'_{ij} + B_{sh}\right) - V_i V_j \left(G'_{ij}\sin\delta_{ij} - B'_{ij}\cos\delta_{ij}\right) \qquad (8)$$

$$P_{ji}^C = V_j^2 G'_{ij} - V_i V_j \left(G'_{ij}\cos\delta_{ij} - B'_{ij}\sin\delta_{ij}\right) \qquad (9)$$

$$Q_{ji}^C = -V_j^2 \left(B'_{ij} + B_{sh}\right) + V_i V_j \left(G'_{ij}\sin\delta_{ij} + B'_{ij}\cos\delta_{ij}\right) \qquad (10)$$

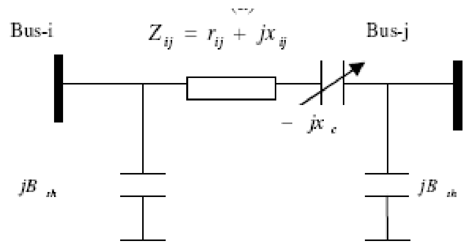


Fig 4 : Model of Transmission line with TCSC

The active and reactive power loss in the line having TCSC can be written as,

$$P_L = P^c{}_{ij} + P^c{}_{ji} = G'_{ij}(V_i^2 + V_j^2) - 2V_iV_jG'_{ij}\cos\delta_{ij} \qquad (11)$$

$$Q_L = Q^c{}_{ij} + Q^c{}_{ji} = -(V_i^2 + V_j^2)(B'_{ij} + B_{sh}) + 2V_iV_jB'_{ij}\cos\delta_{ij} \qquad (12)$$

Where,

$$G'_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_C)^2} \quad B'_{ij} = \frac{-(x_{ij} - x_C)}{r_{ij}^2 + (x_{ij} - x_C)^2} \qquad (13)$$

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in Fig.5.

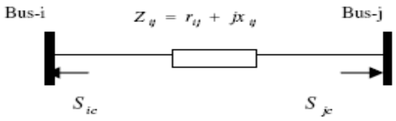


Fig 5 : Injection Model of TCSC

The real and reactive power injections at bus-i and bus-j can be expressed as,

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j \left[\Delta G_{ij} \cos\delta_{ij} + \Delta B_{ij} \sin\delta_{ij}\right] \qquad (14)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j \left[\Delta G_{ij} \cos\delta_{ij} - \Delta B_{ij} \sin\delta_{ij}\right] \qquad (15)$$

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j \left[\Delta G_{ij} \sin\delta_{ij} - \Delta B_{ij} \cos\delta_{ij}\right] \qquad (16)$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin\delta_{ij} + \Delta B_{ij} \cos\delta_{ij}] \qquad (17)$$

Where,

$$\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)} \qquad (18)$$

$$\Delta B_{ij} = \frac{-x_c(r_{ij}^2 - x_{ij}^2 + x_c x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)} \qquad (19)$$

This Model of TCSC is used to properly modify the parameters of transmission line with TCSC for optimal location.

## IV. Optimal Location of TCSC

4.1 REDUCTION OF TOTAL SYSTEM REACTIVE POWER LOSS: [1][2][3] A method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. For TCSC placed between buses i and j we consider net line series reactance as a control parameter. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as,

$$aij = \frac{\partial Q_L}{\partial x_{ij}}$$

$$= \left[V^2{}_i + V^2{}_j - 2V_i V_j \cos\delta_{ij}\right] \frac{r^2{}_{ij} - x^2{}_{ij}}{(r^2{}_{ij} + x^2{}_{ij})^2} \qquad (20)$$

4.2 REAL POWER FLOW PERFORMANCE INDEX SENSITIVITY INDICES: 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 [4],

$$PI = \sum_{m=1}^{NL} \frac{w_m}{2n} \left(\frac{P_{Lm}}{P_{Lm}^{max}}\right)^{2n} \qquad (21)$$

Where PLm is the real power flow and max $P_{Lm}^{max}$ is the rated capacity of line-m, n is the exponent, NL is number of lines and Wm 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,

$$b_k = \left.\frac{\partial PI}{\partial x_{ck}}\right|_{xck=0} \qquad (22)$$

Where□X*ck* is the value of the reactance, as provided by the TCSC installed on line k.

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

$$\frac{\partial PI}{\partial x_{ck}} = \sum_{m=1}^{NL} w_m P_{lm}^3 \left(\frac{1}{P_{lm}^{max}}\right)^4 \frac{\partial Plm}{\partial x_{ck}} \qquad (23)$$

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,

$$P_{Lm} = \begin{cases} \sum_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n & for \quad m \neq k \\ \sum_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n + P_j & for \quad m = k \end{cases} \qquad (24)$$

Using equation-24, the following relationship can be derived,

$$\frac{\partial P_{Lm}}{\partial x_{ck}} = \begin{cases} \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}}\right) & for \quad m \neq k \\ \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}}\right) + \frac{\partial P_j}{\partial x_{ck}} & for \quad m = k \end{cases} \qquad (25)$$

The term,

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0} , \quad \left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0} \tag{26}$$

can be derived as,

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0} = \left.\frac{\partial P_{ic}}{\partial x_{ck}}\right|_{x_{ck}=0} \tag{27}$$

$$= -2(V_i^2 - V_i V_j \cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2 + x_{ij}^2)^2} - V_i V_j \sin\delta_{ij}\frac{(x_{ij}^2 - r_{ij}^2)}{(r_{ij}^2 + x_{ij}^2)^2}$$

$$\left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0} = \left.\frac{\partial P_{jc}}{\partial x_{ck}}\right|_{x_{ck}=0} \tag{28}$$

$$= -2(V_j^2 - V_i V_j \cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2 + x_{ij}^2)^2} + V_i V_j \sin\delta_{ij}\frac{(x_{ij}^2 - r_{ij}^2)}{(r_{ij}^2 + x_{ij}^2)^2}$$

4.3 CRITERIA FOR OPTIMAL LOCATION:

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 placement [1][2][3].

- In reactive power loss reduction method TCSC should be placed in a line having the most positive loss sensitivity index.
- In PI method TCSC should be placed in a line having most negative sensitivity index.

## V. SIMULATION & RESULTS

In order to find the optimal locations of TCSC, we have to implement analysis over 5-bus system as shown in below fig. MATLAB software has been used for simulation.

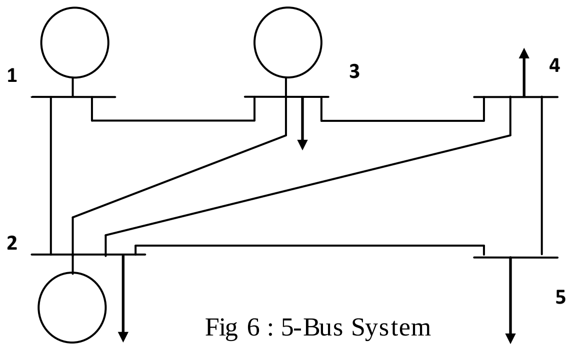


Fig 6 : 5-Bus System

Power flow of above 5-bus system & line limit is shown in table-1. From the load flow, it was found that real power flow in line-1 is 0.93pu & line-6 is 0.586, which is very near to its line loading limit & may create congestion.

***Table-1** : Power flow of 5-Bus System & its limit*

| Line | From-To | Real Power | Real Power flow Limit |
|---|---|---|---|
| 1 | 1 2 | 0.93 | 1 |
| 2 | 1 3 | 0.525 | 0.8 |
| 3 | 2 3 | -0.019 | 0.7 |
| 4 | 2 4 | 0.081 | 0.8 |
| 5 | 2 5 | 0.452 | 0.6 |
| 6 | 3 4 | 0.586 | 0.6 |
| 7 | 4 5 | 0.162 | 0.6 |

***Table-2 :** Calculated Sensitivity Indices*

| Line | aij | bij |
|---|---|---|
| 1 | 0.0326 | 2.0957 |
| 2 | **0.1048** | 0.3189 |
| 3 | 0.0036 | **0.0010** |
| 4 | 0.0041 | **0.0141** |
| 5 | 0.0009 | 1.4953 |
| 6 | 0.0006 | 5.7528 |
| 7 | 0.0011 | **-0.0195** |

The sensitive of reactive power loss reduction and real power flow performance index with respect to TCSC control parameter has been computed and are shown in table 2. The sensitive lines are highlighted in table-2. It can be observed from table-2 that line 2 is more sensitive as per Reduction of total system reactive power loss method. Line 7 is more sensitive as per real power flow performance index method but line 3 & 4 can also be considered because these line also seems to be sensitive. System power flow result after placing TCSC in 2,3,4 & 7 is shown in table-4. The value of control parameter of TCSC for computing power flow are taken as per table-3.

***Table-3 :** Control Parameter (Xtcsc)*

| Line | Compensation | TCSC |
|---|---|---|
| 2 | 0.70 | 0.0588 |
| 7 | 0.70 | 0.168 |
| 3 | 0.70 | 0.126 |
| 4 | 0.70 | 0.126 |

***Table-4 :*** *Power Flow after placing TCSC*

| Line | Power flow without TCSC | Power flow with TCSC in line 2 | Power flow with TCSC in line 7 | Power flow with TCSC in line 3 | Power flow with TCSC in line 4 |
|---|---|---|---|---|---|
| 1 | 0.93 | **0.861** | **0.918** | 0.954 | 0.980 |
| 2 | 0.525 | 0.722 | 0.539 | 0.500 | 0.473 |
| 3 | -0.019 | -0.032 | 0.023 | 0.005 | -0.046 |
| 4 | 0.081 | 0.056 | 0.130 | 0.081 | 0.177 |
| 5 | 0.452 | 0.441 | **0.350** | 0.451 | 0.431 |
| 6 | 0.586 | **0.516** | 0.640 | 0.586 | 0.511 |
| 7 | 0.162 | 0.174 | 0.264 | 0.163 | 0.183 |

***Table-5 :*** *Reactive power Loss*

| Line | Reactive power loss w/o TCSC | Reactive power loss with TCSC in line 2 | Reactive power loss with TCSC in line 7 | Reactive power loss with TCSC in line 3 | Reactive power loss with TCSC in line 4 |
|---|---|---|---|---|---|
| 1 | 0.047 | 0.041 | 0.046 | 0.050 | 0.052 |
| 2 | 0.021 | 0.012 | 0.023 | 0.019 | 0.017 |
| 3 | 0.002 | 0.004 | 0.000 | 0.000 | 0.001 |
| 4 | 0.004 | 0.004 | 0.004 | 0.002 | 0.002 |
| 5 | 0.035 | 0.035 | 0.023 | 0.034 | 0.032 |
| 6 | 0.011 | 0.008 | 0.014 | 0.012 | 0.009 |
| 7 | 0.007 | 0.008 | 0.006 | 0.008 | 0.010 |
| **Tota** | **0.127** | **0.112** | ***0.116*** | **0.125** | **0.122** |

It can be observed from table-4 that congestion has been relieved in line 1 & 6 after placing TCSC in line 2 and also reduced system reactive power loss.

There is not much improvement in congestion & PI after placing TCSC in 3 & 4 but as seen in table-2 that line 7 is more sensitive & hence placing TCSC in line 7 is optimal for reducing PI & congestion relief.

### 5.1 Total Costs of Two Methods:

Due to high cost of FACTS devices, it is necessary to use cost benefit analysis to analyze whether new FACTS device is cost effective among several candidate locations where they actually installed. The TCSC cost in line-k is given by [2][3],

$$C_{TCSC}(k) = c.x_c(k).P_L^{\,2}.Base\_Power$$

Where, PL is power flow in line K (MVA) & c is unit investment cost of TCSC. Here it is considered 22000 \$/MVA-year[5]. Xc is TCSC reactance in pu.

The objective function for placement of TCSC will be[3],

$$\min_{Pi} \sum_i C_i(P_i) + C_{TCSC}$$

The bid prices of generators for 5 bus system are given in table-6, where P is in MW and \$ is a momentary unit which may be scaled by any arbitrary constant without affecting the results and Pimin , Pimax are generation power limits of each generator.

***Table-6*** *: Bid Prices of Generators [1]*

| Generator | Bid prices (\$/h) | $P_{imin}$ | $P_{imax}$ |
|---|---|---|---|
| 1 | $0.11P_1^2 + 5P_1 + 150$ | 0 | 1000 |
| 2 | $0.085P_2^2 + 1.2P_2 + 60$ | 10 | 200 |
| 3 | $0.1225P_3^2 + P_3 + 335$ | 10 | 200 |

Total cost of two methods is shown below chart. It can be observed that placement of TCSC in line -7 is more economical than the placement of TCSC in line-2 for congestion management. From this we can say that PI method is more economical than reduction of total system reactive power loss method for installing the TCSC and congestion relief.

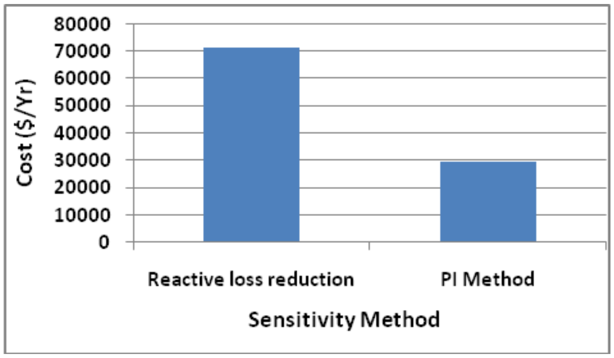


Fig 7 : Cost comparison

## VI. Conclusion

Congestion management is an important issue in deregulated power systems. FACTS devices such as TCSC by controlling the power flows in the network can help to reduce the flows in heavily loaded lines. Because of the considerable costs of FACTS devices, it is important to obtain optimal location for placement of these devices.

Here two sensitivity-based methods have been developed for determining the optimal location of TCSC in an electricity market. In a system, first two optimal locations of TCSC can be achieved based on the sensitivity factors aij and bij and then optimal location is selected based on minimizing production cost plus device cost. Test results obtained for 5-bus power systems show that sensitivity factors could be effectively used for determining optimal location of TCSC. The cost values for two sensitivity methods were compared. Test results divulge that the proposed methodology is effective in managing congestion & optimal location of TCSC.

**SCOPE & FUTURE WORK:**

The completion of project opens the avenues for work in many other related areas. The one of the area is effect of TCSC on line outage in order to relieve congestion can be studied.

## References


[1] 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, 2008 ,

[2] Anwar S. Siddiqui, Rashmi Jain, Majid Jamil and Gupta C. P. "Congestion management in high voltage transmission line using thyrister controlled series capacitors" Journal of Electrical and Electronics Engineering Research Vol. 3(8), pp.151-161,October2011,Available online at http://www.academicjournals.org/JEEER , ISSN – 2141 – 2367 ©2011 Academic Journals

[3] L.Rajalakshmi, M.V.Suganyadevi, S.Parameswari "Congestion Management in Deregulated Power System by Locating Series FACTS Devices" International Journal of Computer Applications (0975 – 8887) Volume 13– No.8, January 2011

[4] Mrinal Ranjan, B. Vedik, "Optimal Location of FACTS Devices in a Power System by Means of Sensitivity Analysis" Science Road Publishing Corporation,
Trends in Electrical and Computer Engineering
TECE 1(1) 1-9, 2011

[5] Nazanin Hosseinipoor, Syed M.H Nabavi, "Optimal Locating and Sizing of TCSC Using Genetic Algorithm for Congestion Management in Deregualted Power Markets"

[6] D. Murali, Dr. M. Rajaram, N. Reka "Comparison of FACTS Devices for Power System Stability Enhancement" International Journal of Computer Applications (0975 – 8887) Volume 8– No.4, October 2010

[7] Naresh Acharya, N. Mithulananthan "Locating series FACTS devices for congestion management in deregulated electricity markets"
Electric Power Systems Research 77 (2007) 352–360

[8] Zamani, F., V., Kazemi, A., Majd, B., A., "Congestion Management in Bilateral Based Power matket by FACT Devices and load curtailments "

[9] Hossein Nasir Aghdam "Analysis of Phase-Shifting Transformer (PST), on Congestion management and Voltage Profile in Power System by MATLAB/Simulink Toolbox"

[10] A.R. Abhyankar, Prof.S.A.Khaparde, "Introduction to Deregulation in Power Industry" IIT Mumbai.

[11] Text Book by Hadi Saadat, "Power System Analysis"Dr . Ibrahim Oumarou, Prof. Daozhuo Jiang, Prof. Cao Yijia "Optimal Placement of Shunt Connected Facts Device in a Series Compensated Long Transmission Line" Proceedings of the World Congress on Engineering 2009 Vol I, WCE 2009, July 1 - 3, 2009, London, U.K.

[12] Elango.K., S.R.Paranjothi, C.Sharmeela "Transmission Congestion Management in Restructured Power Systems by Generation Rescheduling and Load Shedding using Rule Based OPF"
European Journal of Scientific Research, ISSN 1450-216X Vol.57 No.3 (2011), pp.380-390, © EuroJournals Publishing, Inc. 2011, http://www.eurojournals.com/ejsr.htm

[13] S.N. Singh and A. K. David, "Optimal location of FACTS devices for congestion management," Electric Power Systems Research, vol. 58, pp. 71-79, Oct. 2000.

[14] E.V. Larsen, K.Clark, S.A.Miske.Jr, J.Urbanek," Characteristics and rating consideration of Thyristor controlled series compensation", IEEE Transactions on Power Delivery, Vol. 9. No. 2, April 1994.

[15] D. Shirmohammadi, B. Wollenberg, A. Vojdani, P. Sandrin,M. Pereira,F. Rahimi, T. Schneider, and B. Stott, "Transmission dispatch and congestion management in the emerging energy market structures," IEEE Trans. Power Syst., vol. 13, pp. 1466-1474, Nov. 1998.

[16] Text Book by N.G Hingorani & Lazlo Ghyghi. "Understaning FACT" Concept and technology of FACT"



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