Optimum Location of TCSC by Sensitivity Factor Analysis for Congestion Management

Mr. Sonu Gurra
Assistant Professor in Dept. of Electrical and Electronics Engineering
YMCA University of Science and Technology
Faridabad, Haryana (INDIA)
sonu.gurra444@gmail.com

Dr. Poonam Singhal
Associate Professor in Dept. of Electrical Engineering
YMCA University of Science and Technology
Faridabad, Haryana (INDIA)
ymcapoonamsinghal@gmail.com

Abstract—Due to deregulation of electric market transmission congestion occurs due insufficient transmission capacity to accommodate all constraints for transmission of a line. FACTS devices such as Gate Controlled Series Capacitor and Thyristor Control Series Compensator can help to reduce the flow in heavily loaded lines by controlling the power flow in the network. It increases the load ability of the network and reduces the cost of production. Congestion management using series connected FACTS devices can be done in two steps. First, find the optimal location of FACTS device and second, optimize the setting of the control parameter of FACTS device. Three methods to determine the optimal location of series connected FACTS device are discussed in this paper. The approach is based on sensitivity of line loss, total system loss and real power flow performance index. The proposed method has been demonstrated on 9-bus system in MATLAB programming as well as SIMULINK.

Keywords— *Congestion management, TCSC, Sensitivity factor analysis.*

*****

I. INTRODUCTION

The increasing industries and change of life style has led to increase the dependency on the electrical energy. This has resulted into surge of power systems. This increase in power systems has resulted into few uncertainties. Power interruption and power outages are one of the main problems and affects the economy of a country. In contrast to the fast changes in technologies and the power demanded by these technologies, transmission systems are force to operate closer to their stability limits and reaching their thermal limits, because the power delivering through the line is increased. If the power exchanges are not controlled, any line located between any two areas may become overloaded, this phenomenon is called congestion. The main problems faced by power industries to match the supply and demand required are:

- Transmission & Distribution; supply the electric demand keeping the line within the thermal limit.
- In large power system, stability problems causing power interruptions and blackouts which leads to huge losses.

These constraints affect the quality of power supplied. However, these constraints can be suppressed by improving the power system control. Congestion may be removed through different ways. Among the technical solutions, we have system reconfiguration, system re-dispatch, operation of FACTS devices, out-aging of congested lines, and operation of transformer tap changers [10][17].

The issue of transmission congestion is more important in the case of deregulated markets and competitive markets and it needs a very special analysis. In these conditions, independent system operator (ISO) has to remove the congestion, so that the system remains in secure state. To remove the congestion ISO can use followings methodologies [16],

- Out-ageing of overloaded lines
- Operation of on load tap changer transformer or operation of phase shifters [9]
- Use of FACTS devices mainly series devices such as GCSC, SSSC or TCSC
- Change of the generation amounts. By using this method, some generators reduce while others increase their output. The effect of change of generation means generators will no longer run at equal incremental costs as it did in case of economic load dispatch..
- Removal of loads and the operation of load interruption options [13]

FACTS devices are used as one of those technologies which can relieve the transmission congestion and hence leads to better utilization of the existing grid infrastructure. Furthermore, using FACTS devices gives more freedom to ISO [16].

Thyristor Controlled Series Capacitor (TCSC) is a device which is connected in series of a transmission line and its impedance can be varied by varying its firing angle and hence it can increase the power transfer capability, increase the transient stability, decrease the transmission losses and improve the transient stability [6].

This paper deals with the location of the series FACTS devices, especially to manage congestion and to minimize the losses after removal of congestion in the deregulated electricity markets. The location of FACTS devices can be found on the basis of the static performance or dynamic/transient performance of the system. Sensitivity factor analysis methods are used to determine the optimal location for FACTS devices [1-4] and the results are compared with IEEE 9-Bus Model's MATLAB programming results.

This paper presents the comparative analysis of approaches based on line loss sensitivity indices, real power Performance

Index, reduction of total system VAR power losses and MATLAB programming results of IEEE 9-Bus Model for proper location of TCSC for congestion management in power system.

II. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

The FACTS is a concept based on power-electronic controllers, which increase the value of transmission networks by increasing their capacity. As the operation of these controllers is very fast, they increase the safe operating limits of a transmission system without reducing stability. The era of the FACTS is started with the development of new solid-state high power electrical switching devices. The use of the FACTS has improved the new controllable systems.

FACTS devices are divided in three categories based on the connection of these devices to the transmission line: -

A. Series FACTS devices

Series FACTS device consists of series connected capacitor or a series connected current source are used to partially compensate the effects of the series inductances of lines. Series compensation increases the maximum power-transmission capacity of the line. Some of the series connected FACTS devices are: -

- Gate Controlled Series Compensator (GCSC)
- Thyristor Controlled Series Capacitor (TCSC)
- Static Synchronous Series Compensator (SSSC)
- Thyristor Switched Series Reactor (TSSC)
- Thyristor Controlled Power Angle Regulator (TCPAR)

B. Shunt FACTS devices

Shunt devices may be connected permanently or through semiconductor switch. Shunt reactors provide compensation for the line capacitance and due to the reason they control over voltages at no loads or light loads, they are always connected permanently in the line, not to the bus. Shunt capacitors are used to increase the power-transfer capacity and to compensate for the reactive-voltage drop in the line. Some of the Shunt connected FACTS devices are: -

- Static Synchronous Series Compensator (STATCOM)
- Static Var Compensator (SVC)
- Thyristor Controlled Reactor (TCR)
- Thyristor Switched Capacitor (TSC)

C. Series-Shunt FACTS Devices

These are the FACTS devices which are connected in series as well as parallel of the transmission line. The principle of these devices is to inject the current into the system with shunt part and voltage with the series part.

- Unified Power Flow Controller (UPFC)
- Interline Power Flow Controller (IPFC)
- Thyristor Controlled Phase Shifter (TCPS)

III. THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC)

The concept of TCSC is an extremely simple main circuit. In TCSC the capacitor is inserted directly in the series of a transmission line and the Thyristor-controlled inductor is connected in parallel with that capacitor. So there is no requirement of interfacing equipments like high voltage transformers (HVT) are required. Due to this reason TCSC is quiet economic than many of other competing FACTS devices. Hence it makes TCSC simple and easy to understand the construction and operation [2].

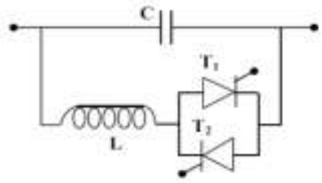


Fig. 1 Diagram of TCSC

A. Operation of TCSC

The operation of a TCSC can be easily explained from electrical circuit analysis. It consists of a series capacitor (for compensation) having a Thyristor controlled reactor (TCR) in parallel. TCR is nothing but a variable inductive reactor whose inductive reactance X_L can controlled by firing angle α. variation of X_L w.r.t. α can be shown as Fig. 2.

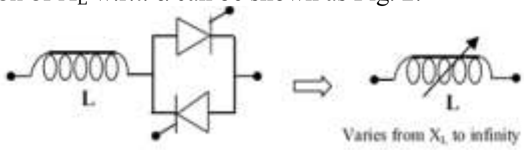


Fig. 2 Equivalent circuit of TCR

By varying α from 0 to 90, $X_L(\alpha)$ start from actual reactance X_L and vary up to infinity. This controlled reactor is connected in parallel of the series capacitor, so that the variable capacitive reactance (fig. 3) is possible across the TCSC to modify the transmission line impedance.

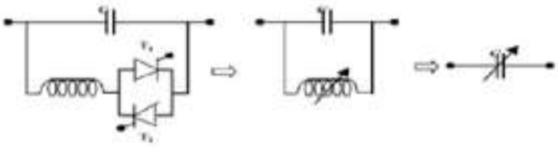


Fig. 3 Equivalent Circuit to TCSC

Where

$$X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \quad (1)$$

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \quad (2)$$

α is the firing angle, XL is the reactance off the inductor and XL(α) is the reactance of the inductor (effective reactance) at firing angle α and is limited thus: $XL \le XL(\alpha) \le \infty$.

B. TCSC impedance characteristics

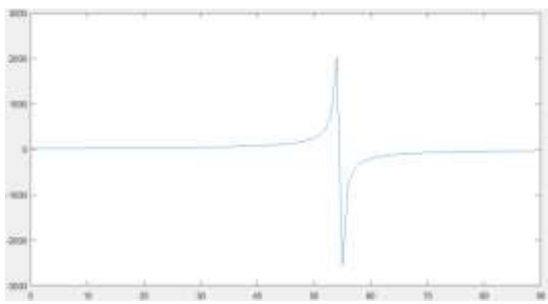


Fig. 4 TCSC impedance characteristics

Here the TCSC thus behave like a tunable parallel LC circuit in the line current that is behaving like a constant AC (alternating current) source. As $X_L(\alpha)$, the impedance of the controlled reactor, is varied from its maximum value (infinity) to its minimum value (ωL), the TCSC changes (increases) its minimum capacitive impedance, $X_{TCSC,min} = X_C = 1/\omega C$ until the parallel resonance is established at $X_C = X_L(\alpha)$ and $X_{TCSC,max}$ becomes infinite theoretically. Further decreasing $X_L(\alpha)$, the impedance of the TCSC, which is $X_{TCSC}(\alpha)$ becomes inductive and reaches its lowest value of $X_L X_C/(X_L - X_C)$ at $\alpha = 0$, where the capacitor is in bypassed by the TCR. Hence, with the ordinary TCSC arrangement in which the impedance of the TCR reactor, X_L, is lower than that of the capacitor, X_C, the TCSC has two operating ranges around its internal circuit resonance which occurs at $X_C = X_L(\alpha)$: first is the $\alpha_{Clim} \le \alpha \le \pi/2$ range, where $X_{TCSC}(\alpha)$ is capacitive, and the second is the $0 \le \alpha \le \alpha_{Clim}$ range, where $X_{TCSC}(\alpha)$ is inductive, as illustrated in Fig. 4.

C. Static Modeling of TCSC

The Fig.5 shows a simple transmission line which is represented by its lumped equivalent parameters in pi model connected between two buses, bus -i and bus-j. Let the complex voltages at bus-i and bus-j are Vi < δi and Vj < δj respectively. The reactive and real power flow from bus-i to bus-j can be written as

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

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

Where δij = δi – δj, similarly the real and reactive power flow from bus-j to bus-i is;

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

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

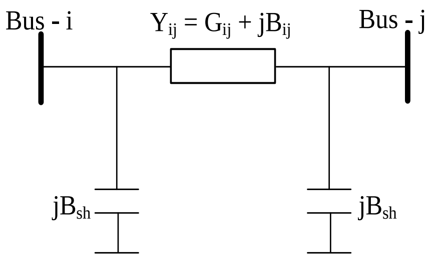


Fig. 5 Model of Transmission line

The model of transmission line with a TCSC connected between bus -i and bus-j is shown in Fig.5. In the steady state conditions, the TCSC can be considered equivalent to a static reactance –jXC. The reactive power and real power flow to bus-j from bus-i, and to bus-i from bus-j of a transmission line which have a series impedance and a series reactance are,

$$P_{ij}^c = V_i^2 G_{ij}^{'} - V_i V_j [G_{ij}^{'}\cos\delta_{ij} + B_{ij}^{'}\sin\delta_{ij}] \quad (7)$$

$$Q_{ij}^c = -V_i^2 (B_{ij}^{'} + B_{sh}) - V_i V_j [G_{ij}^{'}\sin\delta_{ij} - B_{ij}^{'}\cos\delta_{ij}] \quad (8)$$

$$P_{ji}^c = -V_j^2 G_{ij}^{'} - V_i V_j [G_{ij}^{'}\cos\delta_{ij} - B_{ij}^{'}\sin\delta_{ij}] \quad (9)$$

$$Q_{ji}^c = -V_j^2 (B_{ij}^{'} + B_{sh}) + V_i V_j [G_{ij}^{'}\sin\delta_{ij} + B_{ij}^{'}\cos\delta_{ij}] \quad (10)$$

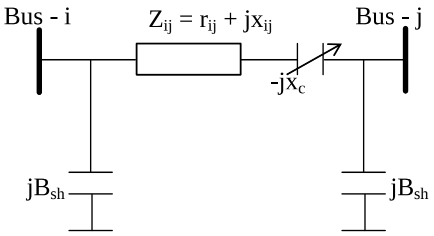


Fig. 6

The reactive power loss and real power loss in the transmission line consisting TCSC can be written as,

$$P_{LK} = P_{ij}^c + P_{ji}^c = G_{ij}^{'}(V_i^2 + V_j^2) - 2V_i^2 V_j^2 G_{ij}^{'}\cos\delta_{ij} \quad (11)$$

$$Q_L = Q_{ij}^c + Q_{ji}^c = (V_i^2 + V_j^2)(B_{ij}^{'} + B_{sh}) - 2V_i^2 V_j^2 B_{ij}^{'}\cos\delta_{ij} \quad (12)$$

Where,

$$G_{ij}^{'} = \frac{r_{ij}^{'}}{r_{ij}^2 + (x_{ij} - x_c)} \qquad and \qquad B_{ij}^{'} = \frac{-(x_{ij} - x_c)}{r_{ij}^2 + (x_{ij} - x_c)}$$

Due to series capacitance the change in the line flow can be represented as a transmission line without any series capacitance with power injected at both the receiving and sending ends of the line as represented in Fig.7.

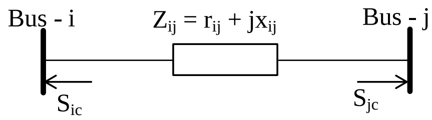


Fig.7. Injection Model of TCSC

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos\delta_{ij} + \Delta B_{ij}\sin\delta_{ij}] \quad (13)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos\delta_{ij} - \Delta B_{ij}\sin\delta_{ij}] \quad (14)$$

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij}\sin\delta_{ij} - \Delta B_{ij}\cos\delta_{ij}] \quad (15)$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij}\sin\delta_{ij} + \Delta B_{ij}\cos\delta_{ij}] \quad (16)$$

Where,

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

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

The above Model of TCSC is used to change the parameters of transmission line properly with the TCSC for optimal location in system.

IV. Methods for Optimal Location of TCSC

This paper utilizes static considerations based on the following objectives:

- Reduction in real power loss of a particular line-k (PLK)

- Reduction in the total system power loss (PLT)
- Reduction in the real power flow performance index (PI).

Using a FACTS device to reduce the real power loss in a particular line as suggested in [5] as an objective of device location may, however, increase the total system loss may increase the overloading of the lines elsewhere. Reduction in the total system active power loss will decrease or eliminate the undesirable loop flows but it doesn't give any guarantee that lines will not be overloaded but this is unlikely when there is no congestion.

A. Line Loss Sensitivity Indices (Method – I)

Define the sensitivity a_k^c of transmission loss (P_{LK}) on a series compensated line-k with respective series capacitive reactance (x_{ck}), as follows:

$$a_k^c = \frac{\partial P_{LK}}{\partial x_{ck}}$$

= line loss sensitivity with respect to TCSC placed in line-k (k = 1,….N_l)

Hence from equation (11), at base load flow

$$a_k^c = \frac{\partial P_{LK}^c}{\partial x_{ck}} = -2[V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}]G_{ij}B_{ij} \quad (17)$$

B. Total System Loss Sensitivity Indices (Method-2)

The exact loss formula of a power system of N buses is, from [15],

$$P_{LK} = \sum_{j=1}^{N}\sum_{k=1}^{N}[a_{jk}(P_jP_k + Q_jQ_k) + \beta_{jk}(Q_jP_k - P_jQ_k] \quad (18)$$

Where P_j and Q_j, are the real and reactive power respectively injected at bus-j while α and β are the loss coefficients which are defined as

$$a_{jk} = \frac{r_{jk}}{V_jV_k}\cos(\delta_j - \delta_k)$$

$$\beta_{jk} = \frac{r_{jk}}{V_jV_k}\sin(\delta_j - \delta_k)$$

Where r_{jk} is the real part of the (j-k)th element of [Z_{bus}] matrix. This total loss of system if one FACTS device at a time, is used, can be represented as follows:

$$P_{LT} = P_{LT} - (P_{ic} + P_{jc}) \quad (19)$$

The total system real power loss sensitivity factor w.r.t. the TCSC parameter can be defined as

$$b_k^c = \frac{\partial P_{LK}}{\partial x_{ck}}$$

= line loss sensitivity with respect to TCSC placed in line-k (k = 1,….N_l)

These factors are computed using equation (19) at a base load flow solution. Let a line-k between bus-i & bus-j.

C. Real power flow performance index(PI) sensitivity indices

The real power line flow performance index is used to describe the severity of the system under normal and contingency cases, as given below [4],

$$PI = \sum_{m=1}^{NL}\frac{w_m}{2n}\left(\frac{P_{Lm}}{P_{Lm}^{\max}}\right)^{2n} \quad (20)$$

Where P_{Lm} is the real power flow and P_{Lm}^{max} is the rated capacity of the line-m, n is the exponent in equation, N_L is the number of lines in the power system and w_m a real non-negative weighting coefficient of line which can be used to reflect the priority of lines. PI will remain a small value if all the lines are within their power transfer capacity limits and reach a high value if overload occurs on any line. Thus, it gives a good measure for safety of the line from overloads for the given condition of the power system. Almost all the works on contingency selection algorithms employ the second order performance indices which suffer from masking effects. Due to the lack of discrimination, the PI for a case with many small violations may be comparable with a value to the PI for a case having one huge violation, is named as masking effect. By mostly all operational standards, the system having one huge violation is much more critical than that of a system having many small violations. Masking effect can be avoided to some extent using higher order PI, i.e., n > 1. However, in this study, we have taken the value of exponent n= 2 and w_i = 1.

The real power flow PI sensitivity factors w.r.t. the parameters of TCSC can be represented as,

$$b_k = \left.\frac{\partial PI}{\partial x_{ck}}\right|_{x_{ck}=0} \quad (21)$$

Where Xck is the value of the reactance given by the TCSC installed in line k.

The sensitivity of PI w.r.t. TCSC parameter which is connected between bus-i and bus-j can be written as;

$$\frac{\partial PI}{\partial x_{ck}} = \sum_{m=1}^{N} w_m P_{lm}^3 \left(\frac{1}{P_{lm}^{\max}}\right)^4 \frac{\partial P_{lm}}{\partial x_{ck}} \quad (22)$$

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

$$P_{Lm} = \begin{cases} \sum_{n=1, n\neq s}^{N} S_{mn}P_n .... & for...m \neq k \\ \sum_{n=1, n\neq s}^{N} S_{mn}P_n + P_n & for...m = k \end{cases} \quad (23)$$

Using equation (23), the following relationship can be evaluated,

$$\begin{cases} \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mi}\frac{\partial P_i}{\partial x_{ck}}\right)........... & for \quad m \neq k \\ \left(S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mi}\frac{\partial P_j}{\partial x_{ck}}\right) + \frac{\partial P_j}{\partial x_{ck}} & for \quad m = k \end{cases} \quad (24)$$

The term,

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0}, \left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0} \quad (25)$$

Can be derived as,

ISSN: 2321-8169
851 – 857

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0} = \left.\frac{\partial P_{ic}}{\partial x_{ck}}\right|_{x_{ck}=0} = -2(V_i^2 V_j^2 \cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} - V_i^2 V_j^2 \sin\delta_{ij}\frac{(r_{ij}^2+x_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (26)$$

$$\left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0} = \left.\frac{\partial P_{jc}}{\partial x_{ck}}\right|_{x_{ck}=0} = -2(V_j^2 - V_i^2 V_j^2 \cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} + V_i^2 V_j^2 \sin\delta_{ij}\frac{(r_{ij}^2+x_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (27)$$

V. CRITERIA F OR OPTIMAL LOCATION

The TCSC device should be placed in the line which is most sensitive. With the sensitivity indices computed for TCSC, following opinion has been carried out for its optimal placement

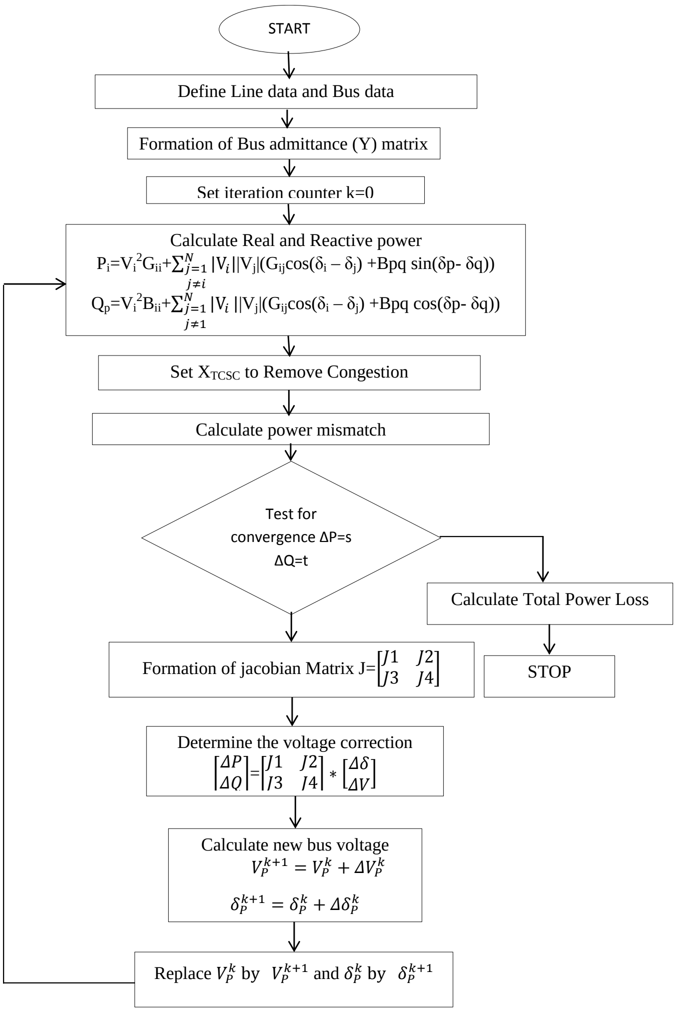
- In reactive power loss reduction method (Method-2) TCSC should be placed in that line which have the most positive loss sensitivity index.
- Where in PI method TCSC should be placed in that line which have most negative sensitivity index.

VI. FLOWCHART AND ALGORITHM

A. Algorithm

Step 1: - Input line data and bus data
Step 2: - Obtain Y-Bus matrix
Step 3: - Calculate Load Flow for Base Case
Step 4: - Change the Load at each load one by one
Step 5: - Put the TCSC on Each line and vary the line compensation from 1% to 70 %
Step 6: - Obtain the load flow for each case
Step 7: - Select the results which have removed the congestion
Step 8: - Select the result having minimum losses from above selected results.

B. Flow Chart



VII. SIMULATION AND RESULTS

To establish the effectiveness of the proposed methods, it has been tested on IEEE 9-bus system consisting of 3 generators and 9 lines representing 230kV buses having highly stressed system with increased load.

Power flow of above 9-bus system & line limit is shown in table-1. From the load flow, it was found that real power flow in line-4 is 108.414MW, which is above to its line loading limit & may create congestion.

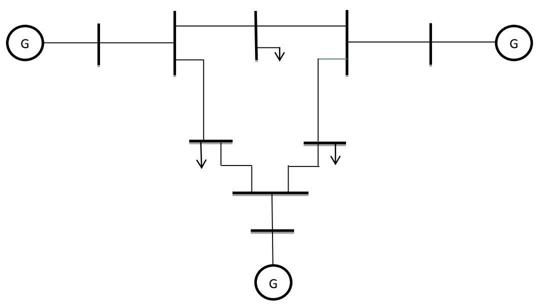


Fig.8 IEEE 9-Bus System

TABLE I. 9-BUS POWER FLOW

Line	*From – To*	*Real Power Flow*	*Real Power Flow Limit*
1	1 – 4	148.756	300
2	2 – 7	163.000	250
3	3 – 9	085.000	200
4	4 – 5	108.414	110
5	5 – 7	093.095	110
6	6 – 4	039.969	50
7	7 – 8	066.723	70
8	8 – 9	033.687	50
9	9 – 6	051.117	70

TABLE II. CALCULATED SENSITIVITY INDICES

Line	a_{ij}	b_{ij}	c_{ij}
1	0.2082	0.0326	2.0957
2	0.5856	0.1048	0.3189
3	0.3027	0.0036	0.0010
4	0.5192	0.0041	0.0141
5	0.4903	0.0009	1.4953
6	0.0374	0.0006	5.7528
7	0.3015	0.0011	-0.0195
8	0.2834	0.0034	3.1265
9	0.2917	0.0143	1.4406

The sensitivity factors 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 noticed from table-2 that line-4 is more sensitive according to total system reactive power loss reduction method. Line-7 is more sensitive according to real power flow performance index method but line-4 & 5 can also be considered because these line also seems to be sensitive. System power flow result after placing TCSC in 4, 5, 6 7, 8 & 9 is shown in table-4. The value of control parameters of TCSC for computing power flow are taken as per table-3.

TABLE III. CONTROL PARAMETER OF X_{TCSC}

Line	*Compensation*	*TCSC*
4	50%	0.04250
5	60%	0.09660
6	30%	0.02760
7	50%	0.03600
8	40%	0.04032
9	70%	0.11900

TABLE IV. POWER FLOW AFTER PLACING TCSC

Line	*Power flow without TCSC*	*Power Flow with TCSC in line 4*	*Power Flow with TCSC in line 5*	*Power Flow with TCSC in line 6*	*Power Flow with TCSC in line 7*	*Power Flow with TCSC in line 8*	*Power Flow with TCSC in line 9*
1	148.756	148.595	149.232	148.827	148.706	148.830	148.716
2	163.000	163.000	163.000	163.000	163.000	163.000	163.000
3	085.000	085.000	085.000	085.000	085.000	085.000	085.000
4	108.414	118.705	089.652	104.103	113.592	104.304	118.964
5	093.095	083.042	115.818	100.798	090.882	100.554	085.294
6	039.969	029.629	059.579	044.724	035.114	044.526	029.752
7	066.723	077.584	047.182	062.202	072.118	062.446	077.706
8	033.687	022.962	053.429	038.393	028.497	038.166	022.964
9	051.117	061.926	031.571	046.607	056.503	046.834	062.036

TABLE V. REACTIVE POWER LOSS

Line	*Reactive Power Loss without TCSC*	*Reactive Power Loss with TCSC in line 4*	*Reactive Power Loss with TCSC in line 5*	*Reactive Power Loss with TCSC in line 6*	*Reactive Power Loss with TCSC in line 7*	*Reactive Power Loss with TCSC in line 8*	*Reactive Power Loss with TCSC in line 9*
1	94.941	96.490	83.875	97.650	94.859	94.340	90.011
2	59.110	48.571	56.085	58.915	60.035	52.554	58.180
3	41.110	38.900	39.587	37.137	37.308	46.623	42.091
4	55.262	55.083	46.771	55.220	54.868	54.219	54.847
5	23.569	11.317	18.677	24.360	23.268	25.103	22.603
6	23.094	24.690	21.498	25.556	23.422	23.585	19.071
7	17.656	20.045	19.731	16.685	18.818	10.003	17.757
8	22.473	20.529	20.444	23.353	18.552	28.577	22.925
9	13.665	13.497	14.240	08.985	13.950	12.803	14.149

It can be seen in table-4 that congestion has been removed in line 4 after placing TCSC in line 6 & 8 and also get reduced system reactive power loss. Also there is not much improvement in congestion and PI after placing TCSC in line 4 & 5 but as seen in table-2 that line 7 is more sensitive and hence the placement of TCSC in line 7 is the most optimal for reducing PI and congestion relief.

VIII. CONCLUSION

Congestion management is a critical issue in interconnected power systems. FACTS devices such as TCSC can help to reduce the flows in heavily loaded lines by controlling the power flows in the network by changing the impedance of any particular line. Because of the high costs of FACTS devices, it is important to get the optimal location for placement of these devices.

Here three sensitivity factor based methods have been discussed for determining the optimal location and optimal percentage of compensation of TCSC in an electricity market and the optimum percentage of compensation is calculated to reduce the losses to its minimum level. In a system, the optimal locations of TCSC can be achieved based on the sensitivity factors a_{ij}, b_{ij} and c_{ij} and then optimal location is selected based on minimizing Total system power loss. Test

 ISSN: 2321-8169
851 – 857

results obtained for 9-bus power systems shows that these sensitivity factors can be adequately used for determining the optimal location of TCSC in power system. Transmission losses for three sensitivity methods were compared with a 9 Bus model's MATLAB programming results. Test results divulge that the proposed methods are useful in managing congestion & to find the optimal location of TCSC.

REFERENCES

[1] Seyed Abbas Taher, Hadi Besharat, "Transmission Congestion Management by Determining Optimal Location of FACTS Devices in Deregu lated Power Sy stems" American Journal of Applied Sciences 5 (3): 242-247, 2008

[2] Poonam Singhal, S.K. Aggarwal, "Tuning of TCSC controller parameters using MATLAB/Simulink for performance enhancement of SMIB power system" YMCAUST International Journal of Research 2, 2014.

[3] Anwar S. Siddiqui, Rashmi Jain, Majid Jamil and Gupta C. P. "Congestion management in high voltage transmission line using thy rister controlled series cap acitors" 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

[4] L.Rajalakshmi, M.V.Su gany adevi, 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

[5] Mrinal Ranjan, B. Vedik, "Op timal Location of FACTS Devices in a Power Sy stem by M eans of Sensitivity Analy sis" Science Road Publishing Corporation, Trends in Electrical and Computer Engineering TECE 1(1) 1-9, 2011

[6] Nazanin Hosseinipoor, Sy ed M.H Nabavi, "Optimal Locating and Sizing of TCSC Using Genetic Algorithm for Congestion Management in Deregu alted Power M arkets"

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

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

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

[10] Hossein Nasir Aghdam "Analy sis of Phase-Shifting Transformer (PST), on Congestion management and Voltage Profile in Power Sy stem by MATLAB/Simulink Toolbo x"

[11] A.R. Abhy ankar, Prof.S.A.Khap arde, "Introduction to Deregu lation in Power Industry " IIT Mumbai.

[12] 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 Comp ensated Long Transmission Line" Proceed in gs of the World Congress on Engineering 2009 Vol I, WCE 2009, July 1 - 3, 2009, London, U.K.

[13] Elan go.K., S.R.Paran jothi, 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

[14] S.N. Sin gh and A. K. Dav id, "Optimal location of FACTS devices for con gestion management," Electric Power Sy stems Research, vol. 58, pp. 71-79, Oct. 2000.

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

[16] D. Shirmohammadi, B. Wollenberg, A. Vojdani, P. Sandrin,M. Pereira,F. Rahimi, T. Schneider, and B. Stott, "Transmission disp atch and congestion management in the emer gin g en er gy market structures," IEEE Trans. Power Syst., vol. 13, pp. 1466-1474, Nov. 1998.

[17] Text Book by N.G Hingorani & Lazlo Ghy ghi. "Understaning FACT" Concept and technology of FACT"