IOSR Journal of Electrical and Electronics Engineering
e-ISSN : 2278-1676, p-ISSN : 2320-3331
PP 07-12
www.iosrjournals.org

FACTS device allocation for Transmission Congestion Management in Deregulated Power Market

Dipak S.Yeole[1], Dr.P.K.Katti[2]
[1]*Department of Electrical Engineering, Dr.Babasaheb Ambedkar Technological University, Lonere, Maharashtra (India)*
[2]*Professor Department of Electrical Engineering, Dr.Babasaheb Ambedkar Technological University, Lonere, Maharashtra (India)*

ABSTRACT:*The electric power industry has over the years been dominated by large utilities had over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have been referred to as vertically integrated utility (VIU).The main part of engineers to reshape three components of today's VIU. In the present day scenario, the restructuring of the electricity industries has gained much attention around the world. The main focus of the restructuring is to enhance the power system performance, increase the customer focus and reduce the cost revenue. This gives rise to a deregulated system. Congestion is one of the technical challenge in power system deregulation. In deregulated electricity market transmission congestion occurs when there is insufficient transmission capacity to simultaneously accommodate all constraints for transmission of a line. This paper proposes to relieve congestion using FACTS devices without disturbing economic matter. Further a methods to determine the optimal location of FACTS has been suggested based on real power flow performance index sensitivity indices.*

Keywords: *- Deregulated Power Market, Flexible AC Transmission Systems (FACTS), Optimal Location,Thyristor Controlled Series Capacitor (TCSC),Transmission Congestion Management.*

I. INTRODUCTION

For a hundred of year's electricity and its delivery were thought to be inseparable. But due to increase in demand from late-1980s and early 1990s things began to force restructuring with necessary expectation that increase in competition. This could lead to reduction of cost electricity while enhancing supply quality and reliability also could encourage new technologies. The success of reforms in airlines and communication sector shows importance of deregulation process. United Kingdom was the first to restructure its owned power system. Deregulation followed in Norway, Australia and New Zealand and then United States in 1992.In India, traditionally power sector owned by Government (>95% distribution and ~98% generation) in various states. In mid-1990's ,Orissa starts of fundamental restructuring of power sector and soon same followed by Andhra Pradesh, Haryana,Uttar Pradesh and Rajasthan, Maharashtra [1]. But there are several complexities in deregulation power market as due to the tremendous demand of electrical energy,transmission lines are often driven close to or even beyond their thermal limits. When producers and consumers of electric energy desire to produce and consume in amounts that would cause transmission system to operate at or beyond one or more transfer limits, the system is said to 'congested'. The action taken to reduce congestion is called congestion management. If congestion is not relief then it may lead to tripping of overloaded lines, consequential tripping of other lines and in some cases to voltage stability problems. Hence to avoid such problem congestion need to be solve. In this deregulated power market 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 mainly two
Types of methods which are as follows:[2]

1) Cost free methods:
- Out-ageing of congested lines
- Operation of transformer taps/phase shifters
- Operation of FACTS devices particularly seriesdevices

2) Cost based methods:
- 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.

Among the above two main methods cost free means do haveadvantages such as without disturbing economic status, so GENCOand DISCO will not be involved. The objective of using FACTS devices, [3]especially series FACTS devices like Thyristor Controlled Series Capacitor (TCSC) are considered one of method that reduced the transmission congestion in the transmission system. In thispaper, where the objective is to provide maximumrelief to the congested line, the optimal location ofFACTS device is found out using sensitivitytechnique so that the power flows through the designated path.

II. CONCEPT, CHARACTERISTICS AND STATIC MODELLING OF TCSC

2.1 Concept and Characteristics

It consists of the series compensating capacitor shunted by a Thyristor controlled reactor (TCR), as shown in Fig.1.The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over wide range and switched upon command to a condition where bi-directional thyristor pairs conduct continuously and insert appropriate reactance in line. When TCR firing angle 180 degrees, the reactor becomes non-conducting and series capacitor has its normal impedance. As firing angle is advanced from 180 degrees to less than 180 degrees capacitive impedance increases.

On the other end, when the firing angle is 90 degrees, the reactor becomes fully conducting and TCR helps in limiting fault current. The control over firing angle produces a variable effective capacitance, which partly compensates for the transmission line inductance and controls the power flow through the line[3][4].This makes TCSC much more economic thansome other competing FACTS technologies.

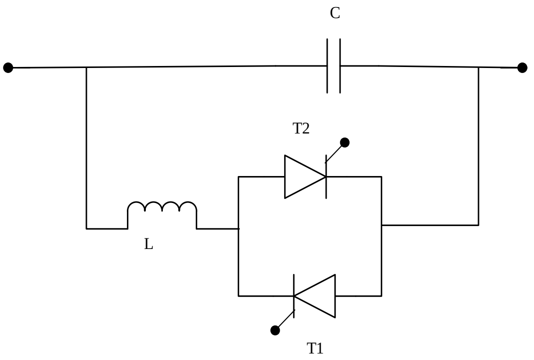

Fig.1schematicdiagram of TCSC

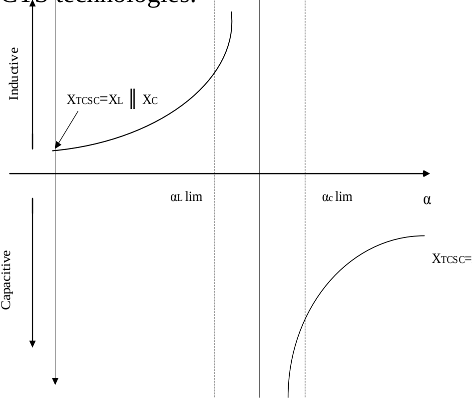

Fig.2variationofimpedanceincase ofTCSC

Fig.2 shows the impedance characteristics curve of a TCSC device [3] [5].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 (α) =X_C, theoretically X_{TCSC} is infinity. This region is inductive region. Further increasing of X_L (α) gives capacitive region. Thus, impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).

- $\alpha_{clim} \leq \alpha \leq \frac{\pi}{2}$ Capacitive region
- $0 \leq \alpha \leq \alpha_{Llim}$ Inductive region

While selecting inductance, X_L should be sufficiently smaller than that of the capacitor X_C. Suppose if X_C 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 X_C value; or else a resonance develops that result in infinite impedance an unacceptable condition.

2.2 Static Modelling

The Fig. 3 (a)shows a simple transmission line represented by its lumped πequivalent parameters connected between bus a-and bus-b. Let complex voltage at bus-a and bus-b are Va∠δa and Vb∠δb respectively. The real and reactive power flow from bus-a to bus-b can be written as: [6] [7] [8]

$P_{ab} = V_a^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} \sin(\delta_{ab})]$(1)

$Q_{ab} = -V_a^2 (B_{ab} + B_{sh}) - V_a V_b [G_{ab} \sin(\delta_{ab}) - B_{ab} \cos(\delta_{ab})]$(2)

Where$\delta_{ab} = \delta_a - \delta_b$. similarly, the real and reactive power flow from bus-b to bus-a is:

$P_{ba} = V_b^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) - B_{ab} \sin(\delta_{ab})]$(3)

$Q_{ba} = -V_b^2 (B_{ab} + B_{sh}) + V_a V_b [G_{ab} \sin(\delta_{ab}) + B_{ab} \cos(\delta_{ab})]$(4)

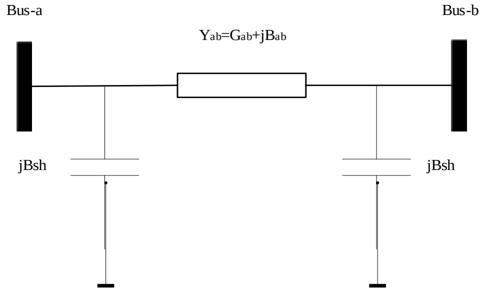

Fig.3 (a) model of transmission line

The model of transmission line with a TCSC connected between bus-a and bus-b is shown in Fig.3 (b). During the steady state the TCSC can be considered as a static reactance -jx_c. The real and reactive power flow from bus-a to bus-b, and from bus-b to bus-a of a line having series impedance and a series reactance are:

$P^c_{ab} = V_a^2 G'_{ab} - V_a V_b [G'_{ab}\cos(\delta_{ab}) + B'_{ab}\sin(\delta_{ab})]$(5)

$Q^c_{ab} = -V_a^2(B'_{ab} + B_{sh}) - V_a V_b [G'_{ab}\sin(\delta_{ab}) - B'_{ab}\cos(\delta_{ab})]$(6)

$P^c_{ba} = V_b^2 G'_{ab} - V_a V_b [G'_{ab}\cos(\delta_{ab}) - B'_{ab}\sin(\delta_{ab})]$(7)

$Q^c_{ba} = -V_b^2(B'_{ab} + B_{sh}) + V_a V_b [G'_{ab}\sin(\delta_{ab}) + B'_{ab}\cos(\delta_{ab})]$(8)

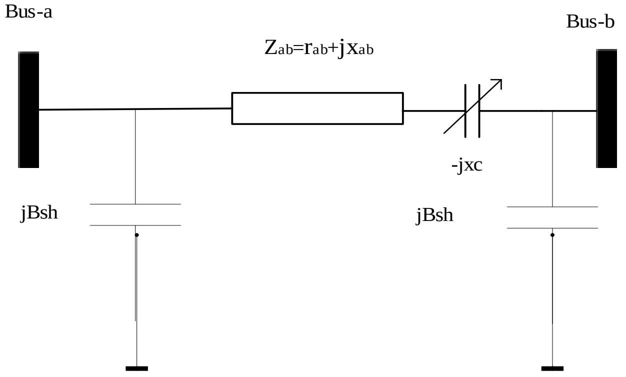

Fig.3 (b) model of TCSC

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

$P_L = P_{ab} + P_{ba} = G'_{ab}(V_a^2 + V_b^2) - 2V_aV_bG'_{ab}\cos(\delta_{ab})$(9)

$Q_L = Q_{ab} + Q_{ba} = -(V_a^2 + V_b^2)(B'_{ab} + B_{sh}) + 2V_aV_bB'_{ab}\cos(\delta_{ab})$(10)

Where $G'_{ab} = \frac{r_{ab}}{r_{ab}^2 + (x_{ab} - x_c)^2}$ and $B'_{ab} = \frac{-(x_{ab} - x_c)}{r_{ab}^2 + (x_{ab} - x_c)^2}$

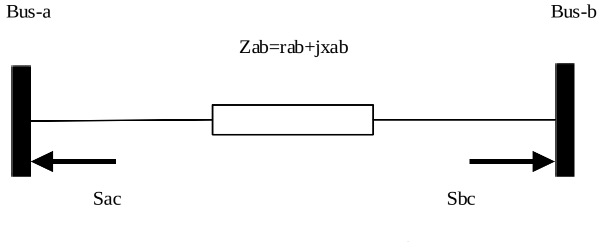

Fig.3 (c) injection model of TCSC

The change in the line flow due to series capacitance can be represented as line without series capacitance with power injected at the receiving and sending ends of the line as shown in Fig.3(c). The real and reactive power injections at bus-a and bus-b can be expressed as:

$$P_{ac} = V_a^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} \cos(\delta_{ab}) + \Delta B_{ab} \sin(\delta_{ab})] (11)$$

$$P_{bc} = V_b^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} \cos(\delta_{ab}) - \Delta B_{ab} \sin(\delta_{ab})] (12)$$

$$Q_{ac} = -V_a^2 \Delta B_{ab} - V_a V_b [\Delta G_{ab} \sin(\delta_{ab}) - \Delta B_{ab} \cos(\delta_{ab})] (13)$$

$$Q_{bc} = -V_b^2 \Delta B_{ab} + V_a V_b [\Delta G_{ab} \sin(\delta_{ab}) + \Delta B_{ab} \cos(\delta_{ab})] (14)$$

Where,

$$\Delta G_{ab} = \frac{x_c r_{ab} (x_c - 2x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)} \text{and} \Delta B_{ab} = \frac{-x_c (r_{ab}^2 - x_{ab}^2 + x_c x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)}$$

Due to high cost of FACTS devices, it is necessary to find out optimal location FACTS devices.

III. OPTIMAL LOCATION OF TCSC

3.1 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 [6], as given below,

$$b_{ij} = PI = \sum_{m=1}^{N_L} \frac{\omega_m}{2n} \left(\frac{P_{Lm}}{P_{Lm}^{max}} \right)^{2n} (15)$$

Where, ω_m is the weighting coefficient used to reflect the importance of lines, P_{Lm} is the real power flow, P_{Lm}^{max} is the thermal limit of line m,n is an exponent used to adjust the index value to avoid the masking effect in the contingency taken as 2 and ω_m=1

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

$$b_k = \frac{\partial PI}{\partial x_{ck}} \bigg| x_{ck} = 0 (16)$$

The sensitivity of PI with respect to TCSC parameter connected between bus-a and bus-b can be written as,

$$\frac{\partial PI}{\partial x_{ck}} = \sum_{m=1}^{N_L} \omega_m P_{Lm}^3 \left(\frac{1}{P_{Lm}^{max}} \right)^4 \frac{\partial P_{Lm}}{\partial x_{ck}} (17)$$

The real power flow in a line-m can be represented in terms of real power injections using DC power flow equations [9] where s is slack bus,

$$P_{Lm} = \begin{cases} \sum_{\substack{n=1 \\ n \neq s}}^{N} S_{mn} P_n & \text{for } m \neq k \\ \sum_{\substack{n=1 \\ n \neq s}}^{N} S_{mn} P_n + P_b & \text{for } m \neq k \end{cases} (18)$$

Using equation (20), the following relationship can be derived,

$$\frac{\partial P_{Lm}}{\partial x_{ck}} = \begin{cases} \left(S_{ma} \frac{\partial P_a}{\partial x_{ck}} + S_{mb} \frac{\partial P_b}{\partial x_{ck}} \right) & \text{for } m \neq k \\ \left(S_{ma} \frac{\partial P_a}{\partial x_{ck}} + S_{mb} \frac{\partial P_b}{\partial x_{ck}} \right) + \frac{\partial P_b}{\partial x_{ck}} & \text{for } m = k \end{cases} \qquad (19)$$

The terms $\frac{\partial P_a}{\partial x_{ck}} \Big| x_{ck}=0$, $\frac{\partial P_b}{\partial x_{ck}} \Big| x_{ck}=0$ can be derived as below $\frac{\partial P_a}{\partial x_{ck}} \Big| x_{ck}=0 = \frac{\partial P_{bc}}{\partial x_{ck}} \Big| x_{ck}=0$

$$= -2(V_a^2 - V_a V_b \cos \delta_{ab}) \frac{r_{ab} x_{ab}}{(r_{ab}^2 + x_{ab}^2)^2} - V_a V_b \sin \delta_{ab} \frac{(x_{ab}^2 - r_{ab}^2)}{(r_{ab}^2 + x_{ab}^2)^2} (20)$$

$$\frac{\partial P_b}{\partial x_{ck}}\bigg|_{x_{ck}=0} = \frac{\partial P_{bc}}{\partial x_{ck}}\bigg|_{x_{ck}=0} == -2(V_b^2 - V_a V_b \cos\delta_{ab})\frac{r_{ab}\, x_{ab}}{(r_{ab}^2 + x_{ab}^2)^2} + V_a V_b \sin\delta_{ab}\frac{(x_{ab}^2 - r_{ab}^2)}{(r_{ab}^2 + x_{ab}^2)^2} \quad (21)$$

3.2 Criteria for Optimal Location

The FACTS device should be placed on the most sensitive line. Following criteria can be used for its optimal placement:

In Real Power Flow Performance Indexmethod TCSC should be placed in a line having most negative sensitivity index.

IV. SIMULATION RESULTS

To find out optimal location of TCSC, the analysis has been implemented on 5-bus system as shown in Fig.4 below. MATLAB has been used for simulation.

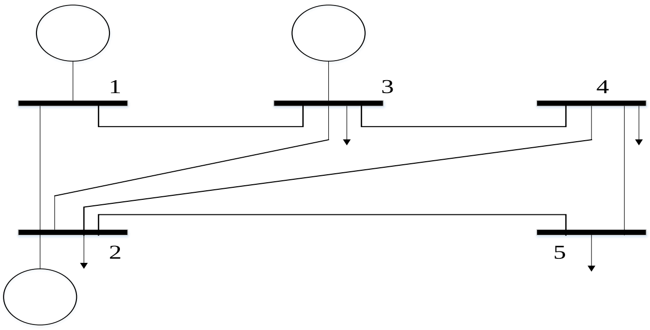

Fig.4 5-bus system

Power flow of above 5-Bus system is calculated. From the load flow, it was found that real power flow in 2-3 was 0.13 which is more than its line loading limit.

Table I: calculated sensitivity indices

Line	i-j	b_{ij}
1	1-2	**-4.1180e+08**
2	1-3	-2.9579e+04
3	2-3	-26.9698
4	2-5	1.4562e+07
5	3-4	6.9982e+08

The sensitive of real power flow performance index sensitivity indices with respect to TCSC control parameter has been computed and are shown in Table I. The sensitive lines are highlighted in Table I. It can be observed from Table I that line 1 is more sensitive as per real power flow performance index method. Power flow result after placing TCSC in line 1 is as shown in Table II.The value of control parameter of TCSC for computing power flow is taken as 0.042.It can be observed from Table IIcongestion is relieved in line3after placing TCSC presented in bold type.

Table II: power flow result after placing TCSC

Line	Power flow without TCSC	Power flow with TCSC in Line-1
1	0.74	0.67
2	0.28	0.36
3	**0.13**	**0.10**
4	0.57	0.56
5	0.51	0.55

V. CONCLUSION

From above discussion, it is observed that congestion is major issues in deregulated power system and need to be solve. FACTS devices are found to be useful to reduce power flow in heavily loaded lines. Because of the considerable costs of FACTS devices, it is important to obtain optimal location for placement of these devices.

This paper summarizes,Real Power Flow Performance Index Sensitivity Indices for optimal placement of the TCSC devices. Using this method optimal location of FACTS devices can be accurately determined in order to reduce line congestion. This methods can be applied to n (n=1, 2, 3…) bus transmission system to relieve congestion.

REFERENCES

[1]. A.R.Abhyankar, Prof.S.A.Khaparde, Introduction to deregulation in power industry L.Rajalakshmi, M.V.Suganyadevi, S.Parameswari "Congestion Management in Deregulated Power System by Locating Series FACTS Devices"
[2]. International Journal of Computer Applications (0975 – 8887) Volume 13– No.8, January 2011 Text Book by N.G.Higorani& Laszlo Gyugyi ,Understanding FACTS Concept and technology of Flexible AC Transmission Systems
[3]. Christian Schaffner,Goran Anderson, "Performance of a TCSC for congestion relief" Anwar S. Siddiqui, Rashmi Jain, Majid Jamil and Gupta C. P. "Congestion management in high voltage transmission line usingthyristor controlled series capacitors" Journal of Electrical and Electronics Engineering Research Vol. 3(8), pp.151-161,October2011,
[4]. Seyed Abbas Taher, Hadi Besharat, "Transmission Congestion Management by Determining Optimal Location of FACTS Devicesin Deregulated Power
[5]. Systems" American Journal of Applied Sciences 5 (3): 242-247, 2008
[6]. Verma K.S., Singh S.N., Gupta H.O., 2001. FACTS devices location for enhancement of total transfer capability, Power
[7]. Engineering Society Winter Meeting, IEEE, Vol. 2: 522-527.
[8]. Singh S.N., David A.K., 2000. Placement of FACTS devices in open power market, Advances in Power System Control, Operation and Management, Vol. 1: 173-177.
[9]. Wood A.J., Wollenberg B.F., Power Generation, Operation and Control (John Wiley, New York, 1996)