Enhancing Power System Security by Proper Placement of Thyristor Controlled Series Compensator (TCSC)

P. S. Vaidya and V. P. Rajderkar

***Abstract*—In stressed electric power systems, due to increased loading or due to severe contingencies often lead to situation where system no longer remains in the secure operating region. FACTS devices can play very important role in power system security enhancement. Due to high capital investment, it is necessary to locate these devices optimally in the power system. The scope of this paper is to decide optimal location of Thyristor controlled series compensator (TCSC) by a real power flow performance index sensitivity based approach & line outage distribution factor. The effectiveness of the proposed controller has been tested on modified IEEE 30 bus system using Power world simulator software version 12.0.**

***Index Terms*—Line outage distribution factor, power system security, power world simulator software, real power flow performance index, sensitivity analysis, TCSC.**

I. Introduction

Electric utilities are forced to operate the system close to their thermal & stability limits due to major hurdles such as enviournmental, right of way and cost problems limit the expansion of the transmission networks. The security of power system can be defined as its ability to withstand a set of severe but credible contingencies & to survive transition to an acceptable new steady state condition[1]. As power systems have become more heavily loaded due to increased load and larger interconnection, there will be ,an increase in number of situations where power flow equation have either no real solution (unsolvable case) or solution with violating operating limits such as voltage limit (insecure case),particularly, in contingency analysis & planning application. The solution of the power flow problem has received much attention over the last several decades. This is due to its fundamental importance to power system analysis. However, little attention has been focused on how to handle situations where power flow equations have no real solutions & any attempt to operate the system there, probably results in the system instability & voltage collapse. [4]

Hence there is an interest in better utilization of available capacities by installing Flexible AC Transmission System Devices such as Thyristor controlled series compensator (TCSC). These devices can help in reducing the power flows in heavily loaded lines, resulting increased system lodability,less system loss & improved security of the system. It is important to locate such devices optimally because of their cost.

In most of the work, the placement of TCSC has been considered for the intact system. Very limited efforts have been made to study the impact of TCSC and their placement under contingencies. J.G.Singh et al [1] has been suggested the optimal placement of TCSC and UPFC for enhancement of power system security. M.K.Verma et al [2] deals with the location of FACTS controllers under contingencies. A. Kazemi et al [3] proposed the comprehensive load flow model for UPFC combined with ESS. S.N.Singh [4] have proposed the sensitivity based approach for the location of FACTS devices for enhancing the security. Teoman et al [5] suggested the location of FACTS devices based on line outage distribution factor.

The main objective of this paper is to locate the TCSC for enhancing the security of power system under contingencies. A real power flow performance index sensitivity based method & line outage distribution factor has been suggested to optimally locate the TCSC for enhancing the power system security. The effectiveness of the proposed method has been demonstrated on modified IEEE 30 bus system by using Power World Simulator Software version 12.0.

II. Modeling of Tyristor Controlled Series Compensator(Tcsc)

The model of TCSC is developed to be used for steady state conditions. This device may take a fixed number of discrete values. TCSC are connected in series with the lines. The effect of a TCSC on the network can be seen as a controllable reactance inserted in the related transmission line that compensates reactance of the line. It may have one of the two possible characteristics: capacitive or inductive to decrease or increase the reactance of the line X_L respectively. Their values are functions of the line where the device is located [6]. Moreover, to avoid over compensation of the line, the working range of the TCSC is considered to be [-0.39X_L, 0.39X_L].

So as to increase the maximum power transfer in that line and also improves voltage profile. It is assumed that only one TCSC per lines is allowed.

Fig. 1 shows a simple transmission line represented by its lumped π equivalent parameters connected between bus i and bus j. G_{ij} is the series conductance and B_{ij} is the series susceptance of a transmission line. B_{sh} is the shunt susceptance of a transmission line. The model of a transmission line with a TCSC connected between bus- i and bus- j is shown in Fig. 2.

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The authors are with the G. H Raisoni Collage of Engg, Nagpur, India (e-mail:prajakta.vaidya@yahoo.co.in, vedashri_raj@yahoo.com).

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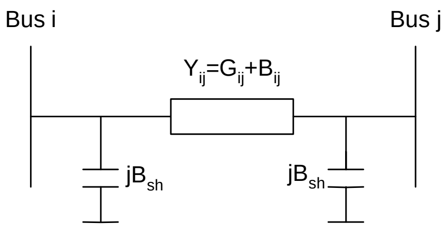

Fig. 1. Model of transmission line.

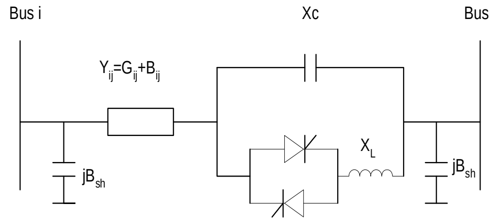

Fig. 2. Model of TCSC.

III. Methods of Optimal Location of TCSC

A. Line Outage Distribution Factor

Linear sensitivities are popular methods of approximating the power system states after a change occur in the system. They are based on reducing the nonlinear power flow equations in to a linear system using the dc assumption. Line outage distribution factors (LODFs) are the sensitivities of line flows to line outages.LODFs tell how the flow changes on a line when some other line in the system is outage. They are used to quickly predict the change in line flows for the outage of another line. For example, flow gates are used in an online capacity to monitor the post contingency state of critical elements in the system.[5]

LODF is the change in flow on a line as a percentage of the pre outage on another line. Thus, the LODF on line l for the outage of line k is defined as

$$LODF_{l,k}=\frac{\Delta p_{1,k}}{p_k} \tag{1}$$

where $LODF_{l,k}$ is the sensitivity on line l for the outage of line k.

B. Real Power Flow Performance Index Sensitivity Approach

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index [1] as given below.

$$PI=\sum_{m=1}^{N_1}\frac{w_m}{2n}\left(\frac{P_{lm}}{P_{lm}^{\max}}\right)^{2n} \tag{2}$$

where P_{lm} is the real power flow and $P_{lm}^{\max}$ is the rated capacity of line m, n is an exponent and w_m 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 lines overloads for a given state of the power system. However in the study, the value of exponent has been taken as n=2 and w_m =1 for all m. The real power flow PI sensitivity factors with respect to the parameter of TCSC can be defined as

$C_k^c=\frac{\partial PI}{\partial x_{ck}}\Big|_{x_{ck=0}}$ = PI sensitivity with respect to TCS placed in line k (k=1,...........N_l)

Using Eq (2), the sensitivity of PI with respect to FACTS device parameter X_k (x_{ck} for TCSC) connected between bus i and bus j for case n=2 can be written as

$$\frac{\partial PI}{\partial X_k}=\sum_{m=1}^{N_l}w_mP_{lm}^3\left(\frac{1}{P_{lm}^{\max}}\right)^4\frac{\partial P_{lm}}{\partial X_k} \tag{3}$$

The real power flow in a line m (P_{lm}) can be represented in terms of real power injections using DC power flow equation [1] where s is a slack bus, as

$$P_{lm}=\begin{cases}\displaystyle\sum_{n=1,n\neq s}^{N}S_{mn}P_n & \text{for } m\neq k\\ \displaystyle\sum_{n=1,n\neq s}^{N}S_{mn}P_n+P_j & \text{for m}=k\end{cases} \tag{4}$$

where S_{mn} is the mn[th] element of matrix [S] which relates line flow with power injections at the buses without TCSC devices and N is the number of buses in the system. Observe that line k, from bus-i to bus-j, is the line containing the TCSC device, as illustrated in Fig. 2. P_j, therefore is the additional flow, at bus-j, in the line containing the TCSC device, due to the presence of the device. Using equation (10), the following relationship can be derived.

$$\frac{\partial P_{lm}}{\partial X_k}=\begin{cases}\left(S_{mi}\dfrac{\partial P_i}{\partial X_k}+S_{mj}\dfrac{\partial P_j}{\partial X_k}\right) & \text{for m}\neq k\\ \left(S_{mi}\dfrac{\partial P_i}{\partial X_k}+S_{mj}\dfrac{\partial P_j}{\partial X_k}\right)+\dfrac{\partial P_j}{\partial X_k} & \text{for m=k}\end{cases} \tag{5}$$

The terms $\frac{\partial P_i}{\partial x_{ck}}\Big|_{x_{ck}=0}$, $\frac{\partial P_j}{\partial x_{ck}}\Big|_{x_{ck}=0}$ can be obtained using equation are given below.

$$P_{ic}=P_{ij}-P_{ij}^c=V_i^2\Delta G_{ij}-V_iV_j\left[\Delta G_{ij}\cos\delta_{ij}+\Delta B_{ij}\sin\delta_{ij}\right] \tag{6}$$

$$P_{jc}=P_{ji}-P_{ji}^c=V_j^2\Delta G_{ij}-V_iV_j\left[\Delta G_{ij}\cos\delta_{ij}-\Delta B_{ij}\sin\delta_{ij}\right] \tag{7}$$

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0}=\left.\frac{\partial P_{ic}}{\partial x_{ck}}\right|_{x_{ck}=0}=\left(V_i^2-V_iV_j\cos(\delta_{ij})\right)\left.\frac{\partial\Delta G_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} -\left(V_iV_j\sin(\delta_{ij})\right)\left.\frac{\partial\Delta B_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} \tag{8}$$

$$\left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0}=\left.\frac{\partial P_{jc}}{\partial x_{ck}}\right|_{x_{ck}=0}=\left(V_j^2-V_iV_j\cos(\delta_{ij})\right)\left.\frac{\partial\Delta G_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} +\left(V_iV_j\sin(\delta_{ij})\right)\left.\frac{\partial\Delta B_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} \tag{9}$$

where

$$\frac{\partial \Delta G_{ij}}{\partial x_{ck}}\bigg|_{x_{ck}=0} = 2G_{ij}B_{ij} \quad \text{and} \quad \frac{\partial \Delta B_{ij}}{\partial x_{ck}}\bigg|_{x_{ck}=0} = B_{ij}^2 - G_{ij}^2$$

The sensitivity factor C_k^c can be found by substituting equation (8) and (9) in equation (5).

The criteria for optimal location is to placed the TCSC [1] in a line having most negative sensitivity index. Additional criteria can also be used while deciding the optimal placement of TCSC should not be placed with generating transformer even though the sensitivity is the negative highest.

IV. Simulation Results

The proposed method for optimal location of TCSC has been tested on modified IEEE -30 bus system by using power world simulator software 12.0. In 30 bus system, line 12-14 is a outage line. To obtain the critical line outages were computed by line outage distribution factor for a single line outage case & sensitivity were calculated for TCSC placed in every line one at a time. The real power flow performance index with respect to TCSC for line outage are presented in Table I.

TABLE I: LODF and PI Sensitivity for TCSC on IEEE 30-Bus When Line12-14 Is Outage.

LINE	% LODF	PI Sensitivity
2-6	2.439	-4.48697
1-2	2.409	-2.45807
1-3	1.2195	1.051722
2-4	0	2.842161
5-7	-1.21951	4.25685

From Table I, it can be seen that line 4-6 is getting overloaded when the line 12-14 outage. The placement of TCSC in a line having most positive line outage distribution factor & a line having most negative sensitivity factor. When the TCSC is placed in line 2-6 validates the effectiveness in the security enhancement.

Fig. 3 shows the outage state of a part of an interconnected power system network, where line 12-14 connected between bus- 12 and bus- 14 is to be considered for the outage study. The power flow in this fictitious line is considered as the pre-outage power flow in the actual line. The power injected due to fictitious sources has been taken to be same as the line flows at the two ends in order to make the net power flow to be zero and thus simulating the line outage condition.

Fig. 4 shows the one TCSC is placed in line 2-6 and it removes the congestion present in line 4-6 from 109% to 95%. Hence the system is operated within the limit. After 2-6, 1-2, 1-3 will be the best location giving a line loading limit of 99% as shown in Fig. 5 & Fig. 6.Then, 2-4 gives line loading limit of 104% and line 5-7 gives 108% as shown in Fig.7 & Fig. 8 which is not good location for enhancing power system security.

V. Conclusion

For enhancing the security of power system, line outage distribution factor and sensitivity based approach has been developed for finding the optimal placement of TCSC. The test results obtained on modified IEEE 30 bus system by using power world simulator software .The TCSC should be placed on the most sensitive lines. Line 2-6 is the best location for TCSC.

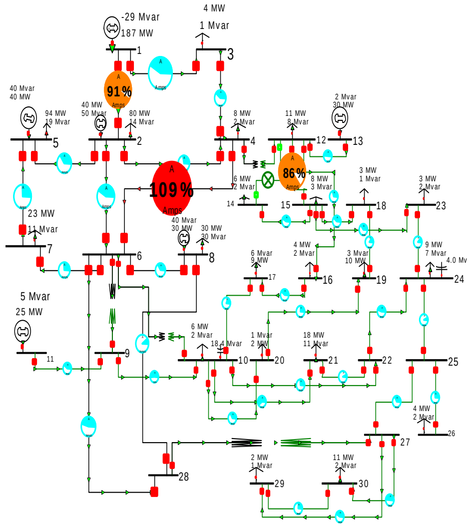

Fig. 3. 30-Bus with line12-14 is open (outage).

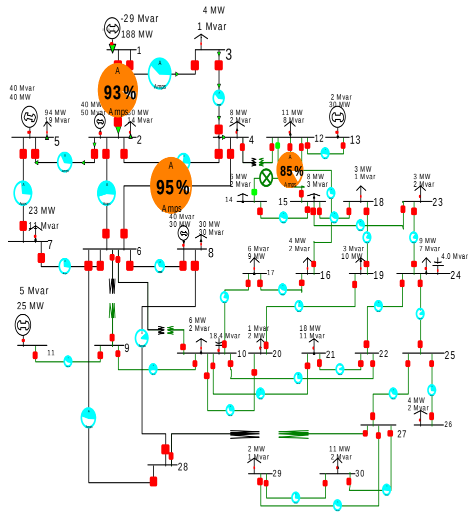

Fig. 4. 30-Bus with one TCSC placed in line 2-6.

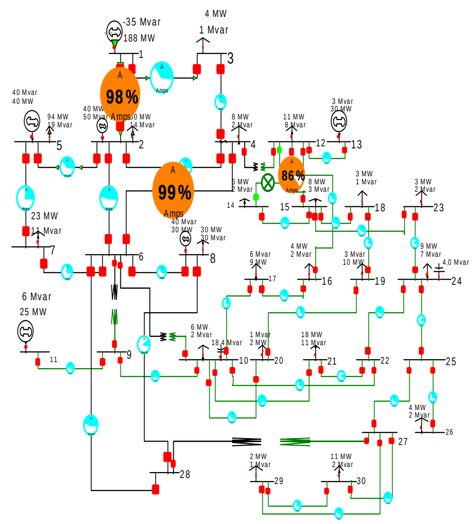

Fig. 5. 30-Bus with one TCSC placed in line 1-2.

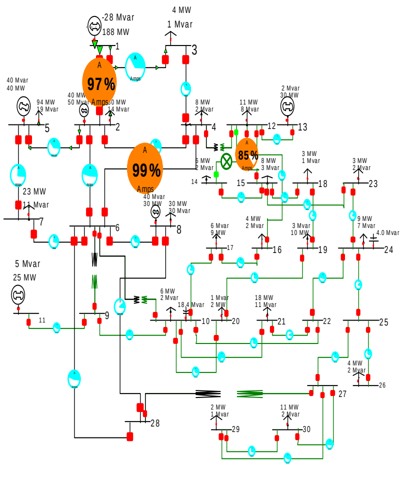

Fig. 6. 30-Bus with one TCSC placed in line 1-3.

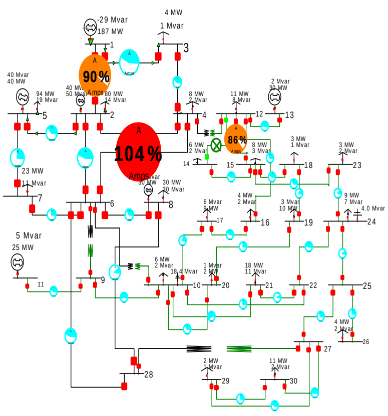

Fig. 7. 30-Bus with one TCSC placed in line 2-4.

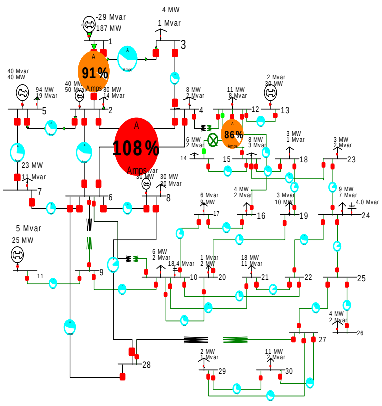

Fig. 8. 30-Bus with one TCSC placed in line 5-7.

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P. S. Vaidya received M. Tech from G. H. Raisoni College of Engineering, Nagpur, India in 2011. She is presently working as Assistant Professor in the Department of Electrical Engineering at Nagpur University (India). Her reaserch interest includes power system restructuring, FACTS.

V. P. Rajderkar completed her M. Tech from G. H. Raisoni College of Engineering, Nagpur, India in 2006. In 2007, she joined the Electrical Engineering Department of G. H. Raisoni college of Engineering, Nagpur, India as Assistant Professor. her area of interest are Power system & FACTS technology.