INTERNATIONAL JOURNAL OF ELECTRICAL ENGINEERING & TECHNOLOGY (IJEET)

ISSN 0976 – 6545(Print)
ISSN 0976 – 6553(Online)
Volume 5, Issue 8, August (2014), pp. 211-221
© IAEME: www.iaeme.com/IJEET.asp
Journal Impact Factor (2014): 6.8310 (Calculated by GISI)
www.jifactor.com

IJEET
©IAEME

ENHANCEMENT OF POWER SYSTEM SECURITY BY TCSC UNDER SINGLE LINE OUTAGES

Sunil kumar B S[1], Rajesh M[1], Prashanth T[1], Indresh G S[1], Dr.Shobha Shankar[2]

[1]Student, Dept. of E & EE, VVCE, Mysore,
[2]Professor and Head, Dept. of E & EE, VVCE, Mysore,

ABSTRACT

The security of power system is its ability to withstand a set of severe but credible contingencies and to survive transition to an acceptable new steady state condition. To maintain security of the system, it is desirable to estimate the effect of contingencies and pertinent control measurement can be taken on to improve the system security. Power system is exposed to various contingencies which often contribute to overloading of branches, violation of voltages and also leads to problems of security/stability. This paper focuses on enhancement of system security and to enhance the system performance under network contingencies through an optimal placement and optimal setting of TCSC. The optimal location of TCSC is identified by a new index called Single Contingency Voltage Sensitivity (SCVS) Index. The methodology developed alleviates overload on the transmission lines and maintains the voltage at all load buses within their specified limits.

Keywords: system security, Thyristor Controlled Series Compensator (TCSC), Single Contingency Voltage Sensitivity (SCVS) *Index.*

1. INTRODUCTION

The demand of the twenty first century with increased growth and interconnection of power grids, will stretch existing delivery system to their limits and create new requirements for flow control, system security, system stability etc. Increased demands on transmission, absence of long-term planning, and the need to provide open access to generating companies and customers, all together have created tendencies toward less security and reduced quality of supply. The loss of one of the power sources could suddenly increase the load demand on the remaining part of the system, causing severe voltage depression that could results in an ultimate voltage collapse. The changes that are going to occur in the network configuration during contingencies, like generator outages or branch outages, the reactive power flow in the system differs widely under different contingencies.

In the process, the voltages at load buses may violate their limits and the existing transmission lines are overloaded and lead to unstable system. Maintaining voltages at all load buses within the specified limits and alleviating the emergency transmission line overloads, through proper reactive power allocation is a critical problem in power system operation. The steady-state transmittable power can be increased and the voltage profile along line can be controlled by appropriate reactive shunt compensation.

New transmission lines or FACTS devices on the existing transmission system can eliminate/alleviate the overloads on the transmission lines, but FACTS devices are preferred in the modern power systems based on its overall performance.

FACTS devices are solid state devices that have the capability of control of various electrical parameters in transmission networks. These devices, by controlling the power flows in the network, can help to reduce the flows in heavily loaded lines, resulting in an increased load ability, low system loss, improved stability of the network, and reduced cost of production [1]-[3]. From the literature review [4]-[11] it is clear that the appropriate location and sizing of the FACTS Controllers has improved the system performance vastly.

The security assessment has been gaining importance in the present day stressed operation of power system networks. To maintain security, it is desirable to estimate the effect of contingencies. Contingency ranking is the process of indexing the possible contingencies of system on the basis of their severity. In the past, contingency rankings were carried out using the algorithms based on line loadings and bus voltages. Contingency screening and ranking is one of the components of on-line system security assessment. Various PI-based methods for contingency screening and ranking have been reported in literature.

Static security of a power system implies the conditions of having a) no overloaded equipment or transmission circuits and b) no buses violating the permissible voltage limits. Previous work have investigated the generation rescheduling and load shedding as the primary corrective strategies for alleviating overloads on transmission lines and enhancing the system security and an alternative method of using TCSC devices is presented[12]. The location of TCSC and other type of flexible AC Transmission System (FACTS) device is important for enhancement of practical power system voltage stability [13] - [15].

In this paper, utilization of the TCSC during single contingencies is investigated. In order to evaluate the suitability of a given branch for placing a TCSC, contingency severity index is calculated for each branch. TCSC can be used effectively in maintaining system security in case of a contingency, by eliminating or reducing overloads along the selected network branches.

After having the ranked list of branches, an optimization problem is formed to find out the best locations among the ranked branches to install the TCSCs and to determine the best settings of the installed TCSC with respect to single contingencies. The objective used in this problem is to eliminate or reduce the line overloads and increase the security margin.

2. MODELLING OF TCSC

Thyristor controlled series compensator (TCSC) device is a series compensator to govern the power flow by compensating the reactance of transmission line. Both capacitive and inductive reactance compensation are possible by proper selection of capacitor and inductor values of the TCSC device which can be realized through reactance equation. A TCSC which consist of a series compensating capacitor(C) shunted by a Thyristor Controlled Reactor (TCR). TCR is a variable inductive reactor (X_L (α)) tuned at firing angle (α). The variation of X_L with respect to alpha can be given as

$$XL(\alpha) = \frac{\pi}{\pi - 2\alpha - sin2\alpha} \qquad (1)$$

$$Xc = \frac{1}{2\pi f C} \tag{2}$$

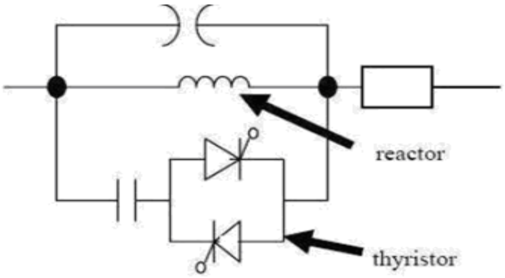


Fig.1 Schematic diagram of TCSC device

For the variation of alpha from 0 to 90°, X_L (α) varies from actual reactance X_L to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance, as fig.1 is possible across the TCSC which modify the transmission line impedance. Effective TCSC reactance X_{TCSC} with respect to α can be given by equation (3-7)

$$\begin{aligned} X_{TCSC}(\alpha) &= -X_C + C_1(2(\pi-\alpha)+\sin(2(\pi-\alpha))) \\ &\quad - C_2\cos^2(\pi-\alpha)(\omega\tan(\omega(\pi-\alpha))-\tan(\pi-\alpha)) \end{aligned} \tag{3}$$

$$C_1 = \frac{X_C + X_{LC}}{\pi} \tag{4}$$

$$C_2 = \frac{4X^2_{LC}}{X_L\pi} \tag{5}$$

$$X_{LC} = \frac{X_C X_L}{X_C - X_L} \tag{6}$$

$$\omega = \sqrt{\frac{X_C}{X_L}} \tag{7}$$

The effective reactance X_{TCSC} (α) of TCSC operates in three region, inductive region, capacitive region and resonance region. Inductive region starts increasing from TCR reactance $X_L||X_C$ value to infinity and decreasing from infinity to capacitive reactance X_C for capacitive region. Between the two regions, resonance occurs.

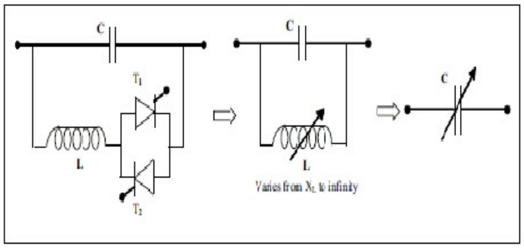
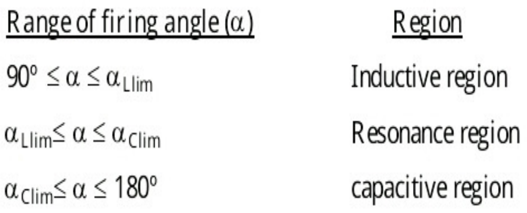


Fig.2 Equivalent circuit of TCSC



Range of firing angle (α)	Region
$90^\circ \le \alpha \le \alpha_{Llim}$	Inductive region
$\alpha_{Llim} \le \alpha \le \alpha_{Clim}$	Resonance region
$\alpha_{Clim} \le \alpha \le 180^\circ$	capacitive region

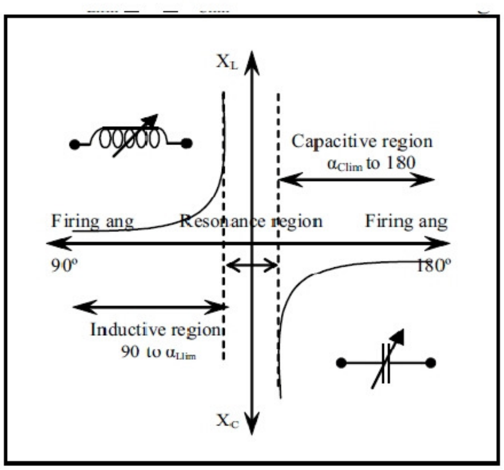


Fig.3 Resonance condition of TCSC

3. PROPOSED METHODOLOGY

The methodology presented in this section is to identify a bus that is most sensitive to the largest number of contingencies through the calculation of single contingency voltage sensitivity (SCVS) index. The SCVS index is determined only for the important contingencies, which are actually causing problems for system security. The important contingencies are short listed using the Voltage Performance Index (PIV). The SCVS index at bus-j is determined through the matrices viz: Participation matrix (PM), Ratio matrix (R), and the contingency Probability array (P). The SCVS is defined as the sum of the sensitivities at Bus-j, to all the considered important contingencies. So the SCVS for node-j is expressed as:

$$SCVS = \sum_{i=1}^{ncont} P_i (PM)_{ij} R_{ij}$$
$$j = 1 \ldots\ldots nlb \qquad (8)$$

where ncont- number of important contingencies.
nlb- number of load buses.

The *participation matrix* (PM) is a (m x n) binary matrix, whose entries are “1” or “0” depending upon whether or not the corresponding load bus is violated their specified limits. Where *m* is the total number of considered contingencies and *n* is the total number of load buses.The *ratio matrix Rij* is a (m x n) matrix of normalized voltages at all load buses.

$$R_{ij} = \frac{V_{jc}}{V_{jn}} - 1 \tag{9}$$

where V_{jc} – Voltage at bus "j" under contingency,
V_{jn} – Voltage at bus "j" under normal condition.

The contingency probability array P is (m x 1) an array of outage probabilities:

$$P_{(m\times 1)} = [\,p_i\,]^T$$

where i = 1,2,…..m, p is the probability of occurrence for contingency " i". The SCVS values will be calculated for all load buses of the system using equation (8). The load buses are then ranked according to their SCVS values. The buses with largest value of SCVS index are considered as the candidate buses for allocation of TCSC at bus "i" for a contingency "j". In general, the bus with larger value of SCVS is considered as more sensitive and is ranked first. The TCSC should be placed according to the ranking made based on SCVS. The TCSC should be placed at a bus having most positive SCVS index. Also additional criterions have also been used while deciding the optimal placement of FACTS device i.e., the TCSC should not be placed at a bus, where, the injected MVAr already exists. A bus that is selected for the optimal placement of TCSC is shunted at a bus along with the other shunted elements, which will provide the most efficient control of the voltage and as well as power flows and will enhance the steady state security of the system.

4. SIMULATION RESULTS

The IEEE 6 bus test system is taken for the purpose of case study is shown in Fig (4). The six-bus system is a simple power system network has got eleven transmission lines with a capacity of 230 kV. The system consists of three generators are at the Buses 1,2,3 and three loads at Buses 4,5,6.

In this case all possible contingencies that are actually causing problems were considered. The participation matrix is a binary matrix, which is formed using the information obtained from the voltage performance index. Rows in the participation matrix correspond to all load buses. For each load bus, the SCVS indexes are calculated for severe contingencies. The outage probabilities of all transmission lines and generators are assumed to be equal to 0.02.

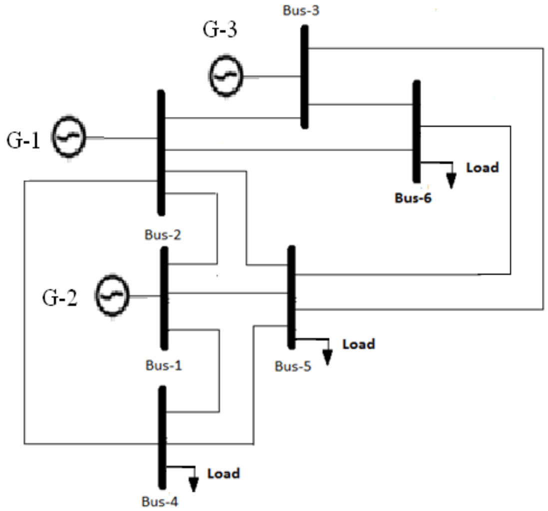


Fig.4 Single Diagram IEEE 6-Bus Test System

The power flow solutions for only three contingencies that are actually causing problems were considered i.e 2-4 Branch outage, 3-5 Branch outage and 2-6 Branch outage. The power flow solutions for only three contingencies that are actually causing problems were considered i.e 2-4 branch outage, 3-5 branch outage and 2-6 branch outage. The power flow solutions are computed and corresponding optimal settings of TCSC were computed.

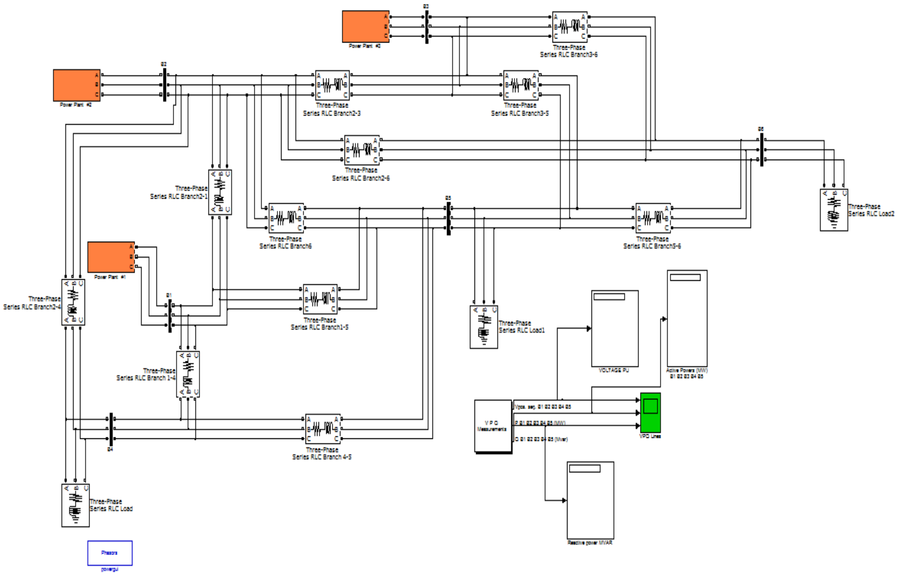


Fig.5 Simulink model of 6-bus system without TCSC

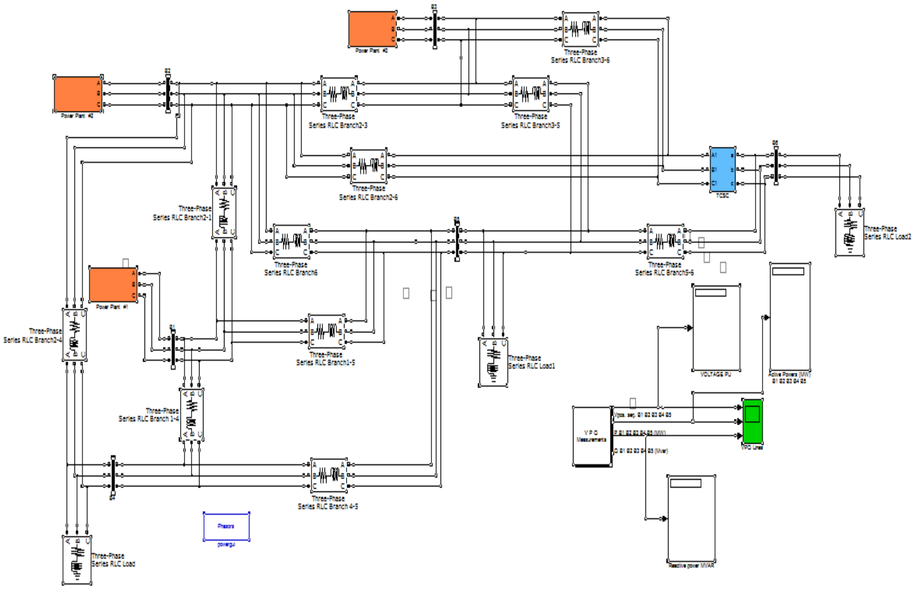


Fig.6 Simulink model of 6-bus system with TCSC

4.1 Calculation of SCVS index values and ranking of 6-bus test system

Table.1 Voltage range under normal and different branch outages

Bus no	Normal condition	2-4 Branch outage	3-5 Branch outage	2-6 Branch outage
1	0.9786	0.9619	0.9661	0.9714
2	0.9746	0.9712	0.9619	0.9691
3	0.9816	0.9747	0.9768	0.9708
4	0.9555	0.9064	0.9358	0.943
5	0.9506	0.9301	0.9215	0.9333
6	0.9547	0.9401	0.9378	0.9276

The SCVS index at Bus-j is determined through the matrices

$$SCVS = \sum_{i=1}^{ncont} P_i (PM)_{ij} R_{ij}$$

$$j = 1.....nlb$$

$$\text{Participation matrix (PM)ij} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}_{3\times 3}$$

where
i = 1,2,3.......... Contigency
j = 1,2,3............Buses

$$\text{contingency Probability array (P)} = \left[\; 0.02 \;\right]$$

The ratio matrix Rij is a (m x n) matrix of normalized voltages at all load buses.

$$R_{ij} = \frac{V_{jc}}{V_{jn}} - 1$$

Where Vjc – Voltage at bus “j” under contingency
Vjn – Voltage at bus “j” under normal condition

R14 =0.9064/0.9402-1=0.035,
R15 =0.9301/0.9345-1=0.0047,
R16 =0.9401/0.9386-1=0.0016
R24=0.9358/0.9402-1=0.0046,
R25 =0.9215/0.9345-1=0.014,
R26 =0.9378/0.9386-1=0.0008,
R34 =0.943/0.9402-1=0.0030,
R35 =0.9333/0.9345-1=0.0013,
R36 =0.9276/0.9386-1=0.0117

$$R_{ij} = \begin{bmatrix} 0.035 & 0.0047 & 0.0016 \\ 0.0046 & 0.014 & 0.0008 \\ 0.003 & 0.0013 & 0.0117 \end{bmatrix}$$

$SCVS4=(P_1)(PM)_{14}(RM)_{14}+(P_2)(PM)_{24}(RM)_{24}+(P_3)(PM)_{34}(RM)_{34}$
$=(0.02)(1)(0.035)+(0.02)(1)(0.0046)+(0.02)(1)(0.003)$
$=0.000282$
$SCVS5 =(P_1)(PM)_{14}(RM)_{14}+(P_2)(PM)_{24}(RM)_{24}+(P_3)(PM)_{34}(RM)_{34}$
$=(0.02)(1)(0.0047)+(0.02)(1)(0.014)+(0.02)(1)(0.0.013)$
$=0.0004$
$SCVS6=(P_1)(PM)_{14}(RM)_{14}+(P_2)(PM)_{24}(RM)_{24}+(P_3)(PM)_{34}(RM)_{34}$
$=(0.02)(1)(0.0016)+(0.02)(1)(0.0008)+(0.02)(1)(0.0117)$
$=0.0008$

SCVS4 = **0.000282,** SCVS5 = **0.0004** SCVS6 = **0.0008**

Table.2 SCVS index values and ranking of 6-bus test system

Load Bus No.	SCVS index	Ranking
4	0.000282	3
5	0.0026	2
6	0.0067	1

Table.3 Voltage comparison with & without TCSC at BUS-6 for 2-4 branch outage

BUS NO	VOLTAGE MAGNITUDE(PU)	
	Without TCSC	With TCSC(TCSC at Bus-6)
1	0.9619	0.9626
2	0.9712	0.9713
3	0.9747	0.9749
4	0.9064	0.9074
5	0.9301	0.9321
6	0.9401	0.9485

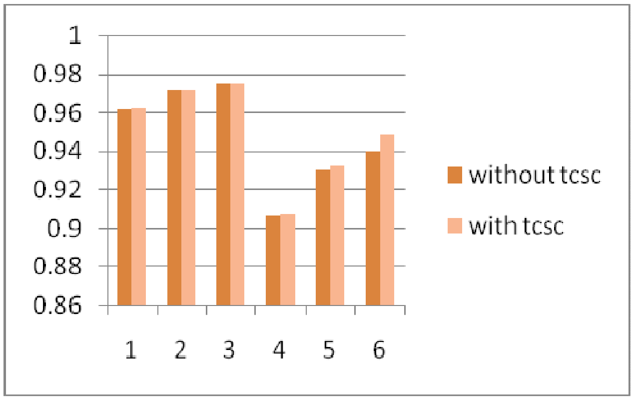


Fig.7 Voltage profile with and without TCSC at BUS-6 for 2-4 Branch outage

Table.4 Voltage comparison with & without TCSC at BUS-6 for 3-5 Branch outage

BUS NO	**VOLTAGE MAGNITUDE(PU)**	
	Without TCSC	**With TCSC(TCSC at Bus-6)**
1	0.9661	0.9669
2	0.9619	0.9622
3	0.9768	0.977
4	0.9358	0.9366
5	0.9215	0.9242
6	0.9378	0.9465

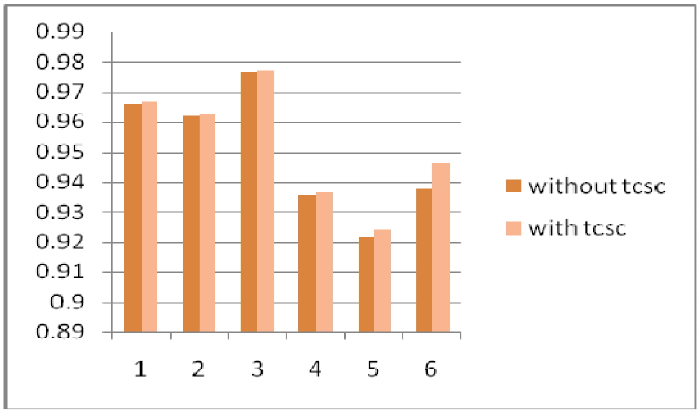


Fig.8 Voltage profile with and without TCSC at BUS-6 for 3-5 Branch outage

Table.5 Voltage comparison with & without TCSC at BUS-6 for 2-6 Branch outage

BUS NO	**VOLTAGE MAGNITUDE(PU)**	
	Without TCSC	**With TCSC(TCSC at Bus-6)**
1	0.9714	0.972
2	0.9691	0.9694
3	0.9708	0.9704
4	0.943	0.9436
5	0.933	0.935
6	0.9276	0.9347

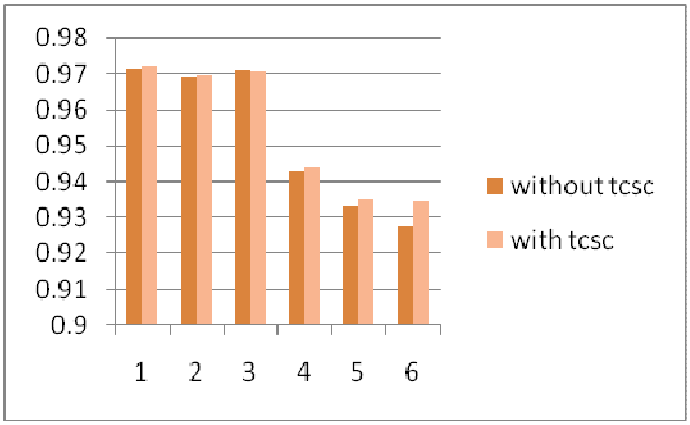


Fig.9 Voltage profile with and without TCSC at BUS-6 for 2-6 Branch outage

5. CONCLUSION

In this paper the analysis is carried out when TCSC connected to a bus to maintain a flat voltage profile during single line outages. There by the reactive power compensation was successfully done in the particular transmission whenever it is required. The power flow and the voltage profile in various transmission lines along with and without the placement of TCSC in a specific transmission line is obtained in order to improve the system performance by using the load flow studies using MATLAB software. This improves system security by maintaining voltage and without overloading transmission lines. The IEEE 6 bus test system is used to evaluate the performance of this approach.

The optimal location of TCSC has been identified using an index called SCVS. The TCSC is placed in suitable branches in the given system to reduce system overloads and to improve the system security margin during single contingencies. Simulations carried out confirmed that TCSC provides the fast acting voltage support necessary to prevent the possibility of voltage reduction and voltage collapse at the bus to which it is connected. Simulation results reveal that the proposed approach can give an optimal placement and settings in security point of view. It is clear that the optimal location of TCSC for branch outage and generator outage, with this location and optimal setting of TCSC, the system performance has improved vastly by reduction in losses and as well as voltage improvement and system security has been enhanced.

6. REFERENCES

1. **Allen J. Wood and Bruce F.Wollenberg**, “Power Generation Operation and Control”, Second edition, John Wiley and Sons, Inc.
2. **Lorrin Philipson and H.Lee Willis**, Understanding Electric Etilities and De-Regulation, Marcell Dekker Inc, New York, 1999.
3. **N.Hingorani and L.Gyugyi**,” Understanding FACTS concepts and Technology of Flexible AC Transmission systems”, IEEE Press 2000.
4. **M.Noroozian L.Angquist, M.Ghandhari and G.Anderson**, “Use of UPFC for Optimal Power Flow Control”, IEEE Transactions on Power Delivery, Vol-12, No. 4, pp. 1629-1634, October 1997.
5. M. Ilic, F. Galiana, and L. Fink (Editors), **Power Systems Restructuring: Engineering & Economics.** Boston: Kluwer Academic Publishers, 1998.
6. **D.Thukaram, K.Vishaka, Lawrence Jenkins, and H.Khincha**, “Selection of UPFC Suitable Location for Security Improvement Under Normal and Network Contingencies”, Power Transmission and Distribution, TENCON 2003, pp. 755-760.
7. **P. Kundur** “Power system stability and control”, Tata Mc-Graw-Hill Publishing Company Limited.
8. **A.Kishore and E.F.Hill,**”Static Optimization of Reactive Power Sources by use of Sensitivity Parameters”, IEEE Trans. On Power Apparatus and Systems, Vol. PAS-90, pp.1166-1173,1971.
9. **K.Lba**,”Practical Reactive Power Allocation/Operation Planning using Successive Linear Programming”, IEEE Trans. On Power Systems, Vol.3, No.2, pp. 558-566, 1988.
10. A**.Aoki, W.Fan and A.Nishikori**, ”Optimal VAR Planning by Approximation Method for Recursive Mixed-Integer Linear Programming”, IEEE Trans. On Power Systems, Vol.3, No.4, pp.1741- 1747, 1988.
11. **N.Deeb and S.M.Shahidehpour,** “Economic Allocation of Reactive Power Supply in an Electric Power Network”, Proceedings of IEEE International Symposium on Circuits and Systems.pp.1859-1862, 1989.

12. **Yunqiang Lu, and Ali Abur**, “Static security enhancement via optimal utilization of thyristor-controlled series capacitors”, IEEE Transactions on Power Systems. Vol-17, No. 2, pp. 324-329, May 2002.
13. **R Madeshwaran and Raja Slochanal,**”Power system Security Enhancement by Optimal Allocation of TCSC using Penalty parameterless real coded GA”, (NPSC), IIT Bombay, 2008.
14. **J. Paserba, N. Miller, E. Larsen, and R. Piwko,** “A thyristor controlled series compensation model for power system stability analysis,” IEEE Trans. Power Delivery, vol. 10, pp. 1471–1478, July 1995
15. [15] Mark Ndubuka NWOHU, “Voltage Stability Improvement using Static Var Compensator in Power Systems”, Leonardo Journal of Sciences, Issue 14, p 167-172, January-June 2009.
16. **S Sutha and N Kamaraj,** “Optimal Location of Multi Type Fact Device for Multiple Contingencies Using Particle Swarm Optimization**”** International journal of Electrical and information Engineering, 2008.
17. **Scott Greene, Ian Dobson and Fernanado L. Alvarado**, “Contingency Ranking for Voltage Collapse via Sensitivities from a Single Nose Curve”, IEEE Transactions on Power Systems, Vol.14, No.1, pp. 232-239, Feb 1999.
18. **Y. Chen and A. Bose**, “Direct ranking for voltage contingency selection, IEEE Trans. on Power Systems”, vol.4, pp. 1335-1344, Oct. 1989.
19. **G. Lauby, T. A. Mikolinnas, N. D. Reppen**, “Contingency selection of branch outages causing voltage problems," IEEE Trans. on PAS, vol. PAS-102, pp. 3899-3904, Dec. 1983
20. **John J. Paserba,** “How FACTS Controllers Benefit AC Transmission Systems”, pp.447-454.
21. **Verma M K and S C Srivastava**, optimal placement of TCSC for static and Dynamic voltage security Enhancement .INT J .Emerging Electrical power system 2005.
22. **H.Ambriz-Perez, E.Acha, C.R.Fuerte-Esquivel**, “Advanced TCSC models for Newton – Raphson Load Flow and Newton Optimal Power Flow Studies.