Voltage Profile Improvement and Power Loss Reduction in Different Power Bus Systems Using TCSC

Megha Parolekar,V.G.Bhongade, S.Dutt

ABSTRACT: With the restructuring of power market, the voltage stability has become a major concern .FACTS devices adaptive to voltage-magnitude controlas well as can regulate the active and reactive powersimultaneously because of their flexibility and fast controlcharacteristics. This paper focused on the mathematical modeling of Flexible Alternating Current Transmission Systems (FACTS) -devices in optimal power flow analysis. A Thyristor Controlled Series Capacitors (TCSC) mathematical models have been established,and the Optimal Power Flow (OPF) with these FACTS-devices is solved by Newtons method. This article employs MATLAB Simulation, the development of OPF and the suitability of Newton-based algorithms for solving OPF-TCSC problem is done. The concept was tested and validated with TCSC in 5-bus,14-bus and 30-bus test system. Optimal Power Flow problem has been explored and tested with and without compensating device. The results show that in large-scale system, where the number of constraints is very large, the Thyristor-Controlled Series Capacitor is effective for controlling the specified amount of active and reactive power in between two buses as well improves voltage profile which improves system security . Placement of these devices in suitable locationcan lead to control in line flow and maintain bus voltages indesired level .

KEYWORDS:Net active and reactive power loss ,Optimal power flow, Optimal location,TCSC device,Voltage magnitude.

I. INTRODUCTION

Many examples show that voltage instability can be the cause of a major blackout. As well as, with the restructuring of power market, the voltage stability has become a major concern. So research and plans are still in process to improve voltage stability margins and reduce power losses to maintain security of power system. FACTS devices can regulate theactive and reactive power control as well as can provide better voltage-magnitude control simultaneously because of theirflexibility and fast control characteristics[13].Placement of these devices in suitable locationcan lead to control in line flow and maintain bus voltages indesired level and so improve voltage stability margins[14,15,16].Use of thesedevicescan lead to control power flowand maintain bus voltages in desired level and so improvevoltage stability margins[2]. A comprehensive work wasdone byFuerte-Esquivel. C.R.; Acha, E.; Ambriz-Perez, H. [8] regarding the aspect.Theypresented a paper on TCSC model incorporated into electrical network having large number of buses. P.H. Ashmole described in IEEE publication [6] that FACTS controller are mainly aim to control three parameters such as voltage, phase angle and impedance. Abdel-Moamen, M.A.; Padhy, N.P, [12].

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Presented a paper on Multi-objective optimal power flow model with TCSC for practical power networks at Power Engineering Society General Meeting, 2004. In this paper he has discussed how the transmission line loss in a 30-bus system can be minimized using Newton's method.The references 10][11][12][13][14][15][16] show FACTS devices located at their own optimal locations is observed to have a better voltage profile and power loss.

The planning and daily operation of modern power systems call for numerous power flow studies.The main objective of a power flow study is to determine the steady state operation condition of the electrical power network. The steady state may be determined by finding out the flow of active and reactive power throughout the network and the voltage magnitude and phase angles at all nodes of the network [1] [4] [8]. Such information is used to carry out security assessment analysis, where the nodal voltage magnitudes and active and reactive power flows in transmission lines and transformers are carefully observed to assess whether or not they are within prescribed operating limits. If the power flow study indicates that there are voltage magnitudes outside bounds at certain points in the network, then appropriate control actions become necessary in order to regulate the voltage magnitude.Similarly, if the study predicts that the power flow in a given transmission line is beyond the power carrying capacity of the line then control action will be taken[3][6].

II. OPTIMAL POWER FLOW

An electrical network consists of various electrical elements such as generator, load, transmission line, transformer etc. Here we assume that all the data for generator, load, and transmission line parameters are givenin per unit system and common MVA base [8].

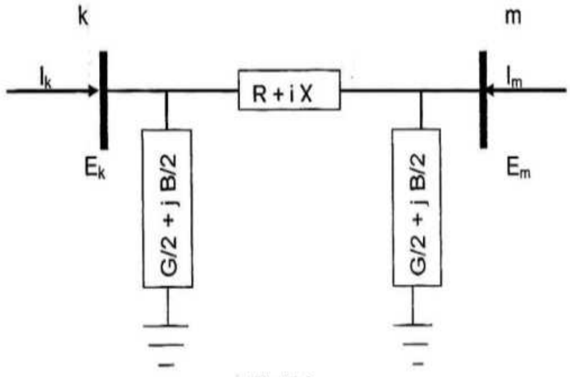

Fig.1 Electrical Network representation

For the power flow equation here we will build a bus admittance matrix for n-bus electrical network. The same principle can be applied to any number buses.

III. BUS ADMITTANCE MATRIX:

Y_{bus} matrix for a n-bus network can be written as [8]:

$$Ybus = \begin{bmatrix} Y_{11} & Y_{12} \cdots\cdots\cdots Y_{1n} \\ Y_{21} & Y_{22} \cdots\cdots\cdots Y_{2n} \\ \vdots & \vdots \quad\quad\quad \vdots \\ Y_{n1} & Y_{n2} \cdots\cdots\cdots Y_{nn} \end{bmatrix}_{nxn}$$

IV. POWER FLOW EQUATION [8]

The suitable power flow equations,based on above fig; the real power injected at k-th bus is

$$P_k^{cal} = -V_k^2 B_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \cos(\theta_k - \theta_m)]$$

Similarly the reactive power injected at k-th bus is

$$Q_k^{cal} = -V_k^2 G_{kk} \_ V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)]$$

From the equations (1.2) and (1.3) it is clear that the powers injected at bus k flows through the ith element of the transmission line. However, a practical power system will consists of many buses and many transmission line elements. This calls for the above two equation to be expressed as the summation of the power flowing at each one of the transmission elements terminating at this bus. This is illustrated in Fig .2 and Fig .3 for the cases of active and reactive powers respectively.

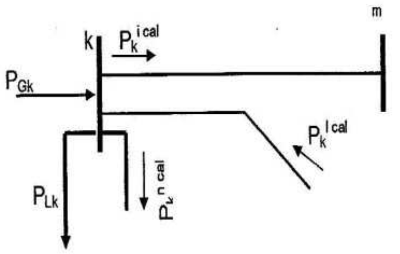

Fig.2.Activepower balance at bus K

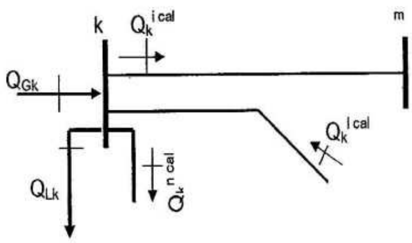

Fig.3. Reactive power balance at bus K

The generic net active and reactive powers injected at bus k are :

$$P_k^{cal} = \sum_{i=1}^{n} P_k^{ical} \quad \text{(eq.1.4)}$$

$$Q_k^{cal} = \sum_{i=1}^{n} Q_k^{ical} \quad \text{(eq.1.5)}$$

where P_k^{cal} and Q_k^{cal} are active and reactive power flows contributed by the mutual admittance elements i.e. from k-bus to m-bus.

V. POWER MISMATCH EQUATIONS [4] [8] :

For steady state operation of power system, at a given bus the generation, load and power exchanged through the transmission elements connecting to the bus must add up to zero. This applies to both active and reactive power. These equation are termed as 'power mismatch equations' and at bus k they take the following form :

(eq.1.1)

$$\Delta P_k = P_{gk} - P_{Lk} - P_k^{cal} = P_k^{sch} - P_k^{cal} = 0$$

$$\Delta Q_k = Q_{gk} - Q_{LK} - Q_k^{cal} = Q_k^{sch} - Q_k^{cal} = 0$$

Where the terms ΔP_k and ΔQ_k are the mismatch active and reactive powers at bus k respectively.P_{GK} and Q_{GK} represent the active and reactive power injected by the generator at bus k respectively.P_{LK} and Q_L represent the active and reactive powers drawn by the load at bus-k respectively.Further for specified levels of power generation and power load at bus k the power mismatch equations can be written as :

(eq.1.2)

(eq.1.3)

$$\Delta P_k = P_{gk} - P_{LK} - \{V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)]\} = 0$$

$$\Delta Q_k = Q_{gk} - Q_{LK} - \{V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)]\} = 0$$

(eq.1.7)

The generic power mismatch equations at bus k are

$$\Delta P_k = P_{Gk} - P_{Lk} - \sum_{i-1}^{n} P_k^{ical} = 0$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - \sum_{i-1}^{n} Q_k^{ical} = 0$$

VI. NET ACTIVE AND REACTIVE POWER

The generation and the load at bus k may be measured by the electric utility and in the parlance of power system engineers, their net values are known as the 'scheduled active and reactive powers':

$$P_k^{sch} = P_{Gk} - P_{LK} \quad Q_k^{sch} = Q_{Gk} - Q_{LK}$$

Four variables are associated with each bus. These are [7];voltage magnitude |V|,phase angle θ ,real power P,reactive power Q.The most common techniques used for the iterative solution of nonlinear algebra equations are Gauss-Seidel, Newton-Raphson method , Fast Decoupled power flow solution method etc. [4]. Out of these three method, use of Newton-Raphson (NR) method is more powerful for medium and large network. This is because it works faster and is sure to converge in most cases. Number of iteration required is less and the convergence process is faster than any other method.

VII. NEWTON-RAPHSON METHOD FOR POWER FLOW PROBLEM

For power flow equation as the power flow equation is a nonlinear algebraic equation consists of variables nodal voltage magnitudes V and phase angles θ ; the power mismatches Equations ΔP and ΔQ are expanded around a base point $(\theta^{(0)}, V^{(0)})$ and hence, the power flow Newton-Raphson algorithm is expressed by the following relationship [8]:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^{(i)} = \begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V} V \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V} V \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix}$$

Further this can be written in this form as :

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix}$$

where J_1, J_2, J_3 and J_4 constitutes the Jacobian matrix, each element of the order of (nb-1) x (nb-1).

Thus Jacobian matrix are written as :

$$J_1 = \frac{\partial P_k}{\partial \theta_m}, \qquad J_2 = \frac{\partial P_k}{\partial V_m} V_m$$

$$J_3 = \frac{\partial Q_k}{\partial \theta_m}, \qquad J_4 = \frac{\partial Q_k}{\partial V_m} V_m$$

where k = 1, 2, …….. nband m = 1, 2, ……..., nb …..but omitting the slack bus entries.

In general,for a bus k containing n transmission elements *l*,the bus self-elements take the following form:

$$\frac{\partial P_k}{\partial \theta_k} = \sum_{l=1}^{n} \frac{\partial P_{k,l}}{\partial \theta_{k,l}}, \qquad \frac{\partial P_k}{\partial V_k} V_k = \sum_{l=1}^{n} \frac{\partial P_{k,l}}{\partial \theta_{k,l}} V_{k,j}$$

$$\frac{\partial Q_k}{\partial \theta_k} = \sum_{l=1}^{n} \frac{\partial Q_{k,l}}{\partial \theta_{k,l}}, \qquad \frac{\partial Q_k}{\partial V_k} V_k = \sum_{l=1}^{n} \frac{\partial Q_{k,l}}{\partial V_{k,l}} V_{k,l}$$

After the convergence of the power flow solution, we get the final value of state variables i.e. voltage magnitudes and phase angles have been calculated. Then active and reactive power flows throughout the transmission system are determined quite straightforwardly.

VIII. STATE VARIABLE INITIALIZATION

The effectiveness of the Newton-Raphson method to achieve feasible interactive solutions is dependent upon the selection of suitable initial values for all the state variables involved in the study [8].The power flow solution starts with initial value of voltage magnitude of 1 p.u. at all PQ buses. The slack and PV buses are given their specified values, which remain constant throughout the iterative solution if no generator reactive power limits are violate. The initial voltage phase angles are selected to be 0 at all buses.

IX. ACTIVE AND REACTIVE POWER FLOW THROUGH TCSC

As Thyristor Controlled Series Capacitor (TCSC) will control the power flow in the transmission line of a large electrical network, here we will model the TCSC as a variable reactance which varies in terms of firing angle of thyristor [7] [8] [9].

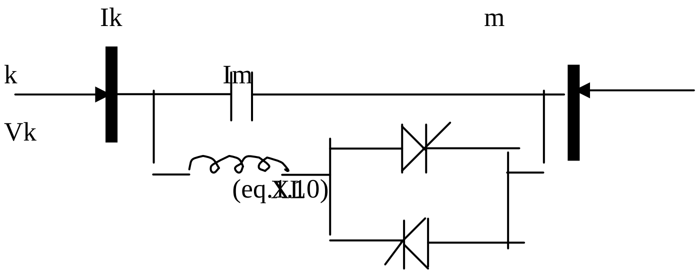

Fig.4- CSC connected between buses k & m

The fundamental frequency equivalent reactance X_{TCSC} of the TCSC is given by : (eq.1.11)

$$X_{TCSC} = -X_C + C_1\{2(\pi-\alpha) + \sin[2(\pi-\alpha)]\} - C_2 \cos^2(\pi-\alpha)\{\varpi \tan[\varpi(\pi-\alpha)] - \tan(\pi-\alpha)\}$$

The TCSC active and reactive power equations at busk are

$$P_k = V_k V_m B_{km} \sin(\theta_k - \theta_m) \qquad \text{(eq.1.12)}$$

$$Q_k = V_k^2 B_{kk} - V_k V_m B_{km} \cos(\theta_k - \theta_m)$$

where $B_{mm} = -B_{mk} = B_{TCSC} = \frac{1}{X_{TCSC}}$

For the case when the TCSC controls active power flowing from bus k to bus m at a specified vale, the set of linearised power flow equations is :

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{km}^{\alpha TCSC} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial V_m} V_m & \frac{\partial P_k}{\partial \alpha} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_k} V_k & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \alpha} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial V_m} V_m & \frac{\partial Q_k}{\partial \alpha} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_k} V_k & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \alpha} \\ \frac{\partial P_{km}^{\alpha TCSC}}{\partial \theta_k} & \frac{\partial P_{km}^{\alpha TCSC}}{\partial \theta_m} & \frac{\partial P_{km}^{\alpha TCSC}}{\partial V_k} V_k & \frac{\partial P_{km}^{\alpha TCSC}}{\partial V_m} V_m & \frac{\partial P_{km}^{\alpha TCSC}}{\partial \alpha^{TCSC}} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta V_k}{V_k} \\ \frac{\Delta V_m}{V_m} \\ \Delta \alpha^{TCSC} \end{bmatrix}$$

Where $\Delta P, \Delta Q, \Delta P_{km}^{\alpha TCSC}$ constitute 'power mismatch equation' and these are expressed as;

$$\Delta P_k = P_{Gk} - P_{Lk} - P_k^{cal} = P_k^{sch} - P_k^{cal} = 0$$

$$\Delta Q_k = Q_{Gk} - Q_{Lk} - Q_k^{cal} = Q_k^{sch} - Q_k^{cal} = 0$$

$$\Delta P_{km}^{\alpha TCSC} = P_{km}^{reg} - P_{km}^{\alpha TCSC,cal}$$

where

P_{km}^{reg} = The active power to be controlled from bus k to bus m

$P_{km}^{\alpha TCSC,cal}$ = calculated active power of the TCSC at bus k

Similarly $\Delta\theta, \Delta V, \Delta\alpha^{TCSC}$ constitute state variables and expressed as :

$$\Delta\theta = \theta^{i+1} - \theta^{i}$$

$$\Delta V = V^{i+1} - V^{i}$$

$$\Delta\alpha^{TCSC} = \alpha^{TCSC\,(i+1)} - \alpha^{TCSC\,(i)}$$

$\Delta\alpha^{TCSC}$ is the incremental change in the TCSC firing angle at the ith iteration.

Partial derivatives of the firing angle model is given by :

$$\frac{\partial P_k}{\partial \alpha} = P_k B_{TCSC} \frac{\partial X_{TCSC}}{\partial \alpha}$$

$$\frac{\partial Q_k}{\partial \alpha} = Q_k B_{TCSC} \frac{\partial X_{TCSC}}{\partial \alpha}$$

$$\frac{\partial B_{TCSC}}{\partial \alpha} = B_{TCSC}^2 \frac{\partial X_{TCSC}}{\partial \alpha}$$

$$\frac{\partial X_{TCSC}}{\partial \alpha} = -2C_1[1+\cos(2\alpha)] + C_2 \sin(2\alpha)\{\varpi \tan[\varpi(\pi-\alpha)] - \tan\alpha\} + C_2\left\{\varpi^2 \frac{\cos^2(\pi-\alpha)}{\cos^2[\varpi(\pi-\alpha)]} - 1\right\}$$

X. SIMULATION AND RESULT

The steady state is determined by finding out the flow of active and reactive power throughout the network and the voltage magnitude at all nodes of the network.Optimal Power Flow problem has been explored and tested with and without compensating devicei.e.TCSC.In this paper we validate it on the IEEE-5 bus,14 bus and 30 bus network using MATLAB simulation.Following are the specifications for compensator TCSC: Number of TCSC's = 1, TCSC's reactance = -0.015, XLo : Lower reactance limit = -0.05,XHi : Higher reactance limit= 0.05,Power flow direction: 1 is for sending to receiving bus; -1for opposite direction.,Active power flow to be controlled = 0.21 p.u.,Initial Firing Angle = 145 ° ,Firing angle lower limit = 90°, Firing angle upper limit =180 °General Parameters : Maximum Iteration = 100,Tolerance = 1e-12

1. 5-Bus system :

Bus no.	Voltage mag. Without TCSC	Voltage magWith TCSC
1	1.06	1.0600
2	1	1.0000
3	1.0061	1.0197
4	0.9879	1.0022
5	0.9815	0.9647

Table 1.voltage profile for 5 –bus

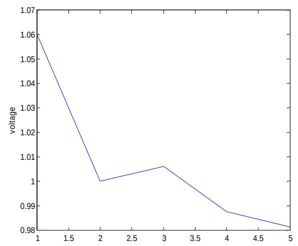

Fig.5.Voltage profile for 5-bus without TCSC

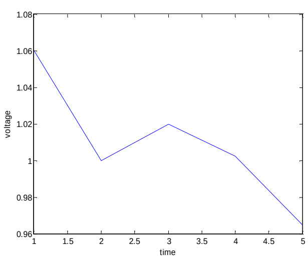

Fig.6.Voltage profile for 5-bus with TCSC

Active and reactive power loss before and after compensation with TCSC..Number of transmission lines=7

Table 2.Power losses in 5-bus

Bus		Ploss without TCSC	Ploss with TCSC	Qloss Without TCSC	Qloss With TCSC
From	To				
1	2	1.8724	1.8857	-0.7536	-0.7136
1	3	2.0209	1.4041	0.7228	-1.1961
2	3	0.0805	0.1347	-3.7832	-3.6753
2	4	1.632	0.6412	-3.6798	-3.9018
2	5	0.3909	1.564	-1.7722	1.7959
3	4	0.4047	0.3064	-0.7742	-1.1247
4	5	0.1831	0.0002	-4.6651	-4.8373

Here we can observe that by placing TCSC can improve the voltage profile and losses are reduced. The bestlocation for TCSC is between bus 2 and bus 5 to minimize thelosses.[10][11][12].

2. 14-Bus system :

Bus no.	Voltage mag. Without TCSC	Voltage mag. With TCSC
1	-4.1053	6.7486
2	-3.8846	1.0450
3	-1.3996	1.0100
4	1.0190	10.3833
5	1.0200	1.0200
6	1.0700	1.0700
7	1.0620	1.0620
8	1.0900	1.0900
9	1.0100	1.0100
10	1.0510	1.0510
11	1.0570	1.0570
12	1.0550	1.0550
13	1.0500	1.0500
14	1.0360	1.0360

Table 3.Voltage profile of 14-bus

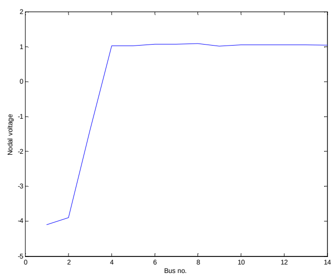

Fig.7.Voltage profile for 14-bus without TCSC

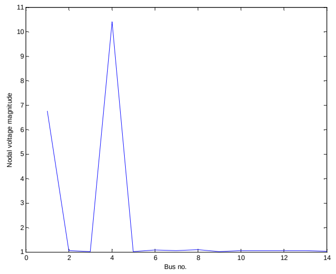

Fig.8.Voltage profile for 14-bus with TCSC

Active and reactive power loss before and after compensation with TCSC.Number of transmission lines=20

Bus		Ploss without TCSC	Ploss with TCSC	Qloss Without TCSC	Qloss With TCSC
From	To				
1	2	2.5567	0	1.047	0
1	5	1.1301	0	0.4621	0
2	3	2.953	0	1.2404	0
2	4	1.493	0.2487	0.4503	0.7521
2	5	3.2505	0	0.9897	0
3	4	0.898	0.2929	0.2273	0.7382
4	5	1.3925	1.009	0.4392	3.1828
4	7	0	0	0.2066	0.7053
4	9	0	0	0.0408	0.2652
5	6	0	0	0.0237	0
6	11	0.2143	0	0.0449	0
6	12	0.0923	0	0.0192	0
6	13	0.146	0	0.0288	0
7	8	0	0	0	0
7	9	0	0	0.1949	0
9	10	0.0112	0	0.003	0
9	14	0.1629	0	0.0347	0
10	11	0.0199	0	0.0047	0
12	13	0.0022	0	0.0002	0
13	14	0.0898	0	0.0183	0

Table 4.Power loses in 14-bus

Here the best location for TCSC is between bus 3 and bus 4 to minimize the losses.

3. 30-bus system :

Bus No.	Voltagemag. Without TCSC	Voltage mag. With TCSC
1	1.0600	1.06
2	-7.7412	1.0430
3	6.4983	0.4821
4	-7.3834	0.2182
5	-0.0416	1.0100
6	0.8855	-2.1623
7	-0.5024	10.1559
8	4.3961	1.01
9	-0.3331	-3.4325
10	-1.3829	0.4638
11	-1.2281	1.080
12	-7.0748	1.6277
13	0.2637	1.0700
14	0.2469	-1.2503
15	-1.2178	1.7590
16	-4.3907	-2.5648
17	-11.9664	-0.4078
18	-2.5892	-6.7338
19	-5.6963	0.5927
20	-25.7305	-7.0616
21	-0.1456	0.0462
22	31.9157	-3.5949
23	2.3523	0.3605
24	4.0312	-0.3696
25	-8.7680	-0.2225
26	-8.5498	1.0926
27	-0.7218	1.1881
28	0.3941	-0.5858
29	0.1795	0.0801
30	0.1227	0.9122

Table 5.Voltage profile of 30-bus

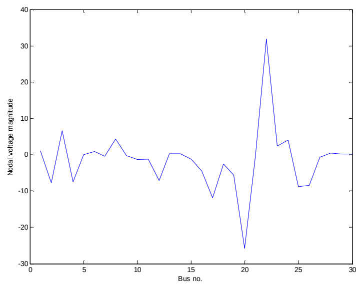

Fig.9.Voltage profile for 30-bus without TCSC

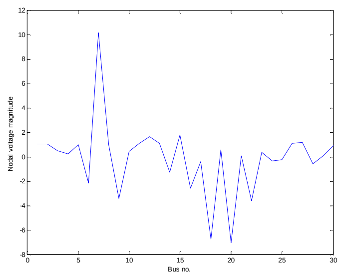

Fig.10.Voltage profile for 30-bus with TCSC

Active and reactive power loss before and after compensation with TCSC.

Number of transmission lines=41

Bus		Ploss before	Ploss after	Qloss before	Qloss after
From	To				
1	2	0.0458	0.3204	0.1876	0.1317
1	3	0.0456	0.2177	0.1872	0.0895
2	4	0.0707	0.1361	0.2953	0.0571
3	4	0.3167	0.0374	0.9594	0.0113
2	5	0.1014	0.4661	0.3085	0.1419

2	6	0.1457	1.1808	0.3679	0.2977
4	6	0.3852	3.866	1.2149	1.2194
5	7	0	0	0.0013	4.0093
6	7	0	0	0.0017	2.7114
6	8	0	0	0.0781	0.0594
6	9	0.0028	6.0694	0.0059	1.271
6	10	0.007	0.688	0.0145	0.1432
9	11	0.0069	1.7169	0.0136	0.3381
9	10	0	0	0.0092	0.7478
4	12	0	0	0.1476	0.266
12	13	0.2035	2.1023	0.5406	0.5585
12	14	0.075	0.9254	0.1594	0.1968
12	15	0.1091	0.6526	0.2555	0.1527
12	16	0.1521	0.6089	0.1376	0.0551
14	15	0.002	0.2613	0.0041	0.0532
16	17	0.2454	0.6402	1.0088	0.2625
15	18	0.0149	3.5559	0.0612	1.456
18	19	0.0139	6.0125	0.0578	2.5231
19	20	1.4952	7.3199	4.5251	2.2125
10	20	1.0199	8.8193	3.1026	2.6841
10	17	0.3434	0.1064	0.8672	0.0269
10	21	0.0132	0.1328	0.0418	0.0419
10	22	0	0	5.302	0.6346
21	23	0	0	0.0104	0.002
15	23	0	0	0.0364	0.1116
22	24	1.526	2.8297	3.1957	0.5926
23	24	0.0053	0.0062	0.011	0.0013
24	25	0.4556	0.0261	0.8973	0.0051
25	26	0	0	1.0344	0.0438
25	27	0	0	0.6554	0.0852
28	27	0.0047	0.3507	0.0125	0.0932
27	29	0.0004	0.1758	0.0009	0.0374
27	30	0.0007	0.8297	0.0016	0.1942
29	30	0	0.2436	0	0.022
8	28	0.0261	0.2479	0.0531	0.0505
6	28	0.0011	0.7041	0.0023	0.1434

Table 6.Power loses in 30-bus

The optimal location for TCSC is between bus 6 and bus 28 to minimize the losses.

XI. DISCUSSION

The contribution of TCSC (FACTS) towards the improvement of voltage profile and reduction of power losses has been tested on a IEEE 5-bus ,14-bus and 30-bus system.Optimal Power Flow problem has been explored and tested with and without compensating device. The results show that in large-scale system, where the number of constraints is very large, the Thyristor-Controlled Series Capacitor is effective compensating device for controlling the specified amount of active power in between two buses.The FACTS device TCSC located at optimal locations is observed to have a better voltage profile and power loss.

XII. FUTURE SCOPE

This method can be used for higher bus system i.e 54-bus and can be assessed for voltage profile,power losses and optimal location of compensator.Effect of random load variation on optimal location of the compensator can be studied.

REFERENCES

1. HadiSaddat, "Power System Analysis (MATLAB concept)", Tata McGraw-Hill, Edition, 2002
2. Muhammad H. Rashid, "Power Electronics (concept of Flexible AC Transmission Systems)", Pearson Education-3rd Edition, 2004
3. Narain G. Hingoriani/Laszlo Gyugyi, "Understanding FACTS", IEE press, 1st Indian Edition, 2001
4. IJ Nagrath / DP Kothari, "Powr System Engineering (concept of series and shunt compensation)", Tata McGraw-Hill, 2003
5. C. L. Wadhwa, "Electrical Power systems (compensation in power system)", *New Age International, 3rd Edition, 2004.*
6. P. Moore and P. Ashmole, "Flexible ac transmission systems : part 4-advanced FACTS controller," *Power Engineering Journal, April 1998, pp.95-100.*
7. E Acha/VG Agelidis / THE Miller, "Power Electronic Control in Electrical Systems", *Newnes Power Engineering Series, 1st Indian Edition, 2006.*
8. Fuerte-Esquivel, C.R.; Acha, E.; Ambriz-Perez, H.: "A thyristor controlled series compensator model for the power flow solution of practical power networks", *power systems, IEEE transactions on Power Delivery, Volume 15, Issue 1, Feb. 2000 Page (s) : 58 – 64*
9. Gama, C.; Tenorio, R.; "Improvements for power systems performance: modeling, analysis and benefits of TCSCs", *Power Engineering Society Winter Meeting, 2000. IEEE Volume 2, 23-27 Jan. 2000 Page(s): 1462-1467 vol. 2.*
10. J.G. Singh, S.N. Singh, S.C. Srivastava, "Placement of FACTS Controllers for Enhancing Power System Loadability," in*Proc.of the IEEE Power India Conference*, 2006, pp. 10-17.
11. S.N. Sing, A.K. David, "A New Approach for Placement of FACTS Devices in Open Power Markets," *IEEE PowerEngineering Review,* 2001, Vol. 21, No.9, pp. 58-60.
12. S. Gerbex, R. Cherkaoui, A.J. Germond, "Optimal Location of FACTS Devices to Enhance Power System Security", in *Proc. of the IEEE Power Tech onference*,2003, Bologna, Vol. 3, pp. 1-7.
13. N.G. Hingurani, L. Gyugyi, *Understanding FACTS:Concepts and Technology of Flexible AC TransmissionSystems*, IEEE Press, New York, 2000.
14. M. Noroozian, L. Angquist, M. Ghandhari, G. Anderson,"Improv- ing Power System Dynamics by SeriesconnectedFACTS De- vices," *IEEE Trans. on Power Delivery*, Vol. 12, No.4, October 1997.
15. J.A. Momoh, J. Zhu, G.D. Boswell, S. Hoffman, "PowerSystem Security Enhancement by OPF with PhaseShifter," *IEEE Trans. on Power Systems*, Vol. 16, No.2,May 2001.
16. Sung-Hwan, L. Jung-Uk, M. Seung-Il, "FACTSOperation Scheme for Enhancement of Power SystemSecurity," in *Proc of IEEE Power Tech Conference*,Bologna, 2003, Vol. 3, pp. 36-41.

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