Power Flow and Static Voltage Stability Improvement using TCSC and SVC

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ABSTRACT
Restructuring of electricity markets is adding new complexities due to the presence of large number of market players. The congestion in transmission lines is one such effect born out of restructuring exercise.

Mitigation of congestion was easier in vertically integrated utilities but this is more complex in restructured system. This paper examines the effect of TCSC and SVC in improvement of power flow and voltage stability enhancement in a power network. The proposal has been tested on IEEE-14 bus system.

Keywords
Power flow, static voltage stability, TCSC, SVC

1. INTRODUCTION
After restructuring of electricity sector, the power system has undergone a sea change. With environmental factors and right of way issues, building of new transmission lines are hampered. The growing demands in power system due to increase in load, wide load diversity, unplanned power exchanges, open access etc. affects secure and reliable operation of power system. The system also experiences severe overload on certain transmission corridors. Hence, to improve system security, reliability and stability, FACTS (Flexible AC Transmission System) are widely used. TCSC (Thyristor Controlled Series Capacitor) and SVC (Static Var Compensator) are two such power electronic devices which are used to improve power flow and voltage stability of networks.

FACTS devices help to improve system stability & reliability, damp power system oscillations, improve voltage profile, increase power flow etc. The use of FACT devices not only helps to increase power flow and improve static voltage stability but also defers the need for new transmission line.

This paper investigates the effect of TCSC in enhancing the power flow by varying the line reactance.

SVC is used to improve the profile of voltage of buses and ensure rapid injection of reactive power into the bus.

This paper is organised as follows- section-2 reviews the literature on the subject, section-3 deals with mathematical modelling of TCSC and SVC. Section-4 discusses simulation result & conclusion is given in section-5.

2. LITERATURE REVIEW
The world's first SVC was installed by Tennesee Valley Authority in USA for the improvement of voltage profile. The concept of FACTS devices were proposed by Hingroni et al [1]. These devices- series, shunt and combined series and shunt are thyristor controlled power electronic devices which

alters line reactance (X), voltage magnitude (V) & voltage angle (θ). SVC is a parallel combination of a capacitor and thyristor controlled reactor. It is used to inject the reactive power into the system thereby controlling voltage profile of buses [2]. Siddiqui and Deb [3] had used SVC to control bus voltage by injecting or absorbing reactive power by varying firing angle of thyristor controlled reactor. Thukaram et al [4] used SVC for voltage stability improvement and determined the rating and location of SVC for optimum gain in power network.

Owlegard et al. [5] had used TCSC to improve power flow in a power network by varying the line reactance. Siddiqui and Deb [6] had used TCSC in restructured electricity markets to reduce line congestion by varying the firing angle of thyristor. It was demonstrated that line reactance is a function of firing angle of thyristor which ultimately regulates power flow in a line.

Cannizarse et al [7] had used both SVC and TCSC to study voltage collapse phenomenon and had demonstrated their successful use.

3. MODELLING OF DEVICES
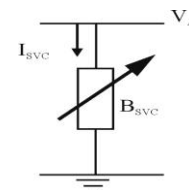### 3.1 Modelling of SVC

Fig. 3.1 SVC equivalent circuit

The positive sequence susceptance of SVC (BSVC) which consists of inductance XL and shunt capacitance XC is given by:

$$B_{SVC} = \frac{1}{X_L X_C}[X_L - \frac{X_C}{\pi}(2\pi - 2\alpha) - \frac{X_C}{\pi} Sin\, 2\alpha]\ldots (1)$$

Since reactive power drawn by SVC at bus 'A' is given by-

$$Q_{SVC} = -\, V_A^2 B_{SVC} \quad \ldots\ldots\ldots (2)$$

Hence, substituting eq.(1) in above equation, (2) reactive power at bus 'A' is given by-

$$Q_A = \frac{-\, V_A^2}{X_L X_C}[X_L - \frac{X_C}{\pi}(2\pi - 2\alpha) - \frac{X_C}{\pi} Sin\, 2\alpha]\ldots (3)$$

The linearized SVC equation is given by

$$\begin{bmatrix} \Delta P_A \\ \Delta Q_A \end{bmatrix}^i \begin{bmatrix} O & 2V_A^2 \\ O & \dfrac{}{\pi X_l} [\cos 2\alpha - 1] \end{bmatrix} \begin{bmatrix} \Delta \theta_A \\ \Delta \alpha \end{bmatrix}^i \quad \ldots (4)$$

At the end of each iteration (i), firing angle (α) is updated as per following

$$\alpha^{i+1} = \alpha^{i-1} + \alpha^i \quad \ldots (5)$$

3.2 Modelling of TCSC

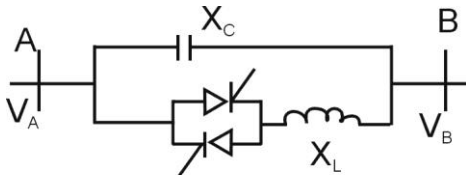A TCSC consists of a fixed capacitor in parallel with a thyristor controlled reactor.

Fig. 3.2 TCSC Model

The equivalent reactance of TCSC model in

Fig. 3.2 is given by [6]

$XC = -XC + C1 [2\pi - 2\alpha + Sin (2\pi - 2\alpha)] -C2 Cos2 (\pi-\alpha) [\omega \tan (\omega\pi - \omega\alpha) - \tan (\pi-\alpha)]\ldots$ (6)

Where

$$C_1 = \frac{X_c + X_{LC}}{\pi} \quad \ldots (7)$$

$$C_2 = \frac{4X_{LC}^2}{XL\pi} \quad \ldots (8)$$

$$X_{LC} = \frac{X_L X_C}{X_C - X_L} \quad \ldots (9)$$

$$\omega = \sqrt{\frac{X_C}{X_L}} \quad \ldots (10)$$

The active and reactive power at bus 'A' are :

PA = VA VBBAB sin (θA - θB) …. (11)

QA = V2A BBB -VA VB BAB cos (θA - θB)…. (12)

Where

BAA = - BAB = BTCSC …. (13)

The linearized power equations for the case when TCSC controls active power flow from bus A to bus B at a specified value is given by

$$\begin{bmatrix} \Delta P_A \\ \Delta P_B \\ \Delta Q_A \\ \Delta Q_B \\ \Delta P_{AB}^{\alpha TCSC} \end{bmatrix} = X.Y. \text{ Where} \quad X = \begin{bmatrix} \triangle \partial Q_A \\ \triangle \partial Q_B \\ \dfrac{\triangle V_A}{V_A} \\ \dfrac{\triangle V_B}{V_B} \\ \dfrac{\triangle \alpha_{TCSC}}{\alpha_{TCSC}} \end{bmatrix}$$

$$Y = \begin{bmatrix} \dfrac{\partial P_A}{\partial \theta_A} & \dfrac{\partial P_A}{\partial \theta_B} & \dfrac{\partial P_A}{\partial V_A}V_A & \dfrac{\partial P_A}{\partial V_B}V_B & \dfrac{\partial P_A}{\partial \alpha} \\ \dfrac{\partial P_B}{\partial \theta_A} & \dfrac{\partial P_B}{\partial \theta_B} & \dfrac{\partial P_B}{\partial V_A}V_A & \dfrac{\partial P_B}{\partial V_B}V_B & \dfrac{\partial P_B}{\partial \alpha} \\ \dfrac{\partial Q_A}{\partial \theta_A} & \dfrac{\partial Q_A}{\partial \theta_B} & \dfrac{\partial Q_A}{\partial V_A}V_A & \dfrac{\partial Q_A}{\partial V_B}V_B & \dfrac{\partial Q_A}{\partial \alpha} \\ \dfrac{\partial Q_B}{\partial \theta_A} & \dfrac{\partial Q_B}{\partial \theta_B} & \dfrac{\partial Q_B}{\partial V_A}V_A & \dfrac{\partial Q_B}{\partial V_B}V_B & \dfrac{\partial Q_B}{\partial \alpha} \\ \dfrac{\Delta P_{AB}^{\alpha TCSC}}{\partial \theta_A} & \dfrac{\Delta P_{AB}^{\alpha TCSC}}{\partial \theta_B} & \dfrac{\Delta P_{AB}^{\alpha TCSC}}{\partial V_A}V_A & \dfrac{\Delta P_{AB}^{\alpha TCSC}}{\partial V_B}V_B & \dfrac{\Delta P_{AB}^{\alpha TCSC}}{\partial \alpha_{TCSC}} \end{bmatrix} \quad \ldots(14)$$

$\Delta P_{AB}^{\alpha TCSC}$ is given by

$$\Delta P_{AB}^{\alpha TCSC} = P_{AB}^{reg} - P_{AB}^{\alpha TCSC.cal}$$

This is active power mismatch and $\Delta\alpha_{TCSC}$ is given by

$$\Delta \alpha_{TCSC} = \alpha_{TCSC}^{i+1} - \alpha_{TCSC}^i \quad \ldots (15)$$

4. RESULTS AND DISCUSSION

IEEE-14 bus system is taken as test case. Load flow is carried out on IEEE-14 bus system using Newton Raphson method. SVC is incorporated into Newton Raphson load flow algorithm.

The base case result shows that voltage in the bus number – 5, 6, 7, 9, 10, 11, 12, 13 and 14 are below 1 pu. So, SVC is connected to these buses to improve voltage of the buses to 1 pu. This is shown in table 4.1.

It is seen that voltage of the buses are improved to 1 per unit with corresponding reactive power and firing angle are shown. Since the bus voltages are less than 1 pu hence reactive power is injected into the buses (shown by − sign). For example, in bus 9, before connection of SVC, bus voltage is 0.9595 pu which after connection of SVC becomes 1 pu with a firing angle of 135.91 degree & reactive power injection of 0.3383 pu.

To test the effectiveness of SVC with varying load. The load on bus is increased by 20% which results in further fall in bus voltages. Now, with SVC connected to the bus, voltage is restored to 1 pu again. This is shown in table 4.2. Hence, it is seen that SVC improves the voltage stability of the bus (Fig. 4.1). Table 4.3 shows improvement in power flow using TCSC. TCSC has been connected to branch 2-4. The base case power flow (without TCSC) is 0.5554 pu.. After connection of TCSC to this branch, power flow is increased to 0.6109 pu with a firing angle of 146.9 degree and TCSC reactance of -0.0275 pu. Similarly, in branch 13-14, base case power flow is 0.0567 pu which increases to 0.0623 pu after connection of TCSC to this branch, the corresponding TCSC reactance is -0.0314 pu with a firing angle of 146.3 degree. Hence, it is seen that TCSC improves active power flow in a branch. (Fig. 4.2).

5. CONCLUSION

SVC was implemented on IEEE-14 bus system. It was observed that SVC could improve static voltage stability of the bus. With higher loading, SVC could still improve voltage profile.

TCSC was implemented on IEEE-14 bus system. It was found that TCSC could increase power flow in a branch even with higher loading.

6. REFERENCES

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Table no. 4.1 Voltage stability improvement using SVC(base case)

Bus no.	Bus voltage without svc (pu)	Bus Voltage with SVC		
		Voltage (pu)	Reactive Power (pu)	Firing Angle (deg)
5	0.9974	1.0	-0.1226	130.64
7	0.9780	1.0	-0.2615	133.93
9	0.9595	1.0	-0.3383	135.91
10	0.9563	1.0	-0.2676	134.08
11	0.9679	1.0	-0.1732	131.79
12	0.9703	1.0	-0.1233	130.63
13	0.9642	1.0	-0.2696	134.13
14	0.9417	1.0	-0.2398	133.39

Table no. 4.2 Voltage stability improvement using SVC with 20% increase in load

Bus no.	Voltage at 20% increased load (without SVC)	20% Increased load with SVC		
		Voltage (pu)	Reactive Power (pu)	Firing Angle (deg)
5	0.9655	1.0	-0.2675	134.08
7	0.9478	1.0	-0.3417	136.00
9	0.9198	1.0	-0.4265	138.38
10	0.9141	1.0	-0.3349	135.82
11	0.9247	1.0	-0.2163	132.82
12	0.9242	1.0	-0.1490	131.24
13	0.9172	1.0	-0.3297	135.68
14	0.8935	1.0	-0.2965	134.81

Table 4.3 Power flow improvement using TCSC

S.NO.	Base case without TCSC		10% increased active power (with TCSC)		
	Branch from	Base case power flow (pu)	Active power flow (pu)	TCSC reactance (pu)	Firing angle (deg)
1	2-4	0.5554	0.6109	-0.0275	146.9
2	12-13	0.0168	0.0184	-0.0178	150.1
3	13-14	0.0567	0.0623	-0.0314	146.3
4	2-3	0.7433	0.8176	-0.0503	144.8
5	2-5	0.4122	0.4500	-0.0241	142.9
6	4-5	0.6130	0.6743	-0.0210	148.6

Bus no.
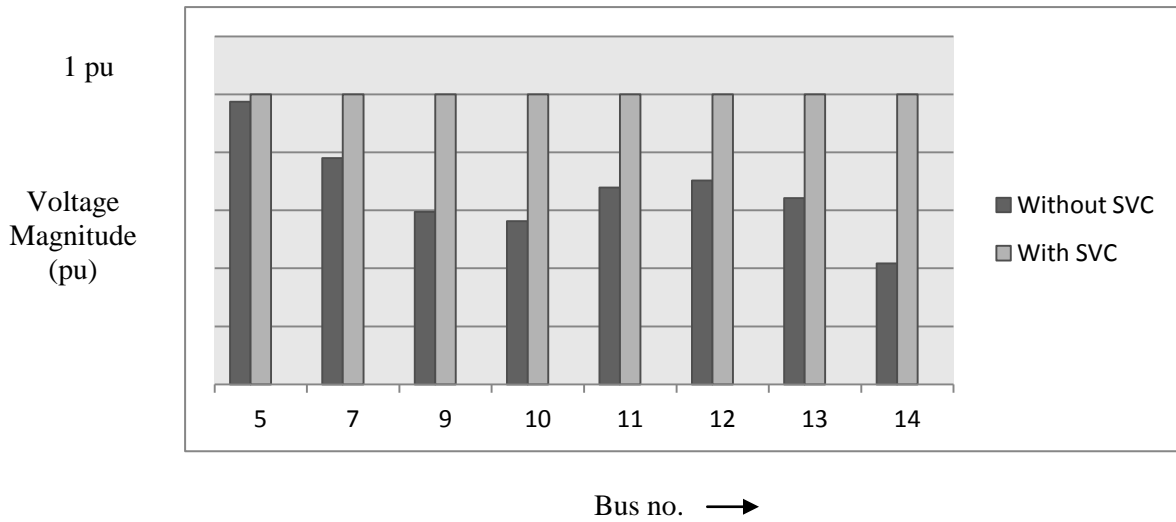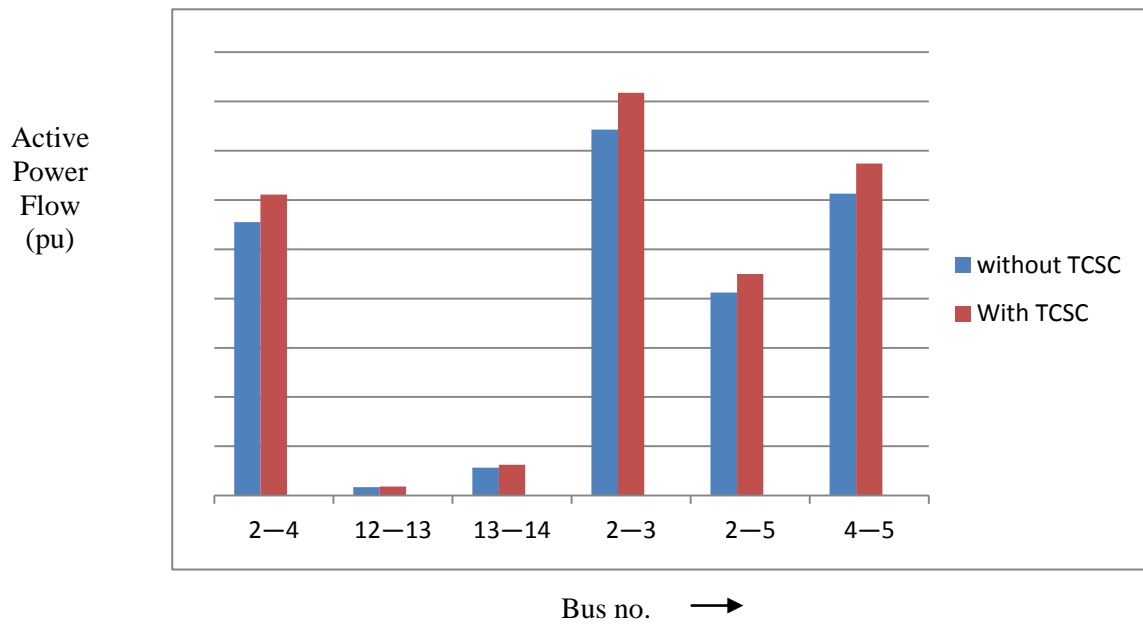**Fig. 4.1 Bus voltage improvement using SVC**

Bus no.
Fig. 4.2 Increased power flow with TCSC