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Voltage Stability Enhancement through Static Var Compensator

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Abstract--- With increase in electricity demand, the voltage stability of buses is affected requiring fast reactive power compensation. With the de-regulated environment, congestion limits the amount of line flow. In this connection, effect of Static Var compensator (SVC) has been investigated under dynamic situation to maintain voltage stability. This paper investigates effect of voltage stability on a IEEE-14 bus system using SVC.

Index terms---SVC, voltage stability, reactive power compensation.

1. Introduction

Consumption of electricity is increasing with economic development with de-regulated electricity market. This is leading to congestion in power transmission lines. With restrictions imposed by right of way issues among others, it is imperative to use existing transmission network more efficiently. Static Var Compensator (SVC) provides a way-out by dynamic voltage support and reactive power compensation. SVC acts as a continuous variable shunt succeptance that adjusts to meet a preset voltage requirement of a bus. Due to its fast acting and continuous compensation, SVC is used in transmission line to enhance power transfer capability. Literature studied discusses use of SVC for reactive power compensation and voltage support. N.G. Hingorani introduced the concept of FACTS devices [1]. E. Acha et. al. has discussed SVC and step down transformer model for power flow studies. The SVC is taken as continuous variable shunt susceptance that is adjusted to meet required magnitude of voltage [2]. Sabai Nang et. al. discusses dynamic performance for system disturbance and effectively regulates system voltage using SVC [3]. A. olwegard et. al. uses SVC to improve transmission capacity by reactive power compensation. [5)]. D. Thukaram & S.A. Loni uses SVC for system voltage stability improvement [6].

2. Principle of SVC

Static Var Compensator is a VAR generator whose output is adjusted to exchange capacitive or inductive currents so as to maintain/control

specific parameters of electrical power system (typically bus voltage).
SVC is a combination of controllable shunt reactor and a shunt capacitor. The controlled shunt reactor is series combination of reactor and ant parallel connected pair of thyristor which is known as TCR (thyristor controlled reactor).

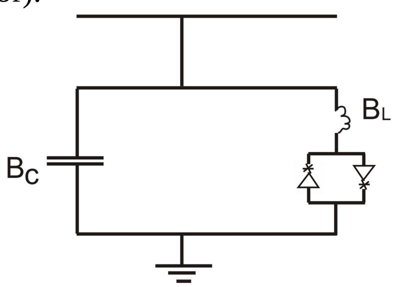

Fig.2.1. Schematic diagram of SVC

The susceptance of SVC can be varied by varying the firing angle of thyristor (TCR branch) in the range of 90^0-180^0. During normal operation, SVC can control total susceptance according to the terminal voltage. At minimum and maximum susceptance, SVC behaves like a fixed capacitor or inductor. When system voltage dips due to any fault, SVC immediately provides reactive power to the system to improve the voltage. There are two configurations of SVC viz- (a) Combination of TCR and fixed Capacitor (b) Combination of TCR and TSC (thyristor switched capacitor).

3. Modeling of SVC

SVC provides shunt controlled reactive power compensation through thyristorized power electronic devices. The switching of inductor is stepless and smooth and that of capacitor in step. SVC tries to maintain bus voltage constant by injective power (either capacitive or inductive). With increase in bus voltage, SVC tries to absorb reactive power and with decrease in bus voltage, SVC injects reactive power.
The equivalent circuit shown below is used to derive the SVC non linear power equations and linearised equations required by Newton method.

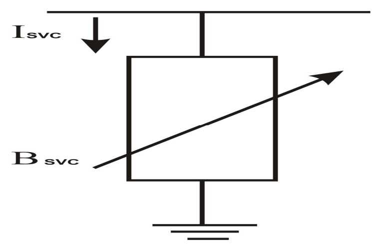

Fig.3.1 Equivalent circuit of SVC

The current drawn by SVC is

$$I_{SVC} = jB_{SVC}\ V_k \longrightarrow (1)$$

Reactive power drawn by SVC, which is also reactive power injected at bus K is

$$Qsvc = Q_k - V_k^2 B_{SVC} \rightarrow (2)$$

The positive sequence susceptance of SVC consisting of TCR of inductance X_1 and shunt capacitance X_c is given by

$$B_{SVC} = B_C - B_{TCR} = \frac{1}{X_C X_L}\left\{ X_L - \frac{X_C}{\pi}\left[2\ (\pi - x) + \sin 2x \right] \right\} \quad (3)$$

By putting eq. (3) in eq (1)

$$Q_K = \frac{-V_K^2}{\ } \left\{ X_L - \frac{X_C}{\ } \right\}$$

$$\frac{X_C X_L}{\pi} \left[2 (\pi - X_{SVC}) + \sin (2 X_{SVC}) \right] \longrightarrow (4)$$

From e.g. (4), the linearised SVC equation is given as:

$$\begin{bmatrix} \Delta P_K \\ \Delta Q_K \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2V^2 \left[\cos (2 X_{SVC}) - 1\right]}{\Pi X_L} \end{bmatrix}^{(i)} \begin{bmatrix} \Delta Q_K \\ \Delta X_{SVC} \end{bmatrix}^{(i)}$$

At the end of iteration (i), the variable firing angle X_{SVC} is updated a curding to:

$$X_{SVC}^{(i)} = X_{SVC}^{(i-1)} + \Delta L_{SVC}^{(i)}$$

4. Problem Formulation

Here, the problem is divided into specific steps.

Step – 1

The test case system is taken as 14 bus IEEE system.

Step – 2

Load flow is carried out for 14 bus IEEE system This is taken as base case result.

Step – 3

By using SVC, the voltage in the bus can be increased or decreased where it is required. The SVC is incorporated into the Newton – Raphson load flow algorithm.

Step – 4

The base case result shows the bus voltages. Wherever the bus voltages are below flat voltage, SVC is connected to bus to improve the bus voltage to flat voltage or nearer to flat voltage.

5. Results and Discussion:

Newton – Raphson load flow method is used to solve load flow problem in power system using SVC. IEEE-14 bus system has been used to demonstrate the proposed method over a small range of power flow variations in the transmission system (see table-r)

As shown in table 2, the lowest base case voltage magnitude (PU) is 0.9417 at bus-14. After connecting SVC to that bus, the voltage improves to 1.0 pu with firing angle position of 133.3866 degree and equivalent susceptance value is –0.2398 pu. Negative sign means that SVC works in capacitive mode and reactive power supplied by SVC is –0.2398 pu.

By increasing 20% load, the reactive power and firing angle.

In Table-1 the data are of IEEE 14 bus system load flow result. This result has taken as the base result of this system. Then by using FACTS devices to this system the new results which is given in Table-2 compared with base case result.

As shown in above table the lowest base case voltage magnitude (pu) is 0.9417 at bus- 14.After connecting SVC to that bus, the voltage improves to 1.0 pu with firing angle position of 133.3866 degree and equivalent susceptance is -0.2398 pu .Negative sign means that SVC works in capacitive mode and the reactive power supplied by SVC is -0.2398 pu.

By increasing 20% load ,the reactive power and firing angle is 134.8140 degree respectively with voltage at that bus improving to 1 pu .
By decreasing 20% load ,the firing angle position and the reactive power supplied by SVC is 132.0789 degree and -0.1853 pu respectively.
Same procedure is repeated with bus nos. 5,7,9,10,11,12, and 13. So there is improvement of bus voltages to 1.0 pu with installation of SVC on these buses. The changes in bus voltages due to load variation (either increasing or decreasing) is taken care off by the SVC, makes bus voltages equal to 1.0 pu. This demonstrates utility of SVC in control of bus voltage.

6. Conclusion

The study was carried out on IEEE – 14 bus system. The SVC is represented as variable reactance whose magnitude changes with firing angle .Results confirms that SVC can provide fast acting voltage support to take care off voltage reduction at the bus.

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8. BIOGRAPHIES

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TABLE-1

BASE CASE

Bus No.	Bus Voltage magnitude (pu)	Bus Voltage Angle (pu)	Branch From – To	PQ Send (pu)	PQ Rec (pu)
1	0.0600	0	1-2	1.5732-0.3287i	-1.5279+0.3040i
2	1.0128	-4.5715	1-5	0.7608-0.1130i	-0.7316+0.0967i
3	1.0000	-13.0732	2-3	0.7433+0.0997i	-0.7179-0.1182i
4	0.9898	-10.2542	2-4	0.5554+0.0579i	-0.5379-0.0428i
5	0.9974	-8.7373	2-5	0.4122+0.0654i	-0.4027-0.0245i
6	0.9875	-15.2057	3-4	-0.2241-0.1416i	0.2291+0.1543i
7	0.9780	-13.7583	4-5	-0.6130-0.0241i	0.6181+0.0080i
8	1.0000	-13.7583	4-7	0.2829-0.0647i	-0.2829+0.0467i
9	0.9595	-15.6592	4-9	0.1608-0.0616i	-0.1608+0.0447i
10	0.9563	-15.9144	5-6	0.4403-0.0641i	-0.4403+0.0140i
11	0.9679	-15.7048	6-11	0.0720-0.0630i	-0.0711+0.0612i
12	0.9703	-16.1963	6-12	0.0786-0.0289i	-0.0778+0.0271i
13	0.9642	-16.2518	6-13	0.1777-0.0871i	-0.1750+0.0818i
14	0.9417	-17.1206	7-8	0.0000+0.1224i	-0.0000-0.1251i
			7-9	0.2829-0.1691i	-0.2829+0.1566i
			9-10	0.0543-0.0158i	-0.0542+0.0155i
			9-14	0.0944-0.0196i	-0.0931+0.0168i
			10-11	-0.0358+0.0425i	0.0361-0.0432i
			12-13	0.0168-0.0111i	-0.0167+0.0110i
			13-14	0.0567-0.0348i	-0.0559+0.0332i

TABLE-2

Bus No.	Bas Case Voltage (pu) (without SVC)	On base case load (With SVC)			Voltage at 20% increase load (pu) (without SVC)	20% increased load (with SVC)			Voltage at 20% increased load (pu)	20% decreased load (With SVC)		
		Voltage (pu)	Reactive power (pu)	Firing Angle (deg)		Voltage (pu)	Reactive power (pu)	Firing Angle (deg)		Voltage (pu)	Reactive power (pu)	Firing Angle (deg)
5	0.9974	1.0	-0.1226	130.6375	0.9655	1.0	-0.2675	134.0757	1.0081	1.0	0.0065	127.8475
7	0.9780	1.0	-0.2615	133.9269	0.9478	1.0	-0.3417	136.0028	0.9881	1.0	-0.1875	132.1198
9	0.9595	1.0	-0.3383	135.9109	0.9198	1.0	-0.4265	138.3815	0.9752	1.0	-0.2543	133.7476
10	0.9563	1.0	-0.2676	134.0777	0.9141	1.0	-0.3349	135.8205	0.9732	1.0	-0.2033	132.5051
11	0.9679	1.0	-0.1732	131.7971	0.9247	1.0	-0.2163	132.8184	0.9834	1.0	-0.1322	130.8537
12	0.9703	1.0	-0.1233	130.6298	0.9242	1.0	-0.1490	131.2376	0.9864	1.0	-0.0962	130.0478
13	0.9642	1.0	-0.2696	134.1282	0.9172	1.0	-0.3297	135.6812	0.9814	1.0	-0.2112	132.6944
14	0.9417	1.0	-0.2398	133.3866	0.8935	1.0	-0.2965	134.8140	0.9625	1.0	-0.1853	132.0789

APPENDIX – 1

POWER FLOW DATA IEEE 14 BUS TEST CASE

Base MVA = 100

Bus Data

Bus	Type	Pd	Qd	Gs	Bs
1	1	0	0	0	0
2	2	21.7	12.7	0	0
3	2	94.2	19	0	0
4	3	47.8	-3.9	0	0
5	3	7.6	16	0	0
6	2	11.2	7.5	0	0
7	3	0	0	0	0
8	2	0	0	0	0
9	3	29.5	16.6	0	0
10	3	9	5.8	0	0
11	3	3.5	1.8	0	0
12	3	6.1	1.6	0	0
13	3	13.5	5.8	0	0
14	3	14.9	5	0	0

Branch Data

Branch From-To	r	x	b
1-2	0.01938	0.05917	0.0528
1-5	0.05403	0.22304	0.0492
2-3	0.04699	0.19797	0.0438
2-4	0.05811	0.17632	0.034
2-5	0.05695	0.17388	0.0346
3-4	0.06701	0.17103	0.0128
4-5	0.01335	0.04211	0
4-7	0	0.20912	0
4-9	0	0.55618	0
5-6	0	0.25202	0
6-11	0.09498	0.1989	0
6-12	0.12291	0.25581	0
6-13	0.06615	0.13027	0
7-8	0	0.17615	0
7-9	0	0.11001	0
9-10	0.03181	0.0845	0
9-14	0.12711	0.27038	0
10-11	0.008205	0.19207	0
12-13	0.22092	0.19988	0
13-14	0.17093	0.34802	0

For simplicity bus voltage magnitude is taken as 1.0 pu and phase angle is0^0 except slack bus. Slack bus voltage magnitude is 1.06 and angle is 00

Generator Data

Gen Bus	P_g	Q_g	Q_{max}	Q_{min}
1	232.4	-16.9	10	0
2	40	42.4	50	-40
3	0	23.4	40	0
6	0	12.2	24	-6
8	0	17.4	24	-6