Optimal location of SVC by Voltage stability index

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Abstract--- Now a days the transmission lines are operated under the heavily stressed condition, hence there is risk of the consequent voltage instability. There is a multi-functional control device which can be effectively control the load flow distribution and the power transfer capability is the Flexible Alternating Current Transmission system (FACTS). Proper placements of FACTS devices reduce the transmission losses and improve the voltage stability. This paper presents an optimal location of SVC to determine the location of SVC for improving the voltage profile in a power system. The location of SVC is placed based on Voltage Stability Index (VSI) or L-index. The 9 bus system is simulated using Mipower software.

I. INTRODUCTION

As a result of recent environmental legislation, rights of way issues, increase in construction cost and deregulation policies, there is an increasing recognition of the necessity to utilize existing transmission system assets to the maximum extent possible which can be achieved with the help of FACTS devices. The flexible ac transmission system is the result of related developments in electronic devices designed to overcome the limitations of traditional mechanically controlled power transmission systems. By using reliable, high speed electronic controllers, this technology offers opportunity for increased efficiency. The parameters such as transmission line impedances, terminal voltages and voltage angle can be controlled by FACTS devices in an efficient way. The benefits brought about FACTS include improvement of system dynamic behaviour and enhancement of system reliability, voltage profile, and power flows with reduction of losses. SVC, STATCOM, SSSC and TCSC are the few examples of FACTS devices. System instability, loop flows, high transmission losses, voltage limit violations, inability to utilize transmission line capability up to the thermal limit, cascade tripping and high operational costs has been mentioned as a result of unregulated active and reactive power flows. Upgrading existing transmission lines by using FACTS controllers is suggested as a solution to these problems. Facts devices provide new control facilities, both under steady power flow control and Dynamic state. The possibility of controlling power flow in an electric power system without generation rescheduling or topological change can solve the problems of planning engineers to much extent and improve the system performance considerably. By using controllable components such as controllable series capacitors, phase shifters, static VAR compensators (SVC), static compensators
(STATCOM), Thyristor controlled series compensator (TCSC), static synchronous series compensator (SSSC), unified power flow controllers (UPFC),line flows can be changed in such a way that thermal limits are not violated, losses are minimized, stability margin are increased and contractual requirements are fulfilled without violating specified power dispatch.[1]

II. STATIC VAR COMPENSATORS (SVC)

A Static Var Compensator (SVC) is a power quality device, which employs power electronics to control the reactive power flow of the system where it is connected .As a result, it is able to provide fast-acting reactive power compensation on electrical systems.

A. *Basic Circuit of SVC*

Electrical loads, both generate and absorb reactive power. Since, the transmitted load varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage amplitude variations, a voltage depression or even a voltage collapse. A rapidly operating SVC can continuously provide the reactive power required to control dynamic voltage swings under various system conditions and thereby improve the power system transmission and distribution performance. Installing an SVC at one or more suitable points in the network can increase transfer capability and reduce losses while maintaining a smooth voltage profile under different network conditions. In addition, an SVC can mitigate active power oscillations through voltage amplitude modulation.Fig.1 shows the single line diagram of SVC.[3]

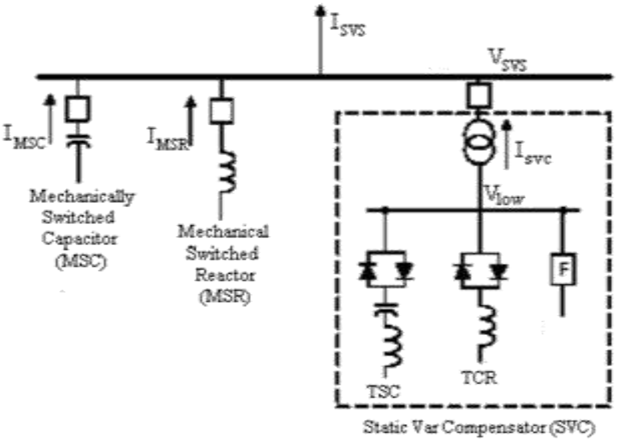

Fig. 1: Single line diagram of SVC

B. *Model of SVC*

The SVC is a shunt connected FACTS controller and is modelled as a variable reactive power connected to a bus in a power system. The effect of SVC is incorporated in power flow problem as reactive power generation/absorption. The

range o reactive power generation is limited between maximum and minimum values of -30 MVAR to +30 MVAR to keep the size minimum for reducing the cost of SVC.[2]
The reactive power generated by SVC is given by
$Qsvc^{min} \leq Qsvc^{min} \leq Qsvc^{1}$………………(1)

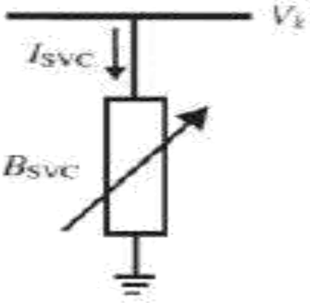

Fig. 2: Variable Shunt Susceptance model

III. .VOLTAGE STABILITY INDEX

The voltage stability index or proximity is the device used to indicate the voltage stability condition formulated based on a line or a bus. The maximum threshold is set at unity as the maximum value beyond which this limit system bifurcation will be experienced.

A. *Proposed VSI Formulation*

The VSI is derived from the voltage quadratic equation at the receiving bus on a two-bus system. The general two-bus representation is illustrated in Figure 3. The symbols are explained as follows

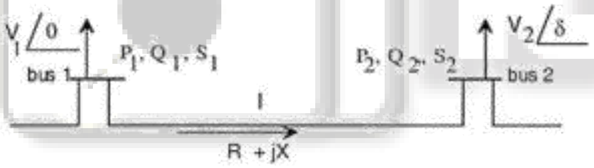

Fig. 3: Two bus power system model

V1, V2 =Voltage on sending and receiving buses.
P1, Q1 = active and reactive power on the sending bus
P2, Q2 = active and reactive power on the receiving bus
S1, S2 = apparent power on the sending and receiving bus
$\delta = \delta1 - \delta2$(Angle difference between sending and receiving end bus)
The line impedance is noted as Z=R+jX with the current that flows in the line is given by;
$I = \frac{V1\angle 0 - V2\angle \delta i}{R+jX}$……………………………………..(1)
V_1 is taken as the references, and therefore the angle is shifted into 0. The apparent power at bus 2 can be written as;
$S2 = V2j^{*}$………………………………………..(2)
Rearranging (2) yields;
$I = \left(\frac{S1}{V2}\right)^{*}$……………….. ……………………..(3)
$= \frac{P2-jQ2}{V2\angle - \delta}$……………………………………….(4)
Equating (1) and (4) we obtained;
$V1V2\angle - \delta - V2^2\angle 0 = (R + jX)(P2 - jQ2)$..(5)
Separating the real and imaginary parts yields;
$V1V2\ COS\ \delta - V2^2 = RP2 + XQ2$……………(6)
And,
$V2^2 - \left(\frac{R}{Xij}\sin\delta + cos\delta\right)V1V2 + \left(Xij + \frac{R^2}{Xij}\right)Q2 - V1V2sin\delta = XijP2 - RQ2$ …………(7)
Rearranging (7) for P_2 and substituting into (6) yields a Quadratic equation of V_2;
$V2^2 - \left(\frac{R}{Xij}\sin\delta + cos\delta\right)V1V2 + \left(Xij + \frac{R^2}{Xij}\right)Q2 = 0$ …(8)
To obtain the real roots for V_2, the discriminant is set greater than or equal to ‘0’; i.e.
$\left[\left(\frac{R}{Xij}\sin\delta + cos\delta\right)V1\right]^2 - 4\left(Xij + \frac{R^2}{Xij}\right)Q2 \geq 0$ …(9)

$$\frac{4Z^2Q2}{V1^2(Rsin\delta + Xijcos\delta)^2} \leq 1$$

Since δ is normally very small then,
$$\delta \cong 0, Rsin\delta \cong 0, Xcos\delta \cong X$$
Taking the symbols ‘i’ as the sending bus and ‘j’ as the receiving bus. Hence, the fast voltage stability index, VSI can be defined by;

$$\boldsymbol{VSIij = \frac{4\,Zij^2Qj}{V1^2Xij}} \quad \text{…(10)}$$

Where:
Z = line impedance
Xij = line reactance
Qj = reactive power at the receiving end
Vi = sending end voltage
The value of VSI that is evaluated close to 1.00 indicates that the particular line is closed to its instability point. Therefore, VSI has to be maintained less than 1.00 in order to maintain a stable system.[3]

IV. OPTIMAL LOCATION OF SVC

To improve the voltage profile and voltage stability of a power system an alternative solution is to locate an appropriate Flexible AC transmission system (FACTS) device. FACTS devices are the solid state converters having capability of improving power transmission capacity, improving voltage profile, enhancing power system stability, minimizing transmission losses etc. In order to optimize and to obtain the maximum benefits from their use, the main issues to be considered are the type of FACTS devices, the settings of FACTS devices and optimal location of FACTS devices. The optimal location of SVC has been selected on the basis of voltage stability index (VSI) for improvement of voltage stability of power system. Voltage stability index can be used for determining the weakest line in a power system. This voltage stability index considers both active and reactive powers to evaluate voltage stability, which provides information about the stability condition of the lines and also determines the weakest line in the system. [2]

V. TEST SYSTEM

For the validation of the proposed FACTS’s devices, SVC has been tested on the WSCC 9-Bus test System. An WSCC 9 bus test system and this test system including 9 buses ,3 generators ,6 lines ,3 transformers and 3 loads is simulated using Mipower and used to try models and control strategies is presented. The generators are modeled as standard PV buses with both P and Q limits; loads are represented as constant PQ loads.

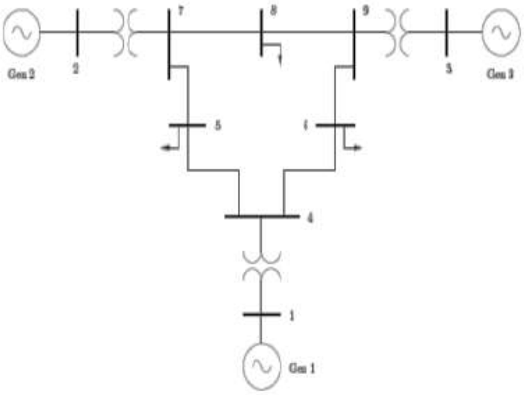

Fig. 4: WSCC 9 bus test system

VI. SIMULATION RESULTS

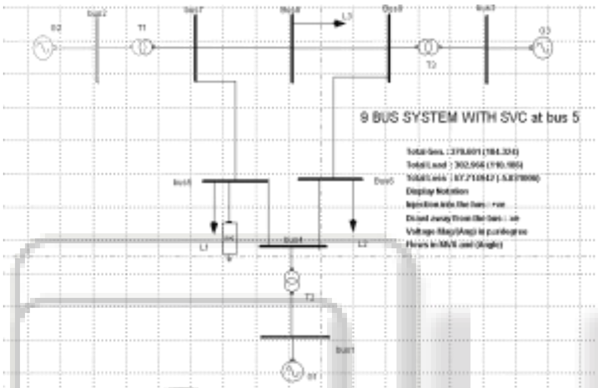

Fig. 5: WSCC 9 bus test system with SVC at bus 5 using Mipower

Line	P (p.u)	Q (p.u)	Voltage Vs	L-index
9-8	0.24183	0.03212	0.910	0.02462
7-8	0.76338	-0.00781	0.825	0.03421
9-6	0.60812	-0.18115	0.910	0.01660
7-5	0.87101	-0.08415	0.825	**0.1285**
5-4	-0.40612	-0.38681	0.789	-0.1252
6-4	-0.3115	-0.16544	0.826	-0.0773
2-7	1.6308	0.066541	0.858	0.0534
3-9	0.8415	-0.108619	0.960	-0.0152
1-4	0.7164	0.27118	1.038	0.0921

Table 1: Power flow and L-index for 9 bus system

Bus	Without SVC (Voltage p.u)	With SVC (Voltage p.u)
1	1.036	1.040
2	0.868	1.025
3	0.950	1.025
4	0.928	1.028
5	0.765	0.987
6	0.912	1.015
7	0.824	1.089
8	0.812	1.027
9	0.914	1.034

Table 2: Analysis of voltage magnitudes with and without SVC

Voltage stability indices or L-index are calculated for the WSCC 9 bus system without SVC as shown in table 1.Voltage Stability index or L-index is calculated using eq. 10, which requires impedance values between two lines, sending end voltage and active and reactive powers in per unit. By considering the Voltage stability index (L-Index) value, it is observed that line 7-5 is more sensitive towards system security. Therefore it is more suitable location for SVC at bus 5 to improve power system security/stability. After placement of SVC voltage stability is improved, the analyses of voltage magnitudes for WSCC 9 bus test system without and with SVC as shown in table 2.

VII. CONCLUSION

In this paper, a method for optimal placement and parameters settings of SVC has been proposed for improving voltage profile in a power system. The proposed approach has been implemented on WSCC 9-bus system. The criterion for selection of optimal placement of SVC was to maintain the voltage profile, minimize the voltage deviations and to reduce the power losses using VSI. Simulations performed on the test system shows that the optimally placed SVC maintains the voltage profile, improve the stability and effectively increases the efficiency of power system.

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