STATIC VOLTAGE STABILITY IMPROVEMENT IN POWER SYSTEM USING STATCOM FACTS CONTROLLER

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ABSTRACT : *This paper presents that one of the major causes of voltage instability is the increasing load demand. The power system to remain voltage stable condition when it experiences a load change and contingency. Prevention of voltage instability and voltage collapse is by using FACTS devices. In this paper, the effects of STATCOM on static voltage stability will be studied. The system reactive power handling capacity can be improved by using FACTS devices. The study has been carried out on IEEE 6 bus system and result is presented. With Newton Raphson method static voltage stability and power flow of the IEEE 6 bus system is investigated.*

KEYWORDS: STATCOM, Voltage Stability, Voltage Collapse, Maximum Loading Point.

1. INTRODUCTION

Voltage instability problems increasing day by day because of demand increase so it is very important to analyze the power system with respect to voltage stability. A system enter a state of voltage instability when a disturbance, increase in load demand or change in system condition cause progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power [5]. The FACTS is a concept based on power electronic controllers, which enhance the value of transmission networks by increasing the use of their capacity. As these controllers operate very fast, they enlarge the safe operating limits of a transmission system without risking stability. The voltage limits of electrical insulating devices, and the structural limits of the supporting infrastructure, the voltage collapse occurs when a system is loaded beyond its maximum loadability point. The consequence of voltage collapse may lead to a partial or full power interruption in the system. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse. Introducing the FACTS controllers at the appropriate location is the most effective way for utilities to improve voltage stability of the system. The recent development and use of FACTS controllers in power transmission system have led to many applications of these controllers not only to improve the voltage stability of the existing power network resources but also to provide operating flexibility to the power system. The following are different types of FACTS controller, Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor-Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) [6].

Improving the system's reactive power handling capacity via Flexible AC transmission System (FACTS) devices is a remedy for prevention of voltage instability and hence voltage collapse. The effects of STATCOM on voltage stability of the power system were studied. The study was performed for IEEE 6 bus test system. It was found that these FACTS controllers significantly enhancement the voltage profile and thus the loadability margin of power system. An analysis is made on the IEEE 6 bus system, the shunt devices like STATCOM gives the best performance for reducing the voltage collapse when compared to the series compensation [6]. Rest of the paper is organized as follows: Voltage source convertor connected to the AC network is discussed in section II. A brief introduction of the STATCOM is presented in Section III. Section IV examines the effects of these controllers on voltage stability using a 6-bus test system. Section V reviews the main points discussed in this paper.

2 VOLTAGE SOURCE CONVERTOR

The interaction between the VSC and the power system may be explained in simple terms, by considering a VSC connected to the AC mains through a loss less reactor, as illustrated in the single-line diagram shown in Figure (1).

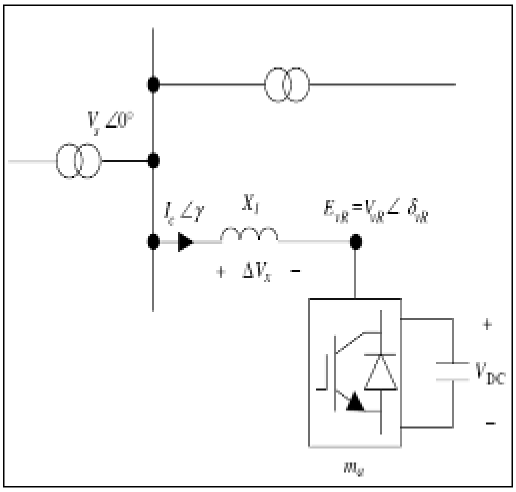

Fig. 1: Basic operation of a voltage source convertor [8].

The premise is that the amplitude and the phase angle of the voltage drop, V_x , across the reactor, X_l, can be controlled, defining the amount and direction of active and reactive power flows through Xl. The voltage at the supply bus is taken to be sinusoidal, of value $V_s \ \angle 0^\circ$. According to figure (1), for both leading and lagging VAR, the active and the reactive powers can be expressed as

$$P = \frac{V_S V_{VR}}{X_1} \sin \delta_{vR} \quad \text{.......... ....(1)}$$

$$Q = \frac{V_S^2}{X_1} - \frac{V_S V_{VR}}{X_1} \text{Cos} \ \delta_{vR} \quad \text{.......... ....(2)}$$

The STATCOM consists of one VSC and its associated shunt connected transformer. It is the static counterpart of the rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the same voltage regulation function as the SVC but in a more robust manner because, unlike the SVC, its operation is not impaired by the presence of low voltages.

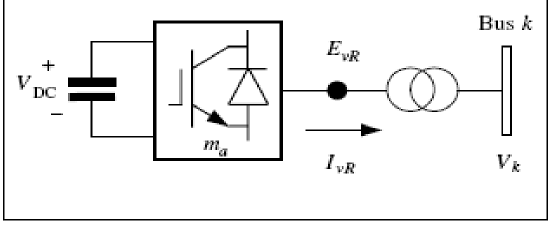

Fig. 2: Voltage source convertor connected to the AC network via a shunt connected transformer [8].

A schematic representation of the STATCOM and its equivalent circuit are shown in Figures 2 and 3 respectively. The equivalent circuit corresponds to the Thevenin equivalent as seen from bus k, with the voltage source E_{vR} being the fundamental frequency component of the VSC output voltage, resulting from the product of VDC and m_a.

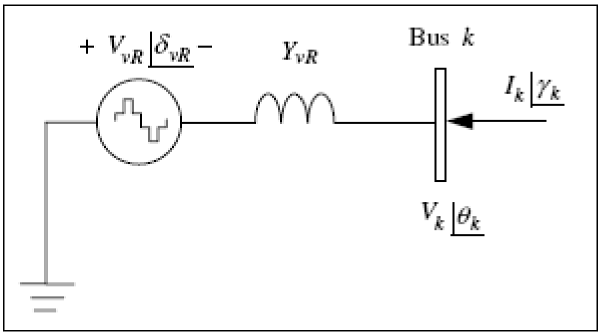

Fig. 3: shunt solid state voltage source [8].

In steady-state fundamental frequency studies the STATCOM may be represented in the same way as a synchronous condenser, which in most cases is the model of a synchronous generator with zero active power generation. A more flexible model may be realised by representing the STATCOM as a variable voltage source E_{vR}, for which the magnitude and phase angle may be adjusted, using a suitable iterative algorithm, to satisfy a specified voltage magnitude at the point of connection with the AC network. The shunt voltage source of the three-phase STATCOM may be represented by: may be represented by:

$$E^{\rho}_{vR} = V^{\rho}_{vR}(\cos \delta^{\rho}_{vR} + j \sin \delta^{\rho}_{vR}) \quad \text{.........................(3)}$$

Where ρ indicates phase quantities, a, b, and c. The voltage magnitude, V_{vR}, is given maximum and minimum limits, which are a function of the STATCOM capacitor rating. However, δ_{vR} may take any value between 0 and 2Π radians. With reference to the equivalent circuit shown in Figure (3), and assuming three phase parameters, the following transfer admittance equation can be written:

$$[I_K] = [Y_{vR} \quad -Y_{vR}] \begin{bmatrix} V_k \\ E_{vR} \end{bmatrix} \quad \text{.......... .... (4)}$$

$$I_k = \left[I^a_k \angle \gamma^a_k \quad I^b_k \angle \gamma^b_k \quad I^c_k \angle \gamma^c_k \right]^t \quad \text{.....................(5)}$$

$$V_k = \left[V^a_k \angle \theta^a_k \quad V^b_k \angle \theta^b_k \quad V^c_k \angle \theta^c_k \right]^t \quad \text{............. (6)}$$

$$E_{vR} = \left[V^{a}_{vRk}\angle\delta^{a}_{vRk} \quad V^{b}_{vRk}\angle\delta^{b}_{vRk} \quad V^{c}_{vRk}\angle\delta^{c}_{vRk} \right]^{t} .(7)$$

$$Y_{vR} = \begin{bmatrix} Y^{a}_{vRk} & 0 & 0 \\ 0 & Y^{b}_{vRk} & 0 \\ 0 & 0 & Y^{c}_{vRk} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

3. STATCOM

It is well-known fact that FACTS devices can be used to provide reactive power compensation. Although there are many types of the FACTS devices, each of them has it own characteristics [6]. Thus, it would be useful to know that , STATCOM, could give the most benefit in terms of voltage stability margin. STATCOM is the static synchronous generator and works as the shunt connected Var generator. Its capacitive or inductive current can be controlled independently from the AC system voltage. STATCOM is either voltage source based or the current source based.

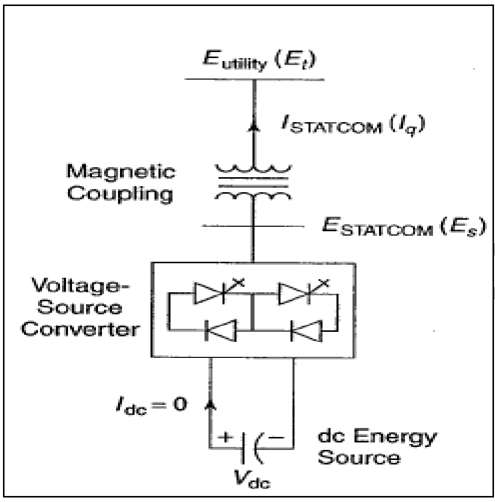

Fig. 4: basic structure of STATCOM [6].

Voltage-Source Inverter (VSI), which converts a DC, input voltage into AC output voltage in order to compensate the active and reactive power needed by the system [6]. Figs. 4 and 5 show the Basic structure and typical steady state V–I characteristic of STATCOM, respectively. From Fig. 4, STATCOM is a shunt-connected device, which controls the voltage at the connected bus to the reference value by adjusting voltage and angle of internal voltage source. In this type DC voltage of capacitor is converted into AC voltage by sequential switching of the device. The magnitude of the AC voltage and its phase with reference to the AC system voltage can also be changed. Current reverse when the power reverse but there is no reversal of voltage.

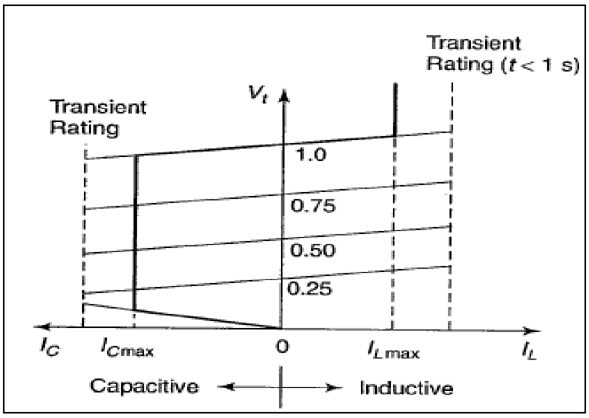

Fig. 5: The V-I characteristic of STATCOM [6].

When the storage capacity of the capacitor is less or when the other source is not connected the converter cannot absorb or supply the real power for more than one cycle. Phase difference of 90 remains between the output AC voltage and AC current. So converter can absorb or supply only the reactive power.

4. CASE STUDY

A IEEE-6 bus test System as shown in figure 6 is used for voltage stability studies.

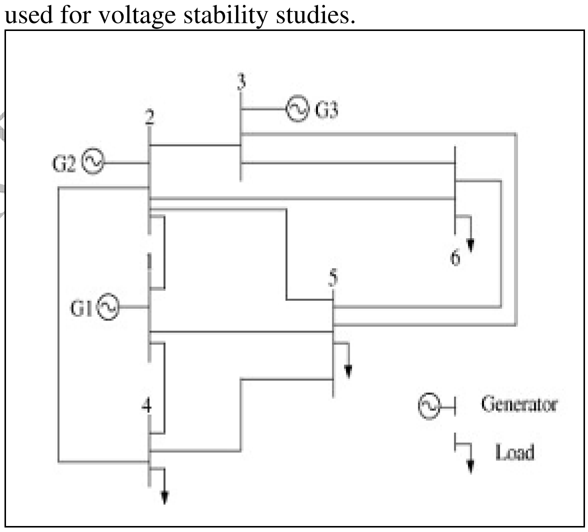

Fig. 6: The IEEE 6-bus test system.

The test system consists of 3 generators and 3PQ bus (or load bus). The simulations studies were carried out on MATLAB platform. The behavior of the test system with and without FACTS devices under different loading conditions is studied. Voltage stability analysis is performed by starting from an initial stable operating point and then increasing the loads by a factor l until singular point of power flow linearization is reached.

Table 1 shows the test result of IEEE 6 bus system without any FACTS device. From the power flow results, the buses 4, 5, 6 are the critical buses. Among these buses, bus 5 has the weakest voltage profile. The system presents a collapse or maximum loading point, where the system Jacobian matrix becomes singular, bus 14 is indicated critical voltage bus.

TABLE I. TABULAR REPRESENTATION OF VOLTAGE PROFILE OF IEEE 6 BUS

Buses	Voltage Profile	
Bus Number	Voltage (p.u.)	Angle (p.u.)
1	1.05	0
2	1.05	-30.02
3	1.07	-37.46
4	0.908	-28.70
5	0.904	-32.24
6	0.940	-42.65

Table 2 show the result of real and reactive power flow between buses. The real power loss is 1.49 (p.u.) and reactive power loss is 4.12 (p.u.).

TABLE II. TABULAR REPRESENTATION OF REAL AND REACTIVE POWER FLOW

Buses	Power Flow			
Between Bus	Real Send.	Reac. Sending	Real Receiving	Reac. Receiving
1-2	2.502	-0.522	-1.91	1.684
1-4	2.46	0.701	-2.16	0.476
1-5	1.82	0.493	-1.56	0.455
2-3	0.55	-0.172	-0.53	0.213
2-4	0.41	1.274	-0.337	-1.119
2-5	0.26	0.412	-0.240	-0.363
2-6	1.17	0.266	-1.084	-0.025
3-5	-0.014	0.688	0.662	-0.600
3-6	1.149	1.188	-1.110	-0.958
4-5	0.106	-0.057	-0.103	0.030
5-6	0.442	-0.221	-4.13	0.284

Now insert the STATCOM at the bus 5 and then repeat the procedure. When STATCOM is connected at bus 5 we can observe that bus 5 has a flatter voltage profile. Table 3 show the test result of voltage magnitude and angle of IEEE 6 bus system with STATCOM at bus 5. The real power loss 1.28 (p.u.) and reactive power loss is 3.62 (p.u.). According to result when STATCOM is connected at bus 5 the voltage magnitude of bus is 1.0 (p.u.) and voltage magnitude of bus 4 and bus 6 is also improved.

When STATCOM is connected at bus 5 curve of voltage profile with and without STATCOM is shown in figure 7. Table 4 shows the comparison of STATCOM at different load bus. The real and reactive loss of bus 4 are 1.28 (p.u.) and 3.62 (p.u.). The real and reactive loss of bus 6 are 1.43 (p.u.) and 3.91 (p.u.).

From the comparison of Voltage with and without STATCOM it is obviously that the MLP of the system with STATCOM is highest. According to result the STATCOM at bus 5 give better voltage magnitude as compare to other bus.

TABLE III. VOLTAGE MAGNITUDE AND ANGLES OF IEEE 6 BUS WITHOUT FACTS AND WITH STATCOM AT BUS 5

Bus	Voltage Magnitude and Angle			
Bus No.	Volt. Mag. (p.u) Without FACTS	Angle (degree) Without FACTS	Voltage Mag. (p.u) With STAT COM at bus 5	Angle (degree) With STAT COM at bus 5
1	1.05	0	1.05	0
2	1.05	-30.02	1.05	-27.98
3	1.07	-37.46	1.07	-34.73
4	0.908	-28.70	0.926	-27.31
5	0.904	-32.24	1.0	-31.71
6	0.940	-42.65	0.961	-40.07

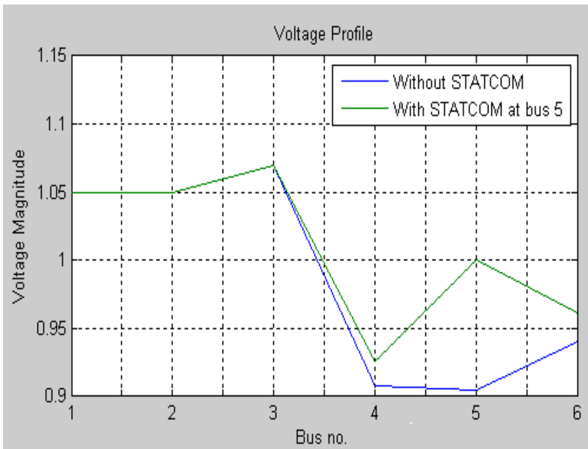

Fig. 7: Voltage profile for bus 5 with and without STATCOM.

Reactive power support at the weakest bus provides better voltage profiles throughout the system.

TABLE IV. VOLTAGE MAGNITUDE AND ANGLES OF IEEE 6 BUS WITHOUT FACTS AND WITH STATCOM

	Voltage Magnitude			
Bus No.	Volt. Mag. (p.u) Without FACTS	Voltage Mag. (p.u) With STAT COM at bus 4	Voltage Mag. (p.u) With STAT COM at bus 5	Voltage Mag. (p.u) With STAT COM at bus 6
1	1.05	1.05	1.05	1.05
2	1.05	1.05	1.05	1.05
3	1.07	1.07	1.07	1.07
4	0.908	1.0	0.926	0.911
5	0.904	0.925	1.0	0.918
6	0.940	0.945	0.961	1.0

5. CONCLUSION

In this paper, voltage stability assessment of the modified IEEE 6-bus test system with STATCOM is studied. STATCOM provide higher voltage stability margin. The test system requires reactive power the most at the weakest bus, which is located in the distribution level. This may not be effective when the system required reactive power at the load level. STATCOM give slightly higher MLP and better voltage profiles compared to without compensation. It was found that these FACTS controllers significantly enhance the voltage profile and thus the loadability margin of power systems.

6. REFERENCES

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APPENDIX

The bus data of IEEE 6 bus test system are as follows:

BUS	TYPE	P_d	Q_d	P_g	Vsp
1	Slack	0	0	0	1.05
2	P-V	0	0	0.5	1.05
3	P-V	0	0	0.6	1.07
4	P-Q	2.4	0.7	0	1
5	P-Q	1.4	0.7	0	1
6	P-Q	2.6	0.7	0	1

The line data of IEEE-6 bus test system are as follows:

Line	From	To bus	R (p.u.)	X (p.u.)	B (p.u.)
1	1	2	0.1	0.2	0.02
2	1	4	0.05	0.2	0.02
3	1	5	0.08	0.2	0.03
4	2	3	0.05	0.25	0.03
5	2	4	0.05	0.1	0.01
6	2	5	0.1	0.3	0.02
7	2	6	0.07	0.2	0.025
8	3	5	0.12	0.26	0.025
9	3	6	0.02	0.1	0.01
10	4	5	0.2	0.4	0.04
11	5	6	0.1	0.3	0.03