Voltage Stability Analysis of Electrical Transmission System Using Reactive Power Sensitivity Indicator

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Abstract: ***Nowadays the biggest challenge of the electrical power transmission system is voltage collapse. As a result, these days a major outlook has been paid with the aid of a variety of research on voltage stability. In this paper, a method has been introduced to determine the voltage stability of an IEEE 14-bus power system. This technique is based on Reactive Power Sensitivity Indicator. Using this indicator, weak buses are identified among the 14 buses of the system under study. Newton-Raphson method of Load Flow Analysis is coded in MATLAB programming to find out different parameters of the IEEE 14-bus system and used for stability analysis. A FACTS device has been installed in the weakest bus to enhance the voltage stability of the network. The results exhibit the effectiveness of the proposed technique.***

Keywords: Voltage Collapse Point; Reactive Power Sensitivity Indicator; Voltage Stability; Static VAR Compensator (SVC).

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1. Introduction

The combinational network of electrical generation, transmission and distribution system is called a power system. The power system converts other equivalent energies into electrical energy. It consists of generator, motor, transformer, circuit breaker, bus bars etc. For providing smooth and good quality customer service the power system must keep bus voltages at an acceptable voltage limit [1]. Maintaining acceptable voltages at all buses in the power system under normal operating conditions and after being subjected to a disturbance is called stability of the power system. In the normal operating state, the voltage of the power system is stable but when a fault or interference occurs in the system, the voltage becomes unstable. The rapid growth in power demand and finite sources for electric power has resulted in a progressively complex interconnected system for this voltage unpredictability [2]. The main causes for voltage instability are changes in system condition and collapse in voltage [3]. Power systems run under heavily emphasize conditions; hence the capacity to balance the voltage has become growing anxiety [4]. A power system is said to be voltage stable if after a disturbance the voltages are near to the normal operating voltage. Voltage stability is of two types, they are static voltage stability and dynamic voltage stability [2]. Voltage stability analysis is important to identify critical buses which are close to their voltage stability limits and thus certain measures to be taken to avoid any incidence of voltage collapse. If remedial actions are not executed properly successive load increases may steer the system to disbalance the operating state. Voltage stability has an immensely salient role in the planning and operation of power systems. So, great attempts are being assembled to recognize the procedure involved with voltage stability [5]-[9]. Reliable, efficient, safe, and secure operation of the system is the main priority of the Power System operator. FACTS device can be used in the weakest bus of the Power System. FACTS device provides multiple facilities, such as regular power flow at any condition, minimizes system loss, and most importantly increases the voltage stability of the system [10].

In this paper, by using the reactive power sensitivity indicator the weakest bus is marked amongst the IEEE 14 bus system and the critical values of active power and voltage magnitude of the system are also determined. A P-V curve is drawn for the standard 14-bus system. After that, a FACTS device is coupled with the weakest bus and new voltages are obtained. Static VAR Compensator also known as SVC is used as a FACTS device in this method. Obtained values of voltage and active power after using the FACTS device are plotted again. A comparison of the P-V curve has been drawn with the help of the voltages obtained before and after using SVC.

2. Reactive Power Sensitivity Indicator

The equation used in the Newton Raphson method is given as equation 1:

$$\Delta C = J\,\Delta X \qquad (1)$$

Where, $\Delta C = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$

J is Jacobian Matrix which is a composition of four Matrices

$$J = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}$$

$$\Delta X = \begin{bmatrix} \Delta \partial \\ \Delta |V| \end{bmatrix}$$

For finding the weakest bus among the standard 14 bus systems the matrix which is required is the Jacobian matrix. Variation of reactive power influences the variation of voltage magnitude [3]. For changing Voltage magnitude, real power change is a little sensitive and for phase angle, it is the most sensitive. From the diagonal elements of J4 of the Jacobian matrix, we can find out the dV/dQ which is also known as the reactive power sensitivity index. From the result shown by solving the Jacobian Matrix, we can find out the strongest and weakest bus among the 14 buses.

The bus whose dV/dQ value is least indicates that the bus is strongest among all and whose dV/dQ value is highest indicates the weakest bus among all. Reactive Power Sensitivity Indicator provides multiple benefits. It improves the Voltage stability of the system, seeks to minimize the congestion of power flow, reduces power losses, and is essential to move active power through the transmission line.

3. Static VAR Compensator (SVC)

A Static VAR Compensator is also known as SVC includes a set of electrical apparatus for providing fast acting reactive power on a high voltage electricity transmission network. Typically, an SVC comprises of one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristor. The SVC is an automated impedance matching device, which is designed basically to bring the transmission system closer to unity power factor. SVC device is used to regulate the transmission voltage known as Transmission SVC, by connecting it to the power system and improve power quality known as industrial SVC by connecting it near large industrial loads.

The magnitude of less voltage source V_{svc} is always controlled by the controller SVC. SVC model V_{svc} is always in phase with the terminal voltage V_R and is given by,

$$V_{SVC} = CV_R = V_R\left(\frac{2\alpha - \sin 2\alpha}{\pi} - 1\right) e^{\frac{st_d}{t+st_s}} \qquad (2)$$

Where, α is a firing angle, t_d is the dead time and t_s is the delay time of the thyristor. Here t_d and t_s are very small so they are negligible. Therefore the new equation is

$$V_{SVC} = CV_R = V_R\left(\frac{2\alpha - \sin 2\alpha}{\pi} - 1\right) \qquad (3)$$

The magnitude of the SVC susceptance [B_{SVC}] is a function of the firing angle α and is obtained as,

$$B_{SVC} = \frac{1}{X_C X_L}\left[X_L - \frac{X_C}{\pi}\{2(\pi - \alpha) + \sin 2\alpha\}\right] \qquad (4)$$

for $\frac{\pi}{2} \le \alpha \le \pi$

And, the formula to find Q_{SVC} is,

$$Q_{SVC} = -V_{SVC}^2 B_{SVC} \quad (5)$$

Initially, the SVC variable is taken as zero at the resonant point for initialization purpose [6]. An SVC device of 0.0008 p.u is installed at the weakest bus in the system under study which is bus no. 14.

4. Result and Simulation

The primary motive of simulation is to outline the voltage stability of a multi-bus power network. In the proposed work IEEE 14 bus system is taken as a standard multi-bus power network which is given in Appendix 1.

In the first step, MATLAB coding has been done based on the Newton Rhapson method of load flow analysis to generate the power flow data for this analysis.

The values of dQ/dV have been obtained from the diagonal elements of J4 of the Jacobian Matrix of the load flow solution (i.e from the above-mentioned load flow coding). dV/dQ index is obtained by reciprocating values of dQ/dV. dV/dQ index is known as Reactive Power Sensitivity

Indicator. For each bus, the values of dV/dQ are shown in the table 1.

Table 1: dV/dQ values of 14-bus system

Bus No.	dV/dQ values
2	0.034
3	0.10233
4	0.0253
5	0.02888
6	0.0563
7	0.0520
8	**0.1761**
9	0.0423
10	0.06771
11	0.1195
12	**0.184**
13	0.0937
14	**0.2114**

The bus which has maximum value of dV/dQ is the weakest bus of the system. From the table: -1 it is noticed that the bus number 14 has the highest dV/dQ value is equal to 0.2114. As per the dV/dQ value the bus number 12 is weaker and bus number 8 is weak among the 14-buses and their values are 0.184and 0.1761 respectively.

4.1 Bus voltages after and before using SVC device at the weakest bus

After using SVC device at the weakest bus, bus-voltages were changed. The changed bus voltages are shown in the table 2.

Table 2: Bus voltages with and without using SVC device

Bus No.	Voltages without using SVC Device [p.u]	Voltages with using SVC Device [p.u]
1	1.0600	1.0600
2	1.0143	1.0186
3	0.9792	0.9866
4	0.9900	0.9996
5	0.9982	1.0070
6	0.9956	1.0156
7	1.0554	1.0730
8	**1.0837**	**1.1008**
9	1.0356	1.0572
10	1.0266	1.0482
11	1.0235	1.0447
12	**0.9832**	**1.0057**
13	0.9815	1.0059
14	**0.9884**	**1.0269**

From table 3 it is observed that the weak, weaker and weakest bus voltages are increased by 0.0171p.u, 0.0225p.u and 0.0385p.u respectively. The new corresponding bus voltages are 1.1008p.u, 1.0057p.u and 1.0269p.u successively.

The bus voltages before and after using SVC device are plotted in a graph in Fig. 1.

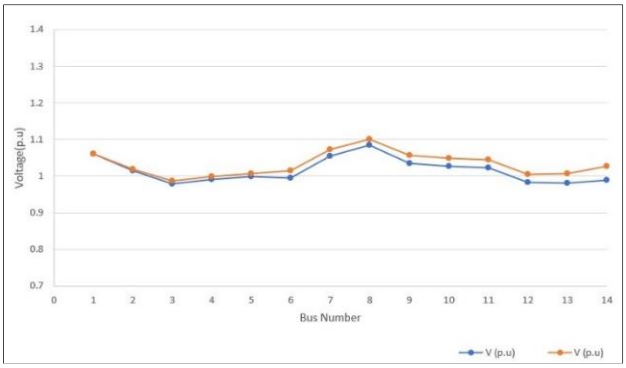

Fig 1: Bus voltage magnitudes before and after installation of SVC in the 14-bus system.

In the fig. 1, the blue dotted line represents the voltages before using SVC device and the orange dotted line represents the voltages after using SVC in the weakest bus. From this graph, it is observed that the voltages of all buses are increased in the system after using SVC device at the weakest bus.

4.2 P-V curve

P-V curves are the most broadly used curve in the field of voltage stability analysis. To examine the voltage security and to compute the real power margin P-V curves are used. The main factor of a P-V curve depicts the voltage collapse point of the network. The point of voltage collapse is different for different load models. Fig. 2 shows the P-V curves before and after installation of SVC in the weakest bus.

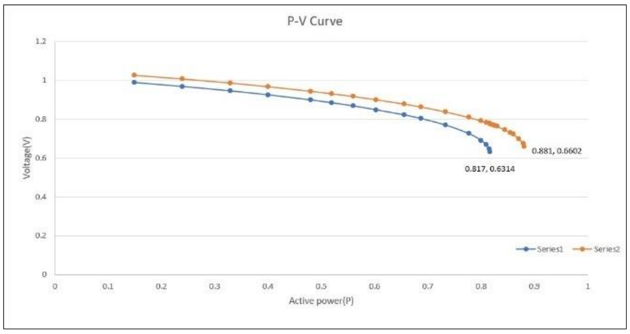

Fig 2: P-V curve before and after installation of SVC.

In this graph, there are two series, series 1, and series 2. The series 1 represents the P-V curve that has been found before using the SVC device. And the series2 represents the P-V curve that has been found after using the SVC device in the weakest bus. In series 1, critical value of the active power load is 0.6314p.u and the corresponding voltage magnitude is 0.817p.u. And in series2, critical value of active power loading is increased by 0.0288 p.u., i.e., 0.6602p.u and the corresponding voltage magnitude is increased by 0.064 p.u. means 0.881p.u.

4.3 Comparison of Critical values before and after installation of SVC

The critical values of active power and corresponding Voltage magnitude are noted down in the Table 3 for comparison.

Table 3: Comparison of critical values of active power loading and corresponding voltage magnitude before and after installation of SVC.

Critical Parameters	Corresponding Buses	Critical values of parameters without SVC [in p.u]	Critical values of parameters with SVC	Change in the critical values in %
P_{cri}	weak	1.06	1.11	4.5
	weaker	0.75	0.80	6.25
	weakest	0.817	0.881	7.26
V_{cri}	weak	1.0837	1.1008	1.55
	weaker	0.9832	1.0057	2.23
	weakest	0.9884	1.0269	3.74

It is noted that the critical values of active power loading and corresponding voltage magnitude have been improved after installing the SVC device. After comparing critical values, the change of critical values of active power loading and corresponding voltage magnitudes are shown in the fourth column of table 3 as a percentage. For the weak, weaker, and weakest bus, the percentage change in the critical values of active power loading is 4.5%, 6.25%, and 7.26%, and for corresponding voltage magnitude percentage changes are 1.55%, 2.23%, and 3.74% respectively.

5. Conclusion

The weak, weaker, and weakest bus of the IEEE 14-bus system has been identified using dV/dQ as an indicator. For the improvement of the voltage stability of that network, an SVC device has been installed in the weakest bus of the system. The critical values of active power loading and corresponding voltage magnitudes before and after installation of SVC have also been compared. From the comparison, it is observed that due to the installation of SVC, the power transfer capacity as well as the voltage profile of the network has been improved. This study will help the power system operator in controlling the operation from the viewpoint of voltage stability.

APPENDIX 1:

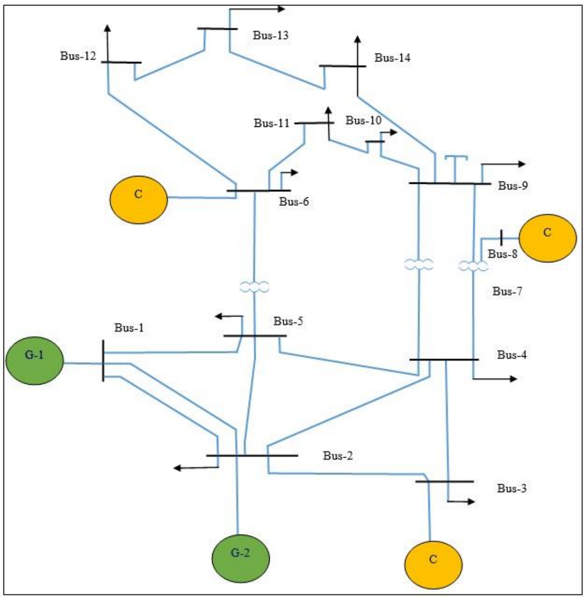

Fig. 3: IEEE 14-bus system

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