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Static Voltage Stability Assessment of Power Systems with FACTS Devices

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Abstract: *This paper presents the impact of location of FACTS devices on the static voltage stability of power systems. The analysis is carried out on the Western System Coordinating Council (WSCC) 9-bus test system. The maximum loadability of the load buses is determined using continuation power flow method with static var compensator (SVC) and static synchronous compensator (STATCOM). The result shows that the reactive power support from the FACTS devices depends on the proper placement of the FACTS devices in the network. The result shows that the location of FACTS devices has an important impact on the stability and power loss of the system. Finally, a suitable location for the compensating device is determined to enhance the voltage stability of the system.*

Keywords: *Power Loss, STATCOM, SVC, Voltage stability.*

I. Introduction

With the rapid development of power industry and expansion of system, voltage stability is one of the main challenges that power system engineers are facing around the world [1]-[3]. Various theories have been established in voltage stability analysis through rigorous mathematical investigation [4]. A novel approach based on multi-input multi-output transfer function for analyzing static voltage stability is proposed in [5]. An improved neural network based algorithm is proposed to monitor voltage stability in [6].

Voltage sensitivity and modal analysis is used to investigate voltage stability in [7] which concludes that voltage stability margins have a precise voltage collapse point when a power system is subjected to sudden load increase. Voltage stability limit is usually dominant in heavily loaded systems [8]. As modern systems are being operated under heavily stressed conditions with reduced stability margins, incorporation of voltage stability analysis is essential for proper planning and control of power systems.

One of the main causes of voltage collapse is the inadequate reactive power in the system. Reactive power sources such as FACTS devices can be used to improve the voltage stability of power systems [9]-[12]. However, as they are very expensive, they should not be placed without proper planning. The types of FACTS devices and their location in the system may have different effects on a power system. Therefore, to enhance the system stability and to reduce the possibility of voltage collapse, a FACTS device placement strategy is proposed in this paper based on the maximum loading point. It is investigated that the proposed approach reduces the system power loss and, thereby, increasing overall system efficiency.

II. System Model

In this paper, the Western System Coordinating Council (WSCC) 9-bus test system shown in Fig. 1 is used. The test system data is given in the Appendix. Bus 1 is considered as slack bus. Two synchronous generators which supply a real power output of 1.63 pu and 0.85 pu are connected at bus 2 and bus 3, respectively. The system has 3-loads connected at bus 5, bus 6 and bus 8. Generators are modeled as PV bus.

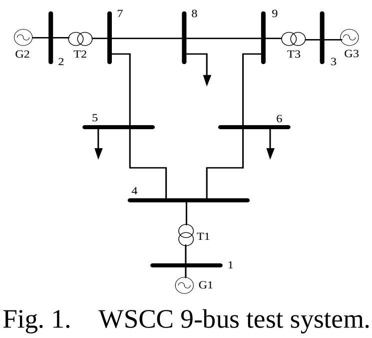


Fig. 1. WSCC 9-bus test system.

As FACTS device, a static var compensator (SVC) and a static synchronous compensator (STATCOM) is used in the analysis [13]. Figure 2 shows the block diagram of a SVC where v is the measured voltage at the connected bus, v_{ref} is the reference voltage, b^{max} and b^{min} is the maximum and minimum reactance, respectively, b_{SVC} is the total reactance, K_r is the regulator gain and T_r is the regulator time constant.

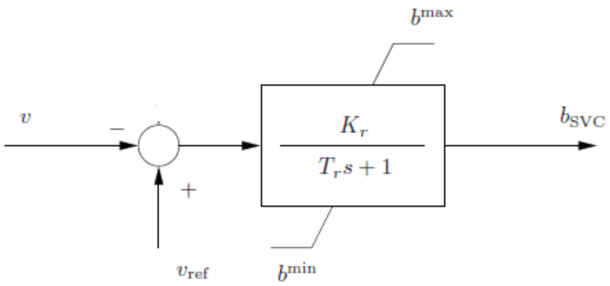


Fig. 2. Block diagram of SVC [13].

Figure 3 shows the block diagram of a STATCOM where v is the measured voltage at the connected bus, v_{ref} is the reference voltage, i^{max} and i^{min} is the maximum and minimum current, respectively, i_{SH} is the total injected current at the connected bus, K_r is the regulator gain and T_r is the regulator time constant.

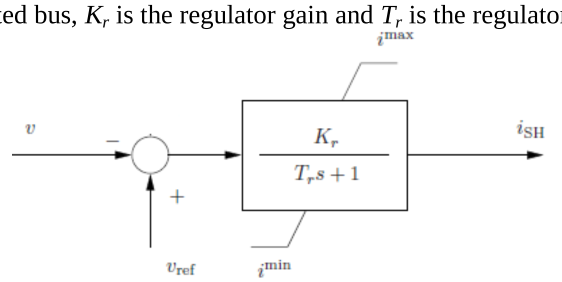


Fig. 3. Block diagram of STATCOM [13].

III. Static Voltage Stability Assessment

A load flow study for the considered test system is conducted using Newton-Raphson method [14]. The bus voltage of the system without FACTS (base case) is shown in Fig. 4. From this Figure it can be seen that the us 5 has the lowest voltage magnitude compared to other buses. To analyze the static voltage stability generally power-voltage (P-V) curves are used which determine the maximum loading limit of a system [1].

Here, this curve has been produced by using a series of power flow solutions using power system analysis toolbox (PSAT) for different load levels. In this paper, initially a SVC and a STATCOM of same capacity is connected at bus 8 separately for a comparative analysis.

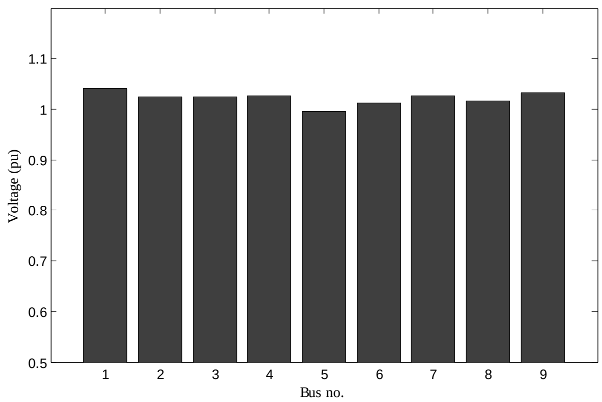


Fig 4: Bus voltages of the system.

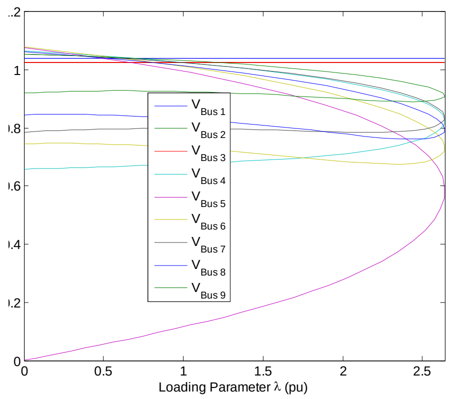
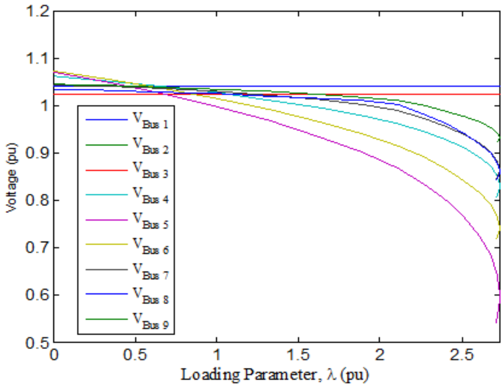


Fig 5: P-V curve without FACTS device.

The variations in load bus voltages with the loading factor are obtained and summarized in Table I from which it can be seen that a FACTS device can improve the maximum loading point (MLP) of the system. The base case P-V curve for all the buses is shown in Fig. 5. The improvement in the MLP for the connection of a FACTS device can be easily visualized from Fig. 6 and Fig. 7. A STATCOM has superior performance in improving MLP of the system due to its inherent control capability. For this reason, the rest of the analysis of this paper is carried out with a STATCOM.

Table I. Mlp With And Without Facts Device

Name of FACTS device	Maximum loading point (MLP), pu
Base case	2.6407
SVC	2.7323
STATCOM	2.9030



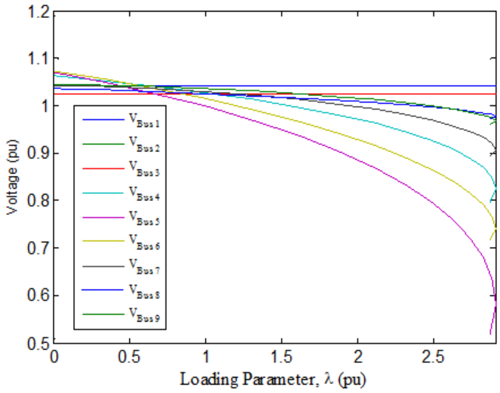


Fig 6: P-V curve with SVC installed at bus 8 Fig 7: P-V curve with STATCOM installed at bus 8

In order to investigate the impact of location of FACTS on the network, a STATCOM is placed in different load buses; and MLP and power losses are calculated for each case. From Table II, it can be seen that the connection of a STATCOM at the weakest bus increases the MLP and power loss compared to its connection at other load buses. As the weakest bus in a system requires the most reactive power, placing a STATCOM at this bus can improve loading margin the most.

Table II. Mlp And Power Loss For Connection Of Statcom At Different Load Buses

Load bus no.	MLP (pu)	Power loss (pu)
Bus 5	3.4477	0.04497
Bus 6	2.6651	0.04618
Bus 8	2.9086	0.04587

Therefore, to reduce the possibility of voltage collapse and power loss, the weak bus is the best choice to install an expensive FACTS device. The voltage profile of the system with a STATCOM connected at bus 5 is shown in Fig. 8 from which it can be seen that the installation of STATCOM at the weakest bus improves the voltage profile of the system significantly compared to the base case.

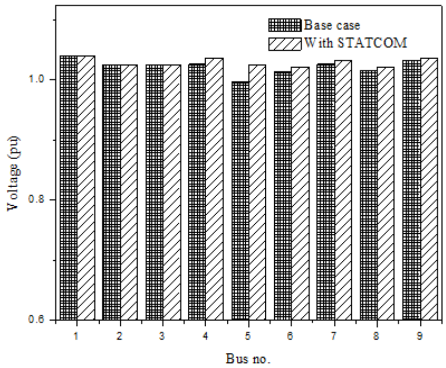


Fig 7: Bus voltages of the system with and without STATCOM (base case).

IV. Conclusion

In this paper, voltage stability assessment of the WSCC 9-bus test system with STATCOM and SVC is investigated. The results show that a STATCOM provides higher voltage stability margin than a SVC. However, the reactive power support from the FACTS devices depends on the proper placement of the FACTS devices in the network. The power loss of the system is also improved if FACTS devices are used in the appropriate location. As the weakest bus requires highest reactive power, the proposed approach suggests placing the

FACTS device at the weakest bus of the network. Determining the optimum size of a STATCOM through static and dynamic analysis is the future aim of this work.

Appendix

Test system data of WSCC 9-bus test system is given in Table III.

Table III. Data Of Wscc 9-Bus System

Lineno.	From bus - To bus	Resistance, R (pu)	Reactance, X (pu)	Susceptance, B (pu)
1	7 – 8	0.0085	0.072	0.149
2	6 – 9	0.039	0.170	0.358
3	5 – 7	0.032	0.161	0.306
4	4 – 5	0.01	0.085	0.176
5	4 – 6	0.017	0.092	0.158
6	8 – 9	0.0119	0.1008	0.209

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