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The Effect of Shunt FACTS Devices on Voltage Regulation in Transmission Lines

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Abstract

FACTS devices are installed in AC transmission networks to increase power transfer capability, stability, and controllability of the networks through series and/or shunt compensation. This paper shows a shunt flexible ac transmission system (FACTS) device used for voltage regulation in transmission lines. Phasor model of shunt FACTS devices is used. All the simulations for this work have been carried out using MATLAB/SIMULINK environment. Simulation results validate that power oscillation and voltage can be damped properly using of static var compensator (SVC) and static synchronous compensator (STATCOM).

Keywords: FACTS devices, static synchronous compensator, static var compensator, voltage regulation.

1. INTRODUCTION

The development of interconnected power systems and their simultaneous operation has created many complexities, which limit the transmission capabilities [1-3].

Phase noise is one of the most vital cases, which is usually considered in the design of

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Stability plays an important role to ensure the stable operation of power system in the occurrence of large disturbances and faults. Voltage instability is one of the major threats to stable, safe, and reliable operation of the power system [4-6]. FACTS devices will affect a real network under variations of system operating conditions.

FACTS devices can be connected to a transmission line in various ways: series, shunt, and a combination of series and shunt [7,8].

These devices are also employed for congestion management and loss optimization.

With FACTS technology, line impedances, bus voltages, and phase angles in the power system can be regulated rapidly and flexibly [9,10].

Shunt FACTS devices, when placed at the midpoint of a long transmission line, play an important role in steady state and dynamic voltage control, improvement of system stability, reactive power control of dynamic loads, and damping of active power oscillations [11,12]. Shunt FACTS devices are classified into two categories, namely variable impedance type (SVC) [13,14] and switching converter type (STATCOM) [15,16].

Alternating properties and infiltration of renewable energies cause voltage stability problems in power systems.

Voltage regulation describes the ability of a system to provide near constant voltage over a wide range of load conditions. Several references in technical literature can be found on utilizing FACTS devices in operating power systems [17-22].

The system modeling and control design for fast load voltage regulation using STATCOMs is presented in [23], which shows that the control problem of load voltage regulation using reactive current is a non-minimum phase. Also, linear and nonlinear controllers for the regulation problem are designed and compared via simulation results.

In [24], to reach the overall stability of the power system, the quantum- inspired evolutionary algorithm is applied to determine PSS parameters and SVC in a coordinated manner, which the proposed method is applied in determining PSS parameters and SVC of four-machine power systems and the New England 39-bus system.

An interval type-II fuzzy logic system-based controller is presented in [25], which consists of current and voltage regulators, applied to the STATCOM, to mitigate bus voltage variations caused by large disturbances. Also, the current regulator is used to produce the phase angle at the voltage-source converter in the STATCOM while the voltage regulator outputs the current reference on the quadrature axis for the STATCOM.

In this paper, the application of shunt FACTS devices on voltage regulators in power system is investigated. Phasor model of shunt FACTS is used. To prove the effectiveness of the shunt FACTS, various simulation results using MATLAB Simulink software are shown under different conditions.

2. SHUNT FACTS DEVICES

This section explains the basic configuration of SVC and STATCOM briefly.

2.1. Static VAR Compensator

A SVC is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks, which regulates voltage, power factor, harmonics and stabilizes the system. A SVC has no significant moving parts [26].

A basic structure of SVC consists of a fixed capacitor bank, in parallel with a thyristor controlled reactor (TCR) as shown in Fig. 1.

Advantages of static VAR Compensator are: improvement of the system transient stability, controlling the steady state and temporary over voltages, improving the load power factor, and therefore, reducing line losses and improving system capability [27,28].

2.2. Static Synchronous Compensator

A STATCOM is a regulating device used on alternating current electricity transmission networks.

It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power, it can also provide active AC power. It is inherently modular and electable [29-31].

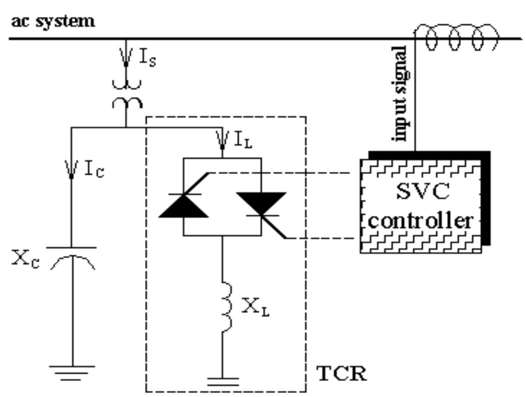

Fig. 1. Basic topology of SVC.

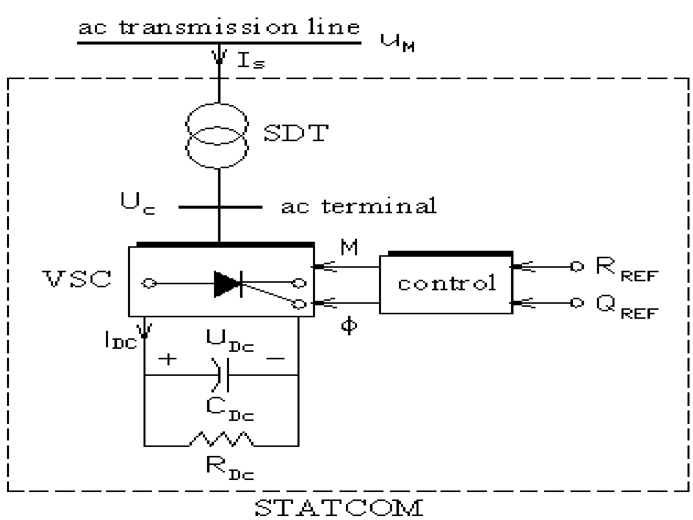

Fig. 2. One-line diagram of a STATCOM.

Table 1. ***System parameters.***

Components	Quantity	Value
STATCOM	rating of STATCOM	±100 MVA
	dc link nominal voltage	40 kV
	equivalent capacitance	375 μF
	total equivalent impedance on the dc side	0.22 pu
transmission line	resistance per unit length	0.01755 Ω/km
	inductance per unit length	0.8737×10^{-3} H/km
	capacitance per unit length	13.33×10^{-9} F/km
	length	30 km

Fig. 2 shows a STATCOM which is placed at bus M which consists of a step down transformer (SDT) and a dc capacitor.

The main difference between a STATCOM and a SVC is the way they operate: a STATCOM works as a controllable voltage source while an SVC works as a dynamically controllable reactance connected in parallel [32,33].

2.3. Advantages of STATCOM Over SVC

Both SVC and STATCOM are important equipment of reactive compensation, which are compared in improving the transient stability, voltage supporting, transmission limit, and damping low frequency oscillation [34, 35].

The main difference between a STATCOM and an SVC is the way they operate: a STATCOM works as a controllable voltage source while an SVC works as a dynamically controllable reactance connected in parallel.

The advantages of STATCOM over SVC are:

a) STATCOM is much better than SVC in improving the transient stability and transmission limit.

b) The ability to provide more reactive power during fault situations is one of the most important advantages of the STATCOM over the SVC, which provides faster recovery of the system during fault situations.

c) On the damping low frequency oscillations, STATCOM is much better than SVC as SVC and STATCOM have the same capacity, and performs similarly with SVC as the two have the same controllable capacity.

3. SYSTEM UNDER STUDY

The mains consist of two sources equivalent to 500 kV (3000 MV and 2500 MV, respectively), which are connected by a 600 km transmission line as shown in Fig. 3.

The SVC and STATCOM are located at the midpoint of the line (bus B2). The parameters of the system are listed in Table I [36].

4. SIMULATION RESULTS

This section presents simulation results obtained with Simulink MATLAB. The simulation results of the dynamic behavior of the power system using the shunt FACTS controller will be shown in this section in order to demonstrate the efficiency of the controller. In this simulation, STATCOM is used to regulate the voltage and has no effect on VAR control.

The measured reactive power generated by the SVC (red trace) and the STATCOM (green trace) is shown in Fig. 4. We can see that during the 10-cycle fault, the reactive power generated by the SVC is -0.48 pu and the reactive power generated by the STATCOM is -0.71 pu.

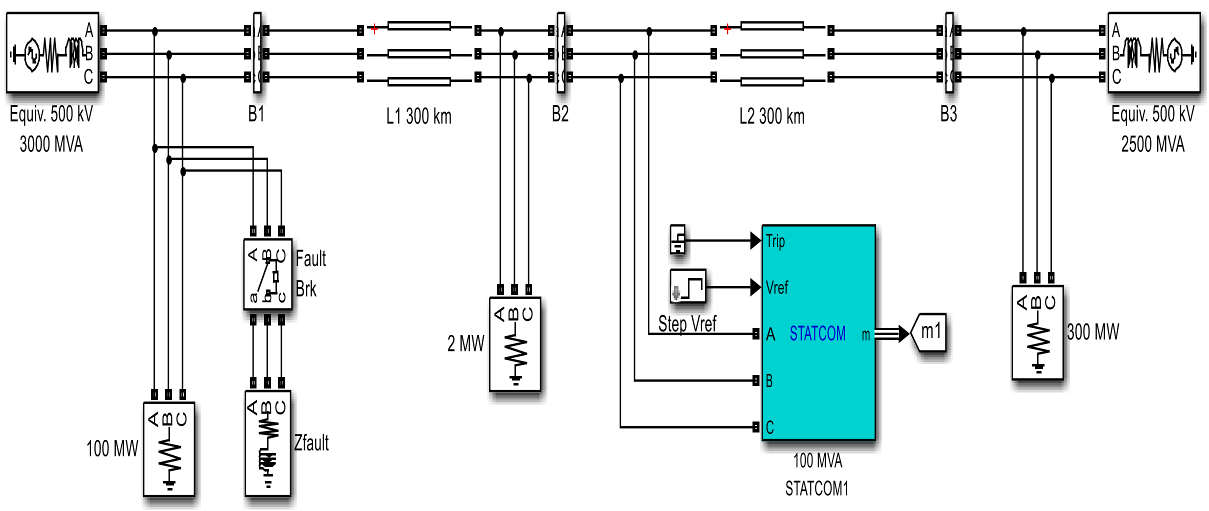

Fig. 3. Simulation block diagram of the power system with a shunt FACTS devices in Matlab Simulink.

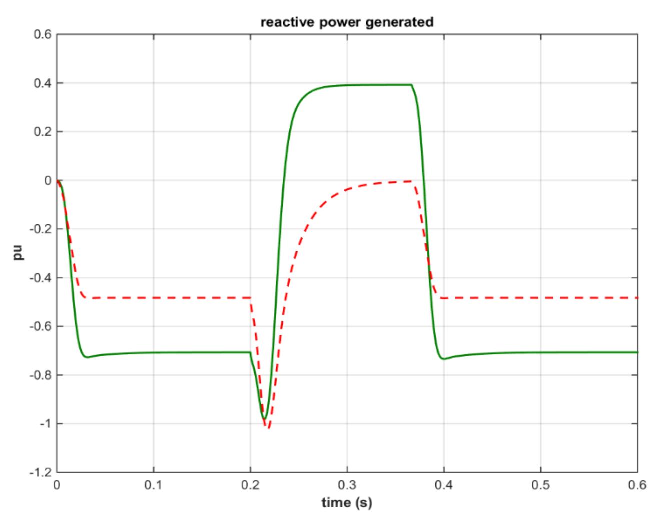

Fig. 4. Measured reactive power generated by shunt FACTS devices during fault, SVC (red trace) and STATCOM (green trace).

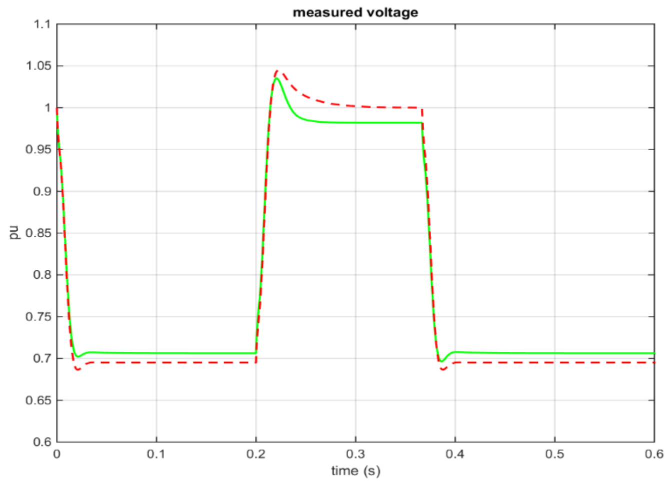

Fig. 5. Measured voltage in compensator bus during fault, SVC (red trace) and STATCOM (green trace).

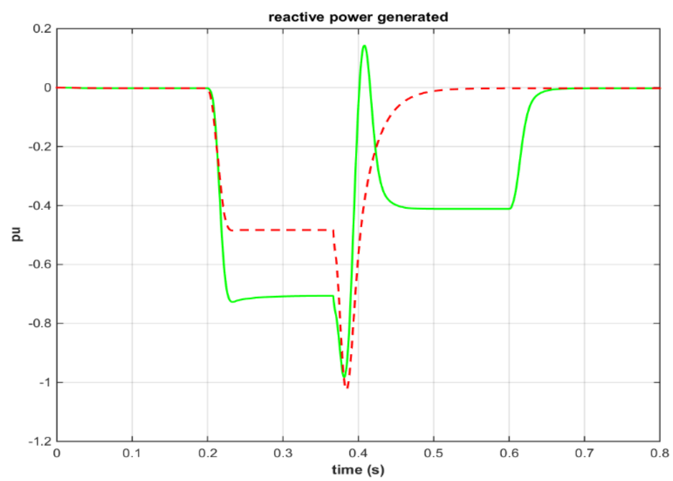

Fig. 6. Measured reactive power generated by shunt FACTS devices, SVC (red trace) and STATCOM (green trace).

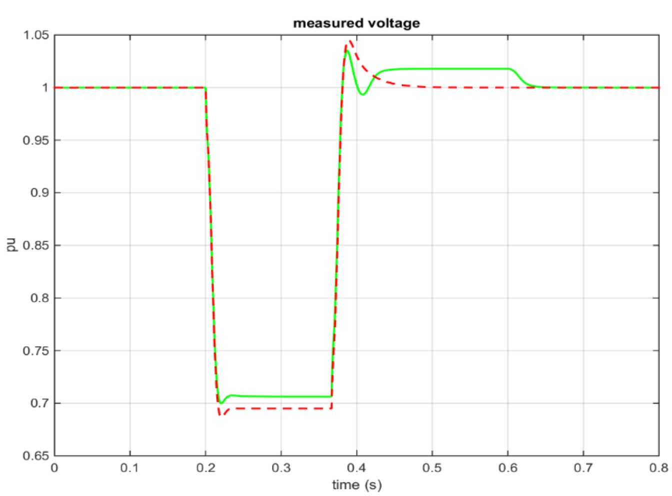

Fig. 7. Measured voltage in compensator bus, SVC (red trace), and STATCOM (green trace).

The measured voltage on compensator bus in both systems is shown in Fig. 5. It is also observed that the STATCOM is very effective during the power system disturbances because, with the voltage source converter, the STATCOM has no delay associated with the thyristor firing.

The measured reactive power generated by the SVC and the STATCOM and the measured voltage on compensator bus in both systems are shown in Figs. 6 and 7.

The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. When the system voltage is high, the STATCOM will absorb reactive power, whereas when the system voltage is low, the STATCOM will generate and inject reactive power into the system.

5. CONCLUSION

FACTS are used to control the transmission line power flow, voltage control, transient stability improvement, and oscillation damping. This paper describes the effect of shunt FACTS to enhance the dynamic stability of power systems. Shunt FACTS can improve power system dynamic performance through reactive power control. Simulation results are performed using the MATLAB Simulink toolbox. Simulation results indicated that both the SVC and STATCOM can significantly improve voltage regulation in transmission line by shunt FACTS devices. It can also be seen that STATCOM can provide more effective attenuation than SVC.

STATCOM is used in power system to provide reactive power compensation. It makes use of the voltage source converter to synthesize a controllable sinusoidal voltage at the fundamental frequency.

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