Reactive Power Sustainability and Voltage Stability with Different FACTS Devices using PSAT

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***Abstract*—The main issues in the current power system network are about load side voltage stability and reactive power sustainability throughout the running time. Both the issues can be upheld by using different shunt and series FACTS devices. There is always a probability of losing stability in the power system because of various disturbances occurring continuously. In this paper, placements of SVC, STATCOM, SSSC and UPFC for the total reactive power loss and voltage stability enhancement have been identified for IEEE 9-BUS as a case study in PSAT/MATLAB software. Relative analysis depending on the distinct location of SVC, STATCOM, SSSC and UPFC is made, it is seen that by placing the FACTS devices at a suitable position, the voltage profile of the buses gets improved. The stability study has been conducted for SVC, STATCOM, SSSC, and UPFC with the help of PSAT/MATLAB whereby it reflects that for UPFC there is maximum voltage stability and minimum total reactive power loss of the system.**

Keywords—FACTS, SVC, STATCOM, SSSC, UPFC, PSAT

NOMENCLUTURE

FACTS	Flexible AC Transmission System
IPFC	Interline Power Flow Controller
PSAT	Power System Analysis Tool
SSSC	Static Series Synchronous Compensator
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
TCPST	Thyristor Control Phase Shift Transformer
TCR	Thyristor Controlled Reactor
TCSC	Thyristor Controlled Series Capacitor
UPFC	Unified Power Flow Controller
VAR	Volt Ampere Reactive
VSC	Voltage Source Converter

I. INTRODUCTION

Transmission networks of current power systems are consistently driven into more stressed level due to the rise in load demands and constraints of constructing new transmission lines. The outcome of such an emphasized system could be losing stability followed by an interruption due to a fault. Usage of FACTS devices has proved to be a very effective method to bring down the stress of the power network and hence results in better utilization of existing facilities in power system without compromising the desired stability margin [1]. FACTS controllers, such as SVC, UPFC, and STATCOM are the application of power electronics switching devices and its different configuration in the power system which have a major impact on controlling voltage profile, power flow and enhancement of stability. In the last few years, the electricity demands increased rapidly. The rise in the demand of electricity is just because of the rise in loads, deficient transmission system and cut-throat competition of power supply market which have propelled the systems to run closer to their static and dynamic constraints [2]. Reactive power generation has great influence on the cost of total power generation because of transmission power loss which encounters the I^2R loss. Therefore to optimize the total loss, reactive power should be taken as variable and bycompensation, the loss can be minimized. In addition, insufficient reactive power support from generator mainly causes voltage instability or voltage collapse [3]. Even though bulk power transfers are expanded and accelerated but the increment in the electrical transmission system is somehow restricted. Power transmission system control should be fast enough and reliable to cope up the aging of the power system network. Dynamic and accelerated research in the field of power electronics increases the choice to obtain power system stability by using the controllable FACTS devices. FACTS devices are not only capable to govern transmitted power and increase the capacity of transmission lines but also propose as a second option to suppress power system fluctuations [4]. Many perspectives are explained for the study of power system stability and also for the study of load flow studies. It is compulsory to find out the system behavior, stability improvement and proper execution of the system considering some limits. The proper placement and optimal tuning of FACTS devices to suppress the power system oscillations [5]. In [6,7], the proper placement of shunt FACTs device for power flow control is studied and understanding of series FACTs controller for optimal loss and voltage stability improvement is explained. Load flow study of STATCOM and SVC for system stability improvement have been illustrated in [6]. The UPFC has the advantages over other FACTS devices is demonstrated in [8,2]. In this paper, the placement of the various FACTs devices in PSAT/MATLAB for same fault condition has been observed to define the impact of the FACTs devices on the voltage stability enhancement and reactive power sustainability of the system. PSAT toolbox facilitates the user with in-depth study of various aspects of the power systems and gives an edge over other MATLAB toolbox like MATPOWER, PAT etc.

II. FACTS DEVICES

A FACT device consists of a group of static elements to enhance the control and power transfer capacity of a.c. transmission system by means of power electronics devices. According to IEEE, FACTS device is "a power-electronic based system and other static equipment that provide control of one or more a.c. transmission system parameters to enhance controllability and increase power-transfer capability". Initially, FACTs were used to deal with system problems because of the constraints in transmission line fabrication and to enhance the power transfer capability in both directions and wheeling transaction among utilities different kind of FACTS controllers have been introduced.

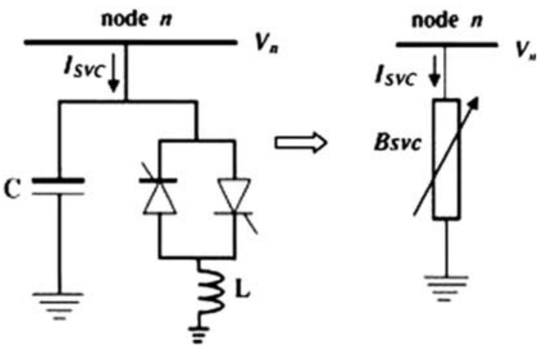
TABLE I. FACTS DEVICES WITH THEIR CONTROL MECHANISM

FACTS Devices	**Control Mechanism**		
	Voltage control device	***Impedance control device***	***Angle control device***
SVC	YES	—	—
STATCOM	YES	—	—
TCSC	—	YES	—
SSSC	YES	YES	YES
UPFC	YES	YES	YES
IPFC	YES	YES	YES
TCPST	—	—	YES

UPFC is considered to be the most versatile device because of its capability to control any of the parameters of the power network simultaneously i.e. voltage, impedance, and phase angle. By installing the FACTS devices in an existing network, transmission capacity can be increased while keeping the other variables undisturbed.

A. Static VAR Compensator

SVC is a shunt-connected device which acts as static VAR generator or absorber. The bus voltage level is controlled by exchange of capacitive or inductive current delivered by SVC. SVC uses thyristor for switching purpose which does not have the turn off capability. Fig.1 indicates that the fixed capacitor is in the series with the inductor along with the power electronic switching device, thus small inductor is introduced because sudden switching is not possible. By changing the firing angle of the thyristor, we can change the equivalent value of the shunt admittance which appears across the line to which SVC is connected [9]. The operating principle and characteristics of thyristors realize SVC variable reactive susceptance.



a.

Fig. 1. Variable shunt susceptance model of SVC

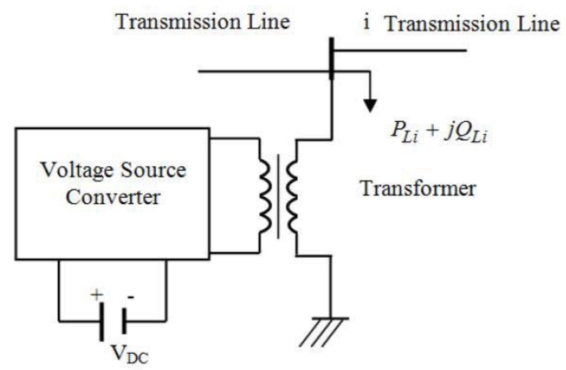
For steady-state analysis, this SVC configuration can be modeled along similar lines. The model considers the firing angle of the TCR as a state variable. It is similar to a power source which produces leading reactive power when the SVC is working within its operating limits [9]. TCR represents the SVC voltage regulation characteristic. The slope of the VI characteristics of SVC gives a clear idea of voltage variation across it. The slope is proportional to the reactor used in SVC.

The current drawn by the SVC is given by

$$I_{svc} = jB_{svc}V_K \quad (1)$$

B. Static Synchronous Compensator (STATCOM)

STATCOM is one of the type of FACTS controller that comprises of a power electronic converter (commonly an electronics switched voltage source converter), an electrolytic capacitor with a reactor in series [6]. The configuration of STATCOM connection is that of a shunt connected which uses power electronics switching devices to have control on the power flow in the bus which also have an impact on the transient stability of the interconnected network i.e. it improves the transient stability. The variation of reactive power is also controlled by the use of a voltage source converter which is connected on the secondary side of the coupling transformer. STATCOM operates as a capacitor or as an inductor depending on the system voltage level. It compares the system voltage level with the reference voltage and if system voltage is found less than the reference voltage it works as a capacitor and produces leading reactive power whereas if the value of system voltage level found to be greater than the reference voltage it start working as an inductor and produce lagging reactive thus by mode if the operation, it helps to maintain system voltage equal to the reference voltage [10].

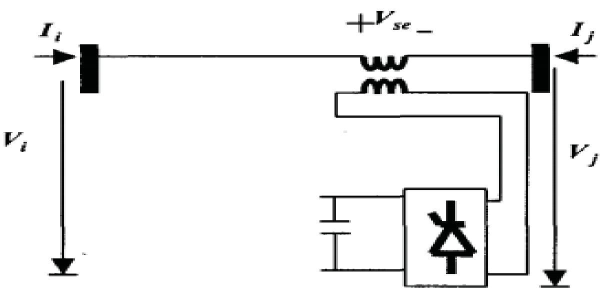


b.

Fig. 2. Simplified model of STATCOM

C. StaticSynchronous Series Compensators (SSSC)

SSSC is a versatile FACTS device which is capable of controlling all three parameters at node simultaneously (line impedance, voltage, and phase angle). SSSC simplified model is shown in Fig. 3 which consists of a solid state voltage source inverter connected with a transformer in order to inject sinusoidal reactive voltage equivalent to a sinusoidal current in the transmission line. SSSC is always connected in series thus it can modify the equivalent impedance of the line and hence power flow of the transmission can be controlled by varying the impedance of the line [11]. Inductive or capacitive effect of the voltage injected by SSSC depends upon the desired voltage compensation. The power flow can also be reversed in the line if sufficiently large reactance voltage is being injected by SSSC. In this way, real and reactive power flow along with voltage (controllablephase as well as magnitude) which is injected in series can be regulated with the help of SSSC and series inverter. Therefore, SSSC can compensate for active power and reactive power and phase shifting in the line.

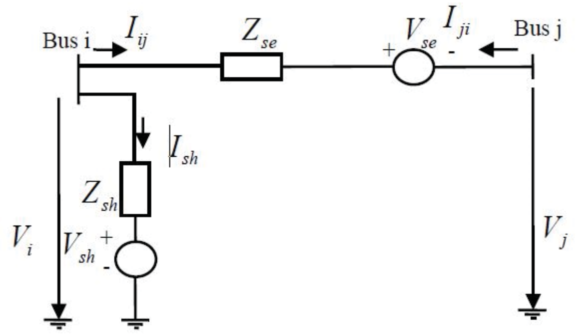


c.

Fig. 3. Simplified model of SSSC link in transmission line.

D. Unified Power Flow Controller (UPFC)

UPFC is an electronic controllerwhich is used to regulate the flow of reactive power and provide compensation to the transmission lines. It injects the currents in the transmission line with the help of series transformer to control line parameters. AUPFC gains a major advantage over others as it controls the active power, reactive power and voltage magnitude of the bus where it is being operated. UPFC controller contains two VSC in which one is used to inject the shunt current to control voltage of the bus and another is for the series current injection in order to control the power flow [12]. A capacitor is used across the d.c. link to cooperate both SVC. The d.c. link voltage magnitude is always held equal to the reference voltage. Shunt converter maintains voltage whereas the series converter injects current with varying phase angle in order to control reactive power flow. So, they can enhance system operation because it allows for more efficient control of power flow, superior control mechanism and voltage stability.



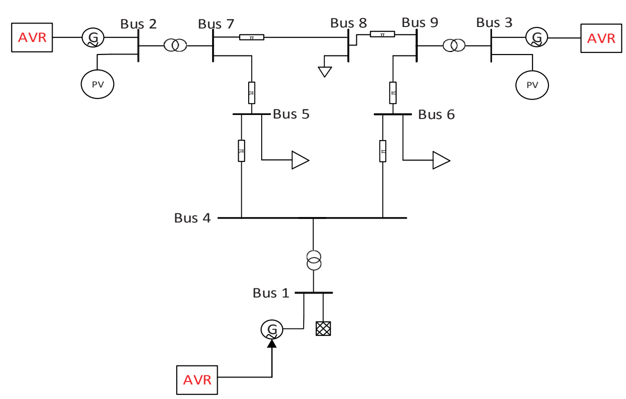
d.

Fig. 4. Equivalent model of UPFC between two buses

III. SIMULATION: MODELING AND RESULTS

A. Test System

This simulation is done on 9 bus system with base MVA=100 and the data [13] is taken for the standard IEEE 9 bus system. The test system is shown in Fig. 5 which includes total 9 bus in which bus 1 is taken as slack bus. Bus 2 and 3 are PV buses, the generator is connected to PV buses as well as with slack bus. Buses 5, 6 and 8 are load buses with the total load of P=3.15 and Q=1.15 in pu. This simulation model is made in PSAT/MATLAB software. Newton Raphson method is used for the load flow analysis of the test system with various FACTS devices. Load-flow programs with and without different FACTS devices are observed for the purpose of comparison.

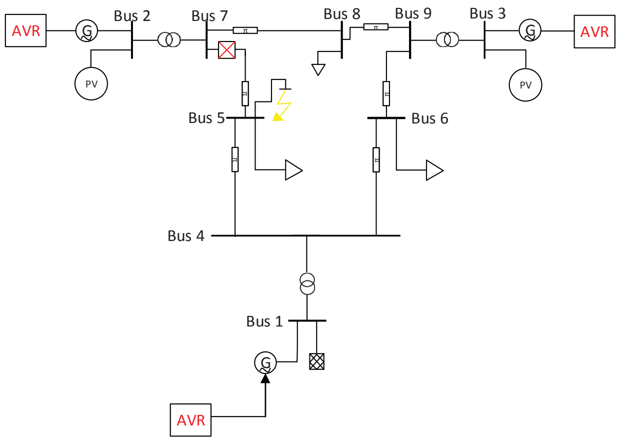


f.

Fig. 5. PSAT IEEE 9 bus test system

B. Test System with Symmetrical Fault at Bus

The test system is subjected to a three-phase symmetrical fault at t=3 s to 3.15 s at bus 5 of shown in Fig. 6. Total reactive power loss and generation of the entire system without compensation are compared with compensation taken from SVC, STATCOM, SSSC, and UPFC. Load-flow programs with and without different FACTS devices are observed for the purpose of comparison.

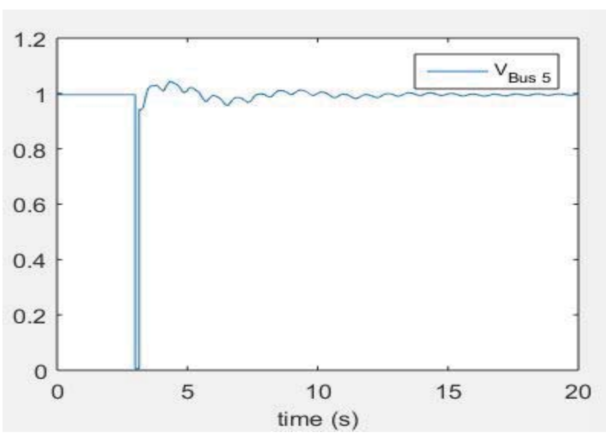


g.

Fig. 6. IEEE 9 bus system with three phase fault.

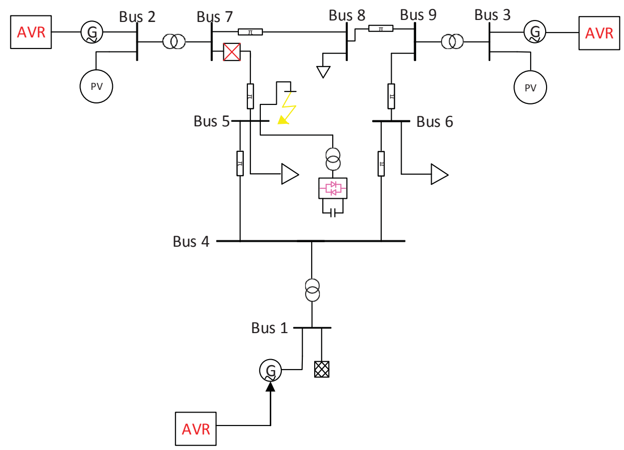
C. Simulation Results

The voltage variation of the bus 5 in which fault is taken is shown in Fig. 7.



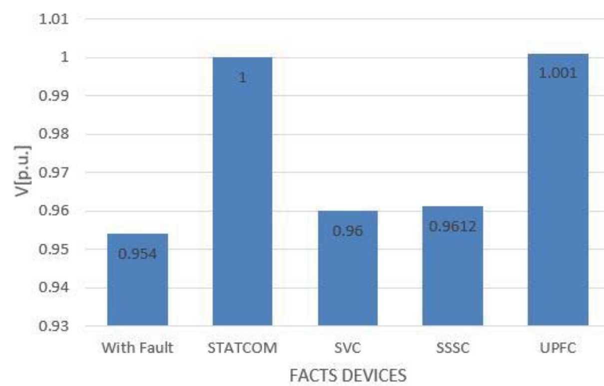
h.

Fig. 7. Bus 5 voltage variation with time.



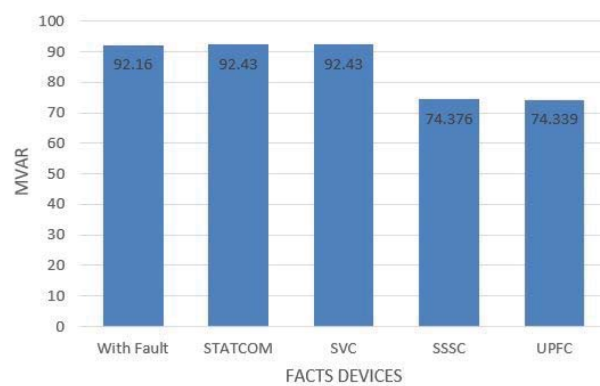
i.

Fig. 8. IEEE 9 bus system with STATCOM



j.

Fig. 9. Voltage profile of bus 5 with different FACTS devices.



k.

Fig. 10. Total rective power loss of the system with different FACTS devices.

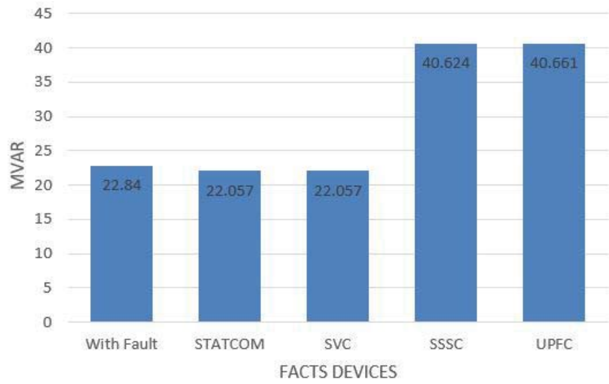


Fig. 11. Total reactive power generation of the system with different FACTS devices

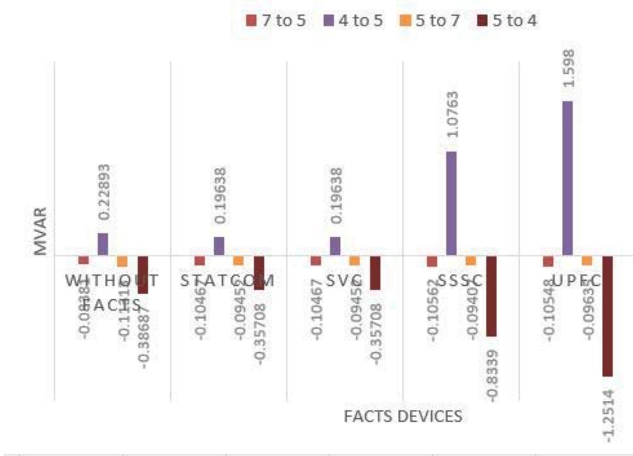


Fig. 12. Reactive power flow in the lines with different FACTS devices.

In this paper, we four FACTS devices i.e. SVC, STATCOM, SSSC and UPFC are compared for their performance based on voltage profile of all the buses, reactive power loss, reactive power generation and net reactive power exchange between bus 5 and other buses connected to 5. The Fig. 9 shows that the voltage profile of all the buses gets improved with STATCOM and UPFC but there is only some slight variation in the case of SSSC and SVC. Fig. 10 represents that reactive power loss with SSSC and UPFC is significantly less as compared to STATCOM and SVC under same fault scenario. Fig.11 concludes that reactive power generation is large in case of UPFC whereas Fig. 12 represents reactive power flow in the lines increases and for UPFC it is maximum.

IV. Conclusion

Performance of various FACTS devices (STATCOM, SSSC, SVC, and UPFC) have been compared under the condition of fault at one of the buses in IEEE 9 test bus system. Voltage stability, reactive power loss, reactive power generation, and reactive power flow in lines have been considered for comparison criteria, however reactive power flow in line is maximum in case of UPFC which maintains voltage stability of the system with minimum total reactive power loss and hence makes the system to sustain line reactive power therefore this paper successfully establishes the platform to conduct the study of various FACTS devices for reactive power sustainability and voltage stability in PSAT.

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