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Comparative Study of Voltage Control Methods in Power Flow Analysis

Nivedita Nayak[1], Dr. Pragya Nema[2]

[1,2]Electrical Engineering Dept, Oriental University, Indore

Abstract:
This paper presents, a comparative study with different methods to improve power quality and voltage control at different buses of the electrical power systems. That becoming increasingly concerned about the power quality of load flow analysis. The term voltage control in load flow analysis has become one of the most prolific useable in the power industry nowadays. In this paper, we have discussed the challenges against voltage control for power quality improvement and the importance of Reactive Power management in this process. This paper shows major types of voltage source converter- based FACTS devices can voltage control and stability ratio, damping out inter-area oscillations successfully. The importance of various FACTS devices in reactive power control has been discussed. STATCOM undoubtedly has an upper hand over other FACTS devices like SVC and SSSC voltage control. Load flow analysis of IEEE 14 bus and 30 bus system has been carried out using Newton-Rephson Method which depends on no. of iterations with and without STATCOM. The study of Load flow analysis between with and without STATCOM, has more improvement in voltage control with the use of STATCOM in the system.

Keywords: FACTS Devices, SVC, STATCOM, SSSC, VAR Generators and voltage control for power Quality improvement.

I. Introduction

For making voltage control and efficient power system, it is necessary to find out the correct method those solving the load flow equation and problems easily and without any failure. We need to solve the load flow equations and get accurate results; it is the first priority to find out the correct method. In power system analysis, power generation and transmission is a complex process, requiring the working of many components of the power system to maximize the output. One of the main components to form a major part is the reactive power in the system is heavy inductive loads due to its power storage capacity. It is required to maintain the voltage to deliver the active power through the transmission lines. Loads like motor loads and other ac circuits loads require reactive power for their operation. To improve the performance of ac power systems, we need to manage this reactive power load efficiently and this is known as reactive power compensation. There are two aspects to the problems of reactive power compensation: load compensation and voltage support[2]. Losses of power transformation depends on load, compensation of load consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation, of large fluctuating loads. Voltage support consists of the reduction of voltage fluctuations at a given terminal of the transmission line. The development and use Flexible AC Transmission System (FACTS) controllers in power transmission systems had led to many applications of these controllers to improve the stability of voltage and power networks. Most flexible ac transmission system (FACTS) devices, such as static synchronous compensators (STATCOMs), static synchronous series compensators (SSSCs), and unified power flow controllers (UPFCs) are increasingly used in power systems because of their ability to stabilize power transmission systems and to improve power quality and voltage control in power distribution systems[3][5]. More often STATCOM technology is gradually employed to increase power transfer capability and provide voltage control support fast acting solid state condition, thyristor switches of the FACTS devices are known to improve both the transient as well as the dynamic performance of load flow power system. For voltage control, STATCOM (Static Synchronous compensator) is one of the most important Flexible AC transmission system (FACTS) devices because of its reliability and ability to regulate voltages in transmission lines, improve transient stability, and compensate variable reactive power in a load flow system. These devices are also interesting at the distribution level, where fast compensation of high, fluctuating commercial and industrial loads (such as electric arc furnaces and rolling mills) can be achieved, substantially improving upon the performance achieve with conventional thyristor-based compensators.

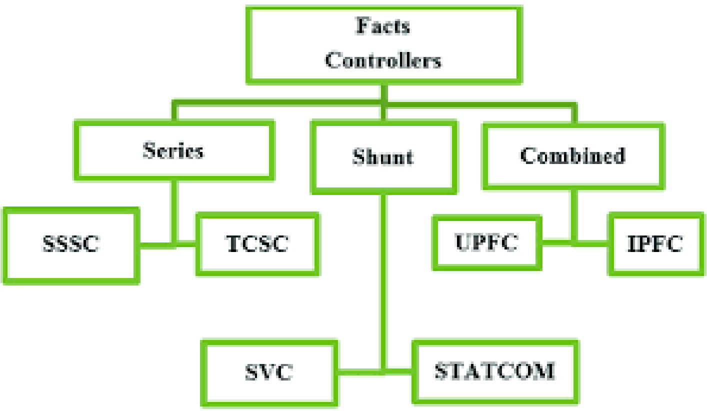

Fig. (1) Block diagram of FACTS controller

STATCOM is an effective and active device, which can control voltage magnitude and to a small extent, the phase angle in very short time duration and therefore has the ability to improve the system damping as well as voltage profiles the control of the system[1]. It has been seen that STATCOM can offer number of performance that is advantages for reactive power control applications over the conventional SVC because of its greater reactive current output at slack voltage bus, faster response, better voltage control stability, lower harmonics and smaller size, etc. Power quality improvement is a economics-influenced issue, and the end user’s point of reference takes precedence. Therefore, the following definition of a power quality improvement is established[6], ultimately we are interested in voltage control in power quality is economic value. There are economic impacts on utilities, their economics, and suppliers of load equipment. The quality of power can have a direct economic impact on many industrial consumers[9]. There has recently been a great emphasis on revitalizing the industry with more automation and more modern equipment which are used in a power transmission systems. This usually means electromechanically controlled, energy-efficient equipment that is often much more sensitive to deviations in the supply voltage than were its electromechanical predecessors.

II. METHODS OF VOLTAGE CONTROL

A. Voltage Control by Static VAR Compensator (SVC)

In transmission applications, the SVC is used to regulate the grid voltage control in the transmission line. If the power system's reactive load is capacitive (leading current), the SVC will use thyristor-controlled reactors to consume VARs from the bus system and lower the system voltage. SVC controls the voltage of a power system bus to which it is connected as the SVC regulates the voltage at its end terminal by controlling the amount of reactive power injected into different buses and absorbed from the power system. When the transmission system bus voltage is low, the SVC generates reactive power (SVC capacitive load). When system voltage is high, it absorbs reactive power (SVC inductive load). Then evaluate the performance of SVC by controlling voltage in a power system when the system voltage is low, the SVC generates reactive power (SVC Capacitive load). When the system voltage is high, the SVC absorbs reactive power (SVC inductive load) as preferred [7].

The Static Var Compensator (SVC) capacitive load is used to control the bus voltage at different lines. It controls the bus voltage profile by injecting or drawing reactive power from the power system network. The basic circuit of SVC is shown in figure (2). It contains a load with a fixed capacitor and variable inductor connected in parallel. By varying the inductive reactance the current drawn or injected by the SVC is controlled in the power system network.

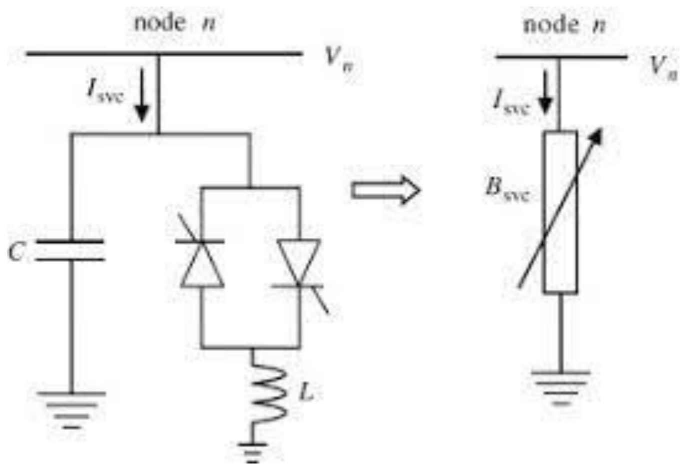

Fig. (2) static VAr compensator diagram

B. Voltage Control by Static Compensator(STATCOM)

A static compensator (STATCOM) is a device that can provide reactive support to a bus in power system transmission lines. It consists of voltage source converters that are connected to an energy storage device on one side and to the power system transmission line on the other side. The conventional method of PI control is compared and contrasted with various feedback control strategies [10]. A linear optimal control is based on LQR control that is superior in terms of response profile and control effort required in the system. These methodologies are applied to an example of the power system.

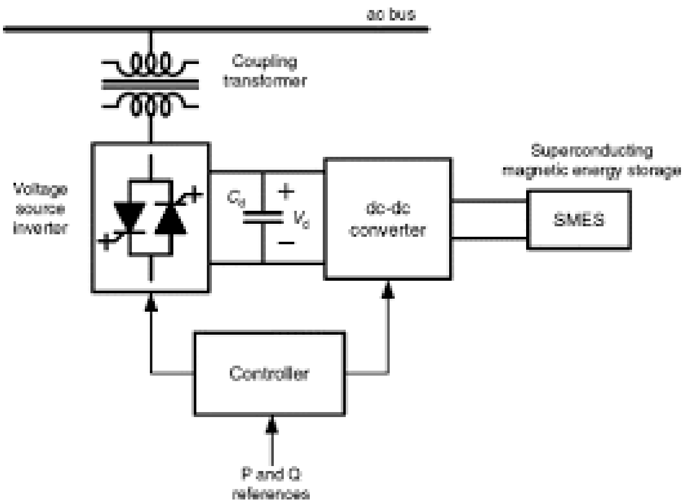

Fig. (3) STATCOM diagram.

One of the many devices under the FACTS family, a STATCOM is a regulating and powerful device that can be used to regulate the flow of reactive power in the system which is independent of other system parameters. STATCOM has no longer parameter term of energy support on the dc side and it cannot exchange real power with the ac system in a network. In the transmission line systems, STATCOMs primarily handle one of only fundamental reactive power exchange and they provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins, and damp out the system oscillations due to these disturbances in transmission lines[5]. A STATCOM also consists of a three-phase inverter (generally a PWM inverter) using no. Of SCR, MOSFET, or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c. supply side, filter components to use, filter out the high-frequency components due to the PWM inverter. From the d.c. side capacitor which is a three-phase voltage generated by the inverter. This is synchronized with the a.c supply. The link inductor is link this voltage to the a.c supply side[8]. This is the basic principle of operation of STATCOM which depends on capacitor and inductor.

The Static Compensator (STATCOM) is mostly used to control the bus voltage in load flow analysis. The basic equivalent circuit of STATCOM is shown in figure 3. It contains a DC source connected to an AC system through a voltage source converter in the transmission line. The converter acts as an inverter or rectifier in this device. STATCOM injects reactive power into the connected bus when acting as an inverter and absorbs when acting as a rectifier in the voltage bus.

In the load flow analysis transmission system, STATCOM can be used to provide voltage and reactive power control, enhance the system damping, suppress low-frequency and sub-synchronous oscillation, and improve power system transient stability which is more important to improve power system efficiency and stability.

C. Voltage Control by Static Synchronous Series Compensator(SSSC)

The static synchronous series compensator (SSSC) is a v voltage controllable FACTS device that employs a voltage source controller VSC connected in series to a transmission line through a transformer and different multilevel inverters.

Static synchronous series compensator (SSSC) is a type of flexible AC transmission line system which consists of a solid-state voltage source inverter which is coupled with a transformer that is connected in series with a transmission line system for load flow analysis. This device can inject an almost sinusoidal voltage in series with the line voltages.
A Static Synchronous Series Compensator (SSSC) is a type of prevalently usual power quality FACTS device that employs a voltage source converter that is connected in series to a transmission line through an AC single-phase transformer [11]. The SSSC operates like a controllable series capacitor and series inductor device in the transmission line. The primary difference is that its injected voltage is not related to the line intensity and can be managed independently to other parameters. This feature of the SSSC is allowed to work acceptably with high loads as well as with low loads in the transmission lines in the power systems.
The Static Synchronous Series Compensator has three basic components like,

1. Voltage Source Converter (VSC) – This is the main component of SSSC.
2. Transformer – It couples with the SSSC to preferable bus.
3. Energy Source – It provides voltage across the DC capacitor and compensates for device losses in the system.

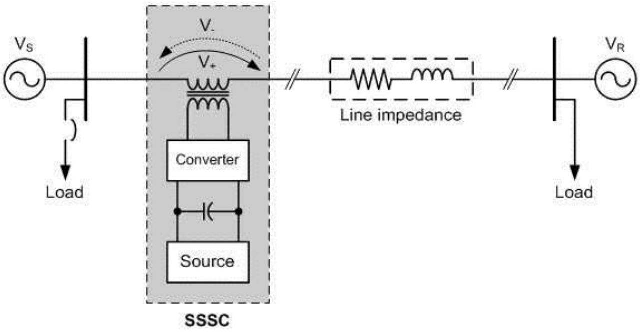

Fig.(4) Static Synchronous Series Compensator (SSSC) Diagram

Operation and Capabilities of Static synchronous series compensator works as like the STATCOM, except that it is serially connected with instead device of shunt [13]. It is able to transfer both active power (P) and reactive power (Q) to the system, permitting it to compensate for the resistive voltage drops and reactive voltage drops, to maintain a high effective X/R ratio that is independent of the degree of series compensation device. However, this is costly as a relatively large energy source that is required in a power system for load flow analysis.
On the other point of view, if voltage control is limited to reactive compensation then a smaller power supply should be enough. In this case, only the voltage is controllable by this because the voltage drop vector forms 90^{o} with the line intensity available. After a while, the serial injected voltage can advance or delay the line current, meaning, the SSSC can be uniformly controlled in any value of load flow analysis.
The SSSC when operated with the regular energy supply in terms of power can inject a voltage component, which is of the same magnitude (V) but opposite in phase angle (delta) with the voltage developed across the line [12]. As for the result, the effect of the voltage drop on power transmission will offset. So the static synchronous series compensator (SSSC) provides fast voltage control and is inh-

erently neutral to sub-synchronous resonance in transmission lines for power supply.

III. Comparison between SVC, STATCOM, and SSSC

SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator) both are more important equipment for reactive power compensation, which are compared in voltage control, improving the transient stability and transmission limit with damping ratio at low-frequency oscillation. According to different papers review high capacity static var system for SVC or STATCOM is placed on the transmission path of power system for voltage control. Single SVC and STATCOM are limited in voltage control after fault occurrence in the transmission line, STATCOM is little better than SVC. STATCOM is much better than SVC in improving the transient stability and transmission limit for voltage control in the transmission lines. The damping ratio at low-frequency oscillation, STATCOM is much better than SVC as STATCOM have the same capacity and performs power system voltage control similarly with SVC as having the same controllable capacity [14]. The dynamical response of speed effects is little though at STATCOM responses much faster than SVC. The STATCOM is basically an alternating voltage source after a coupling Reactance whereas SVC is composed of thyristor switched capacitors and inductors. The capability of STATCOM is to maintain full capacitive output current at a low voltage system that makes it more efficient than SVC in improving the batter transient stability. Obtainable responses of time and bandwidth of the voltage regulation loop of STATCOM are significantly better than that of SVC voltage control. STATCOM has more storage capacity of energy and hence has a high capability to exchange real power (P) as compared to SVC. STATCOM can operate better at unbalanced AC systems in transmission line systems for load flow conditions. STATCOM not only voltage controls but also internally generate the reactive power output at both inductive and capacitive load which gives more better and significant result in the reduction of overall size.

STATCOM is also provides good reactive power support at both capacitive and inductive load at low AC voltages better than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage supply as the current can be maintained at the rated value even down to low AC voltage supply.

Table 1 Comparison of SVC and SSSC

Issue	SVC	SSSC
V/I characteristic	Good overvoltage performance Impedance	Good under voltage performance Voltage source
Control range	freely adjustable to any range by TCR/TSR /TSC branches	Symmetrical
Modularity	TCR/TSR/TSC branches used in SVC and TCSC/TPSC Redundancy Degraded mode operation	Same converter usable for various applications UPFC, SSSC configurations are used in the CSC
Response time	2 to 3 cycle	3 to 4 cycle
Transient behavior	Available before, during and after critical system conditions	Self protecting at critical system faults
Space requirements	100 %	60 to 70 %
Availability	> 99 %	90 to 92 %

Flexible Alternating Current Transmission Systems (FACTS) devices capable to control multi-power system parameters simultaneously and independently, FACTS devices have a high application potential and can be considered as one of the more workable solutions to damp out inter-area oscillations in an effective manner in transmission lines. The studied FACTS devices in this paper are Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), and SVC.

SSSC can improve active power flow predictability in transmission line systems. SSSC can reduce the active power flow predictability index, severely. SSSC can also decrease the voltage predictability index. STATCOM just about improves active power flow predictability compared to base system parameters in load flow analysis.

The STATCOM is better than SSSC for voltage regulation and voltage control, while the SSSC is best in the core of controlling the flow of power and damping out the oscillation in transmission lines. When the system is operated on one element that is out of service was tested in the presence of these devices.

The SSSC is capable to control power flow on the transmission line without changing the bus voltages while the STATCOM can change the power by increasing the bus voltage with a preferable limit. In the case of system stability and power factor improving both SSSC and STATCOM can improve these parameters. But the SSSC is more effective for damping oscillation factors in the transmission lines.

Table 2 Comparison of SSSC, SVC and STATCOM

SSSC	SVC	STATCOM
Slow Response	Slower than STATCOM	Faster
Cost is low	Cost is low	Cost is high
Low losses	Losses lower than STATCOM	High losses
Better VI characteristics	Good as STATCOM	Best VI characteristics
Large in size	Large in size	Smaller in size
Controllable current source	Dynamically controlled reactance	Controllable voltage source
Series controllers inject voltage in series at the point of connection	Shunt controllers inject current	Shunt controllers inject current

The impact of STATCOM and Static Series Synchronous Compensator (SSSC) on comparatively of power system study STATCOM is better in system stability. For this manner of investigation, predictability indices are utilized in the power system network. This paper clarifies some important concerns about power systems such as do the STATCOM and SSSC improve or reduce the certain system transmission state. Also, this paper warns the operator of the system about ignoring the predictability concept in FACTS including STATCOM and SSSC with voltage control power systems. Moreover, the necessity of utilizing predictability indices in optimization problems besides conventional objectives, such as voltage control and power factor improvement by FACTS devices is discussed.

IV. CONCLUSION

The study observations and compares the SVC, STATCOM, and SSSC devices in the power system network, and their applications to solving power system problems, such as power flow control, voltage control, stability, an increase of transmission capability, damping as well as the impact of these devices to improve system stability when a fault occurs. The ability of the system is to operate when one element is out of service in the presence of these devices can resolve the problem of constant power transfer at load flow networks. In this Critical Clearing Time (CCT) of the system with and without FACTS devices, the IEEE 14 bus and 30 buses were selected to perform this study by using MATLAB Simulink models. The most of paper reading observations showed that the STATCOM is better than SSSC for voltage control and regulation, while the SSSC is best in the core of controlling the power flow in the transmission line.

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