DETAILED ANALYSIS AND COMPARISON OF SVC AND UPFC FOR POWER QUALITY ISSUES

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Abstract: Power Quality is majorly characterized by Reactive Power and Voltage Imbalance. In this paper a detailed analysis of Flexible AC Transmission System (FACTS) i.e. SVC and UPFC and their effects on the system voltage profiles and reactive power compensation are analyzed using MATLAB simulation. In this work, Newton-Raphson load flow algorithm is used and steady state models of FACTS are used for the analysis. Voltage profile improvement and reactive power capability at every bus with mentioned FACTS devices are shown in results for IEEE 9, 14 and 30 bus systems.

Keywords: Power Quality, FACTS, loadability, Voltage Imbalance, SVC, UPFC.

Introduction: Electrical equipment susceptible to Power Quality would fall seemingly boundless domain. Power Quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy [13]. Due to non linear loads, there is large amount of power loss, voltage drop and reactive power drop. There would be a tremendous increase in the power transfer capability of the existing transmission lines if the operating parameters of the transmission line could be controlled like current, line reactance [1]. This could possibly be achieved by placing capacitances in the transmission system. These devices offer poor voltage regulation and beyond certain level of compensation a stable operating point is unattainable. Fast control of system parameters is not possible using Capacitors. It is true that a new solution to such problems will rely on the upgrading of existing transmission corridors by using the latest power electronic equipment and methods, a new technological thinking that comes under the generic title of FACTS – an acronym for flexible alternating current transmission systems. FACTS devices not only improve the power transfer capability but also increase the voltage profile. With the improvements in current and Voltage handling Capabilities of these FACTS devices the possibility has arisen of using different types of controllers for efficient shunt and series compensation. FACTS devices have fast response and the voltage improvement obtained is in a desired range. It is well known that shunt and series compensation can be used to increase the maximum transfer capabilities of power networks. The ability to control the line impedance and the nodal voltage magnitudes and phase angles at both the sending and the receiving ends of key transmission lines, with almost no delay, has significantly increased the transmission capabilities of the network while considerably enhancing the security of the system. Each of them has its own characteristics and limitations. All series Controllers inject voltage in series with the line. Even variable impedance multiplied by the current flow through it, represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. An example foe series controller is TCSC (Thyristor controlled series compensator). All shunt Controllers inject current into the system at the point of connection. Even variable shunt impedance with a series controller and voltage regulation with a shunt controller can also provide a cost effective means to connect to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. An example foe series controller is SVC (Static VAR compensator). Combination of the line impedance controls both the active and reactive power flow between the system and the FACTS device. Another type of controller involves in the combination of both series and shunt devices. These inject current into the system with the shunt part of the controller and voltage in series in the line with the series part of the controller [1]. An example for the series-shunt controller is UPFC (unified power flow controller). In this paper, based on the results obtained an effort has been made to compare the FACTS devices, namely, SVC and UPFC using MATLAB programming. In the primitive section the practical working of the various devices mentioned above have been discussed. In the second section, the algorithm which has been used has been discussed with digital computation technique using MATLAB programs. Later the results obtained are analyzed for various IEEE standard buses and their losses, reactive power capability and voltage profiles are compared when these devices are placed at various locations.

Mathematical Models And Equations:

a) Static VAR Compensator (SVC)

SVC is a shunt connected FACTS device that helps in controlling and maintaining the specific power system variable by varying its output capacitive current or reactive current. Two widely used models of SVC are the fixed capacitor (FC) with a thyristor controlled reactor (TCR) model and the thyristor switched capacitor (TSC) with TCR. In this paper the FC-SVC model of SVC is used for the analysis [10].

By controlling the Firing angle of the thyristor the fundamental component of the controller current can be varied from its maximum value to the zero. Fig.1 represents the steady-state model of SVC. This effect is equivalent to varying the impedance of the controller [8]. Hence by varying the Firing Angle the current (Lead/Lag) supplied can be varied

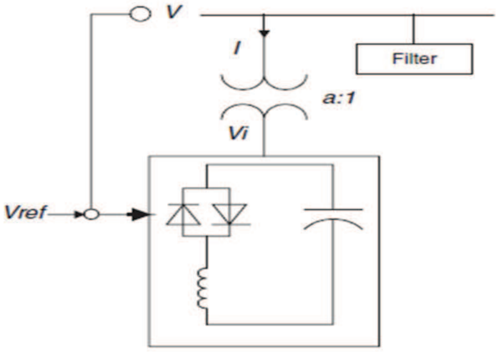


Fig.1 Basic structure of SVC

However several harmonics are produces which can be removed by using a filter tuned at power frequency. Assuming voltage of the controller equal to the bus voltage fundamental component of only TCR current could be obtained by performing Fourier series analysis.

$$I = \frac{V * 2(\Pi - \alpha) + Sin\,2\alpha}{\Pi X_l} \quad \text{...... (i)}$$

$$Xv = \frac{X_l * \Pi}{2(\Pi - \alpha) + \sin\,2\alpha} \quad \text{...... (ii)}$$

Where, I= Fundamental component of TCR current.

X_l = reactance caused by the fundamental frequency without thyristor control and α is the firing angle.

X_v= Variable reactance of the TCR.

Hence, the total equivalent impedance of the SVC can be represented as:

$$X_e = \left(X_c \frac{\Pi\, {}^{1}\!/_{r}}{\sin 2\alpha - 2\alpha + \Pi(2 - \frac{1}{r})} \right) \quad \text{...... (iii)}$$

$$r = \frac{X_c}{X_l}.$$

X_e= Reactance of SVC, X_c=Capacitive reactance

The limits of the controller are given by the firing angle limits which are fixed by design. In-order to have a clear idea about the working of SVC when installed in the power system its steady state V-I characteristics have to be studied. From Fig.2, the operation of SVC can be explained as follows.

When the system is operating at normal situation the voltage is at point A.

Increase in Load: When there is any increase in load the current drawn increases due to which voltage drop increases and the receiving end voltage decreases. In-order to improve the voltage profile, reactive power has to be supplied which could be accomplished by the SVC. It has to be controlled in such a way that it supplies net capacitive current providing reactive power and improving the voltage profile. This can be done by firing the thyristors so that they have a maximum value of the Capacitance. Thus the voltage profile is improved to V_4 drawing the current I_4.

Decrease in load: Due to decrease in the load, current drawn decreases and the drop decreases which results in an increase in the receiving end voltage. In-order to maintain voltage at its previous point reactive power has to absorbed, which could be accomplished by using SVC[10]. It has to be operated in such a way that it supplies net lagging current, absorbing the reactive power and decreasing the voltage profile. This can be done by firing the thyristors; so that they include large value of inductance (Assuming Inductance rating is higher than capacitance). Thus the voltage profile is brought back to V_3 by drawing current I_3.

b) Unified Power Flow Controller(UPFC):

The UPFC is a generalized synchronous voltage source (SVS), represented at the fundamental or power system frequency by voltage phasor Vpq with controllable magnitude V_{pq} ($0 \leq V_{pq} \leq V_{pqmax}$) and angle ρ ($0 \leq p \leq 2\pi$), in series with the transmission line. The SVS generally exchanges both reactive and real power with the transmission system. Since, an SVS is able to generate only the reactive power exchanged, the real power must be supplied to it, or absorbed from it, by a suitable power supply or sink [12].

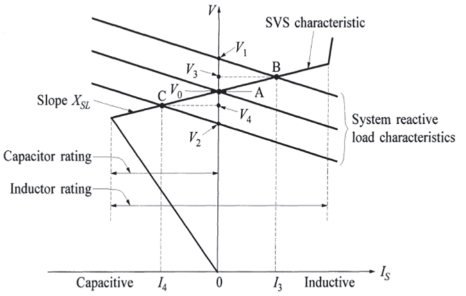
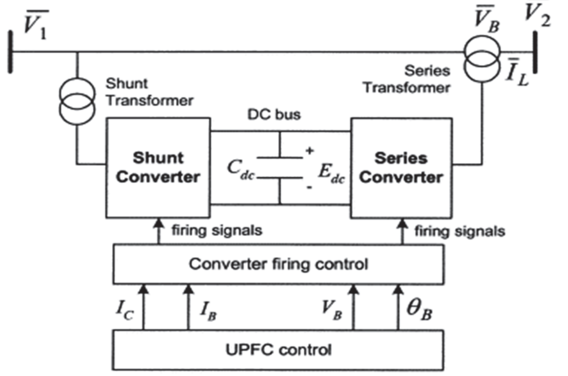


Fig.2 V-I characteristics of SVC

The UPFC consists of two voltage-sourced converters connected in back to back fashion namely A & B. These are operated from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal ac-to-ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters, and each converter can independently generate or absorb reactive power at its own ac output terminal. B provides the main function of the UPFC by injecting a voltage $V_{pq}$with controllable magnitude $V_{pq}$and phase angle p in series with the line via an insertion transformer ,this voltage acts as a synchronous AC voltage source. The reactive power is generated internally by the converter. DC link holds the positive and reactive power demand [11].



Series voltage injection takes place when both the converters work in coordination. A absorbs or generate real power to DC link as per demands of B. This power is converted again into AC power and fed back to the transmission line using shunt transformer [3] [4].Note that there is a closed direct path for the real power negotiated by the action of series voltage injection through A and B back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by B and therefore does not have to be transmitted by the line [2].

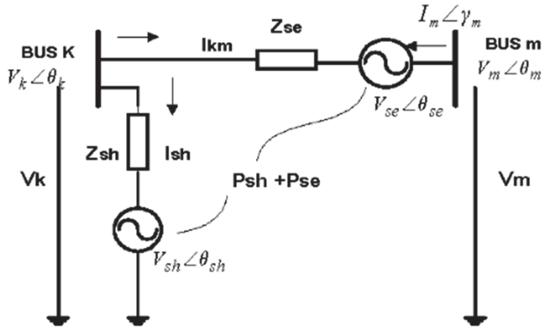


Fig.3 Equivalent circuit of UPFC

Thus, A can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by B

$$E_{vr} = V_{vr} * (\cos \delta_{vr} + j \sin \delta_{vr}) \quad \text{.... (iv)}$$

$$E_{cr} = V_{cr} * (\cos \delta_{cr} + j \sin \delta_{cr}) \quad \text{..... (v)}$$

V_{vr} describes the magnitude of the voltage for shunt element

δ_{vr} describes the value of angle for shunt element

V_{cr} describes the magnitude of the voltage for series element

δ_{cr} describes the value of angle for series element

$$P_{cr} = V_{cr}^2 G_{mm} + V_{cr} V_k (G_{km} \cos(\delta_{cr} - \theta_k) + B_{km} \sin(\delta_{cr} - \theta_k)) + V_{cr} V_m (G_{mm} \cos(\delta_{cr} - \theta_m) + B_{mm} \sin(\delta_{cr} - \theta_m))$$

...... (vi)

$$Q_{cr} = -V_{cr}^2 B_{mm} + V_{cr} V_k (G_{km} \sin(\delta_{cr} - \theta_k) + B_{km} \cos(\delta_{cr} - \theta_k)) + V_{cr} V_m (G_{mm} \sin(\delta_{cr} - \theta_m) + B_{mm} \cos(\delta_{cr} - \theta_m))$$

...... (vii)

$$P_{vr} = -V_{vr}^2 G_{vr} + V_{vr} V_k (G_{vr} \cos(\delta_{vr} - \theta_k) + B_{vr} \sin(\delta_{vr} - \theta_k))$$

$$Q_{vr} = -V_{vr}^2 B_{vr} + V_{vr} V_k (G_{vr} \sin(\delta_{vr} - \theta_k) + B_{vr} \cos(\delta_{vr} - \theta_k))$$

...... (viii)

V_k , V_m: the magnitudes of voltages at buses at k and m

θ_k, θ_m: angles at bus k and m

P_{cr}, Q_{cr}: the active and reactive power of series element

P_{vr}, Q_{vr}: the active and reactive power of shunt element

G_{mm}, G_{kk}, G_{mk}, G_{km}: conductance element

B_{mm}, B_{kk}, B_{mk}, B_{km}: susceptance element

Result and observations:

Load flow was carried out first without using any FACT device to find out the weakest bus. The weakest bus can be defined as the bus which has the maximum deviation from the prescribed voltage magnitude ranges. As per the Newton Raphson Load flow Analysis, 1 per unit is assumed as voltage magnitude at an angle of 0 for PV and PQ buses. SVC and UPFC are installed at or near the weakest bus and the new voltage profiles which are obtained with respect to the voltage profile without the inclusion of FACTS devices and also its effect on the transmission line losses in the system have been observed.

The following are the graphs relating to our analysis which have been performed under various test systems like 5 bus, IEEE 9 bus, IEEE 14 bus and IEEE 30 bus.

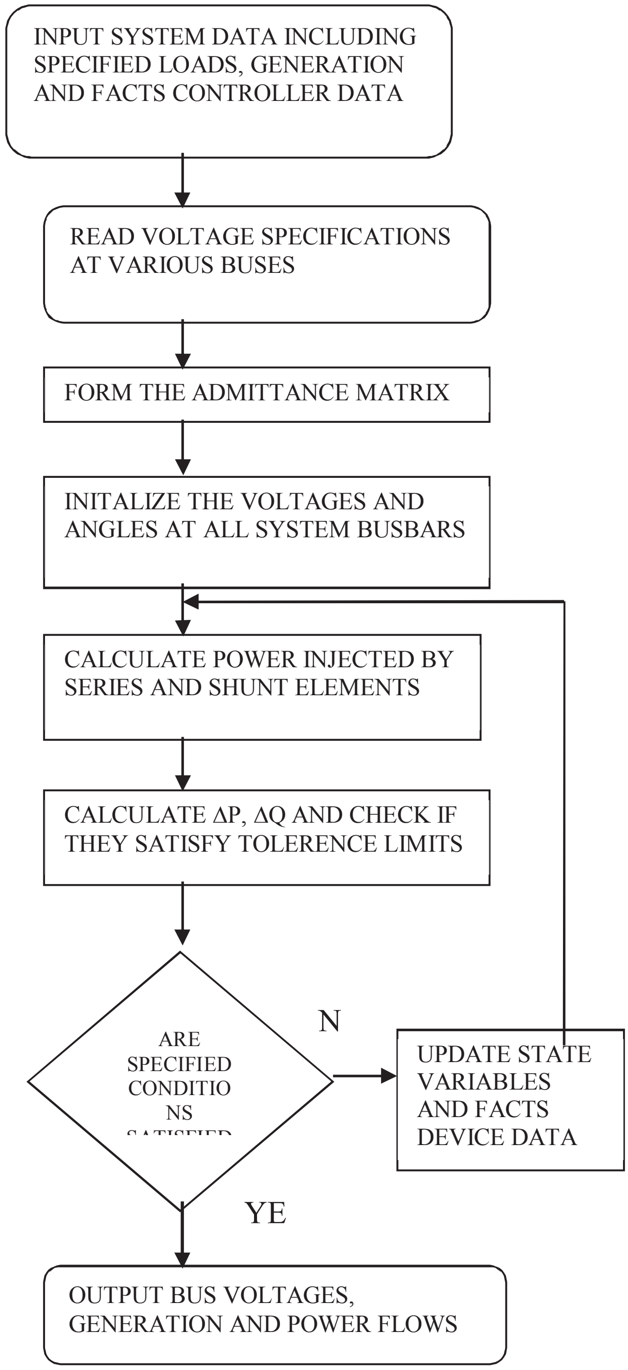


Fig.4 Newton-Raphson load flow algorithm

i. Voltage Magnitude: From our analysis, we can conclude that after the installation of the FACTS device at the weakest bus there is a drastic improvement in the voltage profile. Our desire is that the voltage profiles should be improved to 1 p.u. which is the ideal voltage. The improvement in the voltage profiles is done by supplying the required reactive power by installing these devices. Through the graph, we can observe that UPFC is better than SVC in improving the voltage profiles as they are closer to the desired value. The above graph shows the voltage profiles for the IEEE 9 bus system, similarly the analysis has been carried out for IEEE standard 14 bus and 30 bus. Their graphs are shown below.Data regarding the FACTS devices SVC and UPFC are given below:

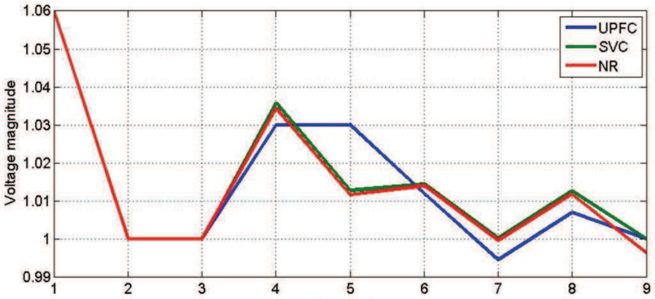
SVC: The values of the capacitive reactance (X_c) and Inductive Reactance (X_l) are taken as 1.07and 0.288

UPFC: Initial conditions for the series source voltage (V_{cr}) is 0.04 and its range is $0.001<V_{cr}<0.2$, series source voltage angle (V_{vr}) -1.523 and its range is $0.9<V_{vr}<1.1$, shunt source voltage magnitude 1.0, shunt source voltage angle 0.0

Case (1): 9 BUS

SVC- is installed at the 9th bus to improve the voltage profile. It supplies 4.01MVAR of Reactive power to improve the voltage magnitude to 1p.u.

UPFC- is installed in the transmission line between the buses 8 and 9 (assuming the device to be located very close to 9th bus) to improve the voltage profile of the 9th bus. At either ends of its connection, UPFC supplies 25.9MVAR and 5.3MVAR.



Bus number

Fig.5 Voltage profile of IEEE 9 bus system

Case (2): 14 BUS

SVC- is connected at the 14th bus to improve the voltage profile. It supplies 24.33VAR of Reactive power to improve the voltage magnitude to 1 p.u.

UPFC- It is connected in the transmission line between 13th and 14th buses (assuming the device to be located very close to 14th bus) to improve the voltage magnitude of the 14th bus. At either ends of its connection, UPFC supplies Reactive power of 262MVAR and 100MVAR.

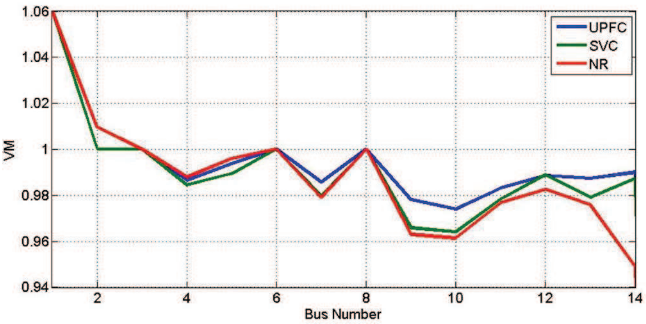
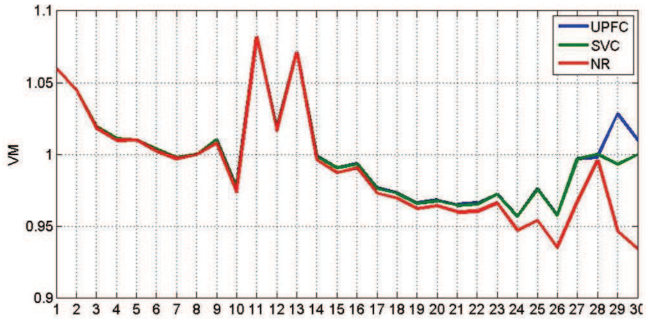


Fig.6 Voltage profile of IEEE 14 bus system

Case (3): 30 BUS

SVC- is installed at the 30th bus to improve voltage profile. It supplies 9.85 MVAR of Reactive power to improve the voltage magnitude to 1p.u.

UPFC- is installed in the transmission line between the buses 27 and 30(assuming the device to be located very close to 30th bus) to improve the voltage profile of the 30th bus. At either ends of its connection, UPFC supplies 36.1 MVAR and 244 MVAR.

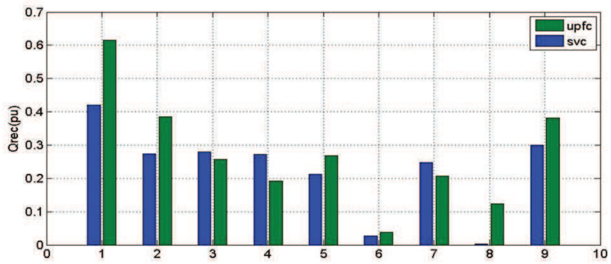


Bus number

Fig.7 Voltage profile of IEEE 30 bus system

ii. Reactive Power Capability:

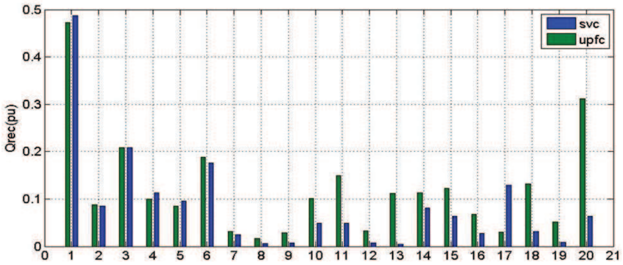
Due to the PQ loss in the transmission lines the receiving end power is lower than sending end power. When a FACTS device is installed, the receiving end power is improved due to the supply of the reactive power by the FACTS device. This is evident from the following results.



Transmission Lines

Fig.8 Receiving end reactive power of IEEE 9 bus system

Above graphs indicates the receiving end reactive power in each transmission line when SVC is installed at bus 9 and UPFC installed between 8th and 9th bus. The main problem always lies in finding the weakest bus. Once it has been found out by keen observation, experience or trial and error method the installation of FACT is done.

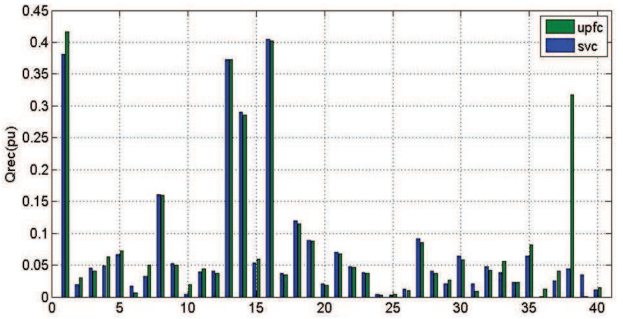


Transmission Lines

Fig.9 Receiving end reactive power of IEEE 14 bus system

A similar kind of method is adopted here and the device is installed at the desired location. This improves the reactive power transfer capability in the system. In the 14 bus system the device is installed between 13th and 14th bus and the respective graphs are plotted. It is significant from the plots that the reactive power has improved by a great margin.

In 30 bus system the device is installed between 29th and 30th bus and corresponding reactive power loss is determined at all the transmission lines and impressive change is observed. It can be seen that the receiving end reactive power in the case of UPFC installation is more compared to the SVC installation. From this it can be concluded that the Reactive power capability of UPFC is more than SVC.



Transmission Lines

Fig.10 Receiving end reactive power of IEEE 30 bus system

Conclusion

Power Quality is improved with the installation of SVC /UPFC and it is higher in the case of UPFC. Voltage collapse could be prevented with the installation of SVC/UPFC because these FACTS devices have the capability to supply reactive power such that voltage stability is maintained.

From the above results and discussions regarding the parameters of the system, we can conclude that the

Reactive Power Capability of UPFC is higher than the SVC which is evident from the higher values of the Q_{rec} (Receiving end Reactive power) for UPFC over SVC which implies that the transmission power loss could be reduced with the installation of SVC /UPFC at the weakest bus.

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