International Journal of Current Engineering and Technology ISSN 2277 – 4106

Available at http://inpressco.com/category/ijcet

Research Article

Flexible A C Transmission and a study of Static Voltage Compensator

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Abstract

Development of electrical power transmission systems follows closely the increasing demand on electrical energy. With the increasing size and complexity of the transmission networks, the performance of the power systems decreases due to problems related to with load flow, power oscillations and voltage quality. Flexible ac transmission systems (FACTS) and High-voltage direct current (HVDC) technologies offer some effective schemes to meet these demands. In recent years, FACTS technology has been considered as one feasible planning alternative in India to increase power grid delivery capability and remove identified network bottlenecks. An attempt is made in this paper to discuss the development of FACTS, types of FACTS and simulation of VSC, using SIMULINK is carried out for comparing voltage regulation issues, total harmonic distortion (THD) with varying transmission line distances.

Keywords: *FACTS, Static Voltage Compensator*

1. Introduction

The present power systems have a high rate of complexity and there is expansion in power transmission networks due to the increase in generation and loads and also due to extensive interconnections due among various power utilities. The present AC poses following challenges.

1) Power flow in parallel paths is determined according to their reactances.
2) Power flow in AC lines is limited by stability considerations.
3) Lack of control in AC lines implies that that normal power flow in a line is kept much below the peak value which itself is limited by stability. Reserve is required to maintain system security under contingency conditions.
4) The AC transmission network required dynamic reactive power control to maintain satisfactory profile under varying load conditions and transient disturbances.
5) The increase in load levels may result in higher reactive power consumption in the line reactance. Mismatch of reactive power balance in the system can result in voltage instability and collapse.

Flexible AC Transmission Systems (FACTS) is a concept that involves the application of high power electronic controllers in AC transmission networks which enable fast and reliable control of power flows and voltages (Hingorani et al, 1999). FACTS technology is collection of high power electronic controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters.(K. R. Padiyar et al, 1997). The thyristor or high-power transistor is the basic element for a variety of high-power electronic Controllers. FACTS deal with:

1) Regulation of power flow in prescribed transmission routes
2) Secure loading of lines near the thermal limits
3) Prevention of cascading outages by contributing to emergency control
4) Damping oscillations which can threaten the security or limit the usable line capacity.

Transient stability and power flow models of thyristor controlled reactor (TCR) and voltage sourced inverter (VSI) based FACTS. Models of the static VAr compensator (SVC), the thyristor controlled series compensator (TCSC), the static VAr compensator (STATCOM), the static synchronous source series compensator, and the unified power flow controller appropriate for voltage and angle stability studies are discussed in detail (Canizares C .A 2000).

Reactive power compensation in a power distribution network plays a vital role in improving power quality, correcting power factor and maintaining constant distribution voltage. Among the various compensation devices available voltage source converter (VSC) based controllers offer very fast response to reactive power demand and thus can be effectively used for power factor correction and voltage regulation. One such VSC based controller called the distribution static compensator (DSTATCOM) proves to

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be a viable alternative to the conventional SVC. (Masand D et al, 2006)

Static var compensator is an important component of flexible AC transmission system, which provides an effective approach to enhance voltage stability and to increase the power transfer capability. This paper discusses the effect of SVC controller on voltage stability Based on Generalized Tellegen's Theorem. The method determines the maximum power transfer limit by finding the critical value of equivalent impedance model by the reactive compensation.(Baochun Lu et al,2008)

The principle of SVC is analyzed in detail, and a kind of SVC system which consists of Thyristor Controlled Reactors (TCR) and Fixed Capacitor (FC) is designed. Bridge rectifier and L-R circuit is used to simulate the symmetrical three-phase load. Based on instantaneous reactive power theory, the SVC system signals are detected rapidly and precisely. In order to maintain the stability of the client node voltage and satisfy the requirements of system power factor, the voltage and admittance double loop control strategy is adopted, and the well-behaved steady-state effects is obtained. The break of node voltage caused by load disturbance or any other factors is restrained, and system power factor is well improved too. Finally, the SVC model is established under the environment of MATLAB simulation. (Zheng Shicheng et al, 2010).

The SVC has fast dynamic characteristics that can support effective system voltage following disturbances. Keeping reactive power reserve in an SVC during steady-state operation is always needed to provide reactive power requirements during system dynamics.(Abdul-Rahman M H et al, 2006)

It will be necessary to provide high speed continuous control in distribution lines in the future. So, we propose a series SVC, which is highly suitable for use in power distribution lines compared with parallel static VAr compensators. It controls voltage regulation to keep the allowed value at load center point. (Fuzuaku,N et al,2000)

A high performance advanced static VAR compensator (ASVC) based on the theory of the instantaneous reactive power which uses a voltage source inverter is presented and analyzed in this paper. The ASVC correct the power factor on the supply side by generating the same amount of reactive power supplied by the load in order to improve the stability and the performances of the electrical network. (Tahri,F et al,2007).

2. Types of Facts Controllers

A) Series Controllers**:** Variable impedance such as capacitor, reactor etc., or power electronics based variable source of main frequency, sub-synchronous frequency and harmonic frequency or any combination of these can be used as a series controller. The basic principle of series controller is to inject voltage in series with the line. If the injected voltage is in phase with line current, real power is not consumed or supplied. Types of series connected controllers are;

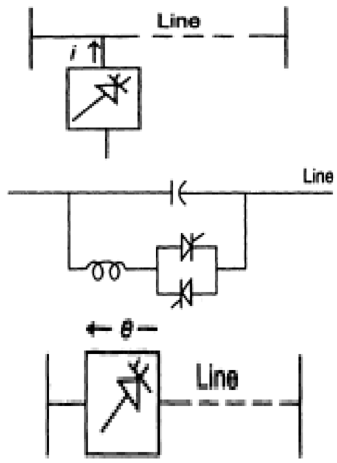


Fig 1. TCSC Circuit Symbol

1) Static Synchronous Series Compensator (SSSC): A static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behaviour of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line.
2) Thyristor Controlled Series Capacitor (TCSC**):** A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance.

B) Shunt controllers**:** Any series controller element can be used as a shunt controller by connecting it in parallel with the line. The basic principle of shunt controller is to inject current into the line at the point of connection. If the injected current is in phase with line current, real power is not consumed or supplied. Following are the types of Shunt connected controllers.

a) Static Synchronous Compensator (STATCOM): A static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.
b) Thyristor Switched Capacitor (TSC): A shunt-connected, thyristor-switched capacitor whose effective reactance is varied in a stepwise manner by full or zero conduction operation of the thyristor valve.
c) Thyristor Controlled Reactor (TCR): A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.
d) Static Var Compensator (SVC): A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current

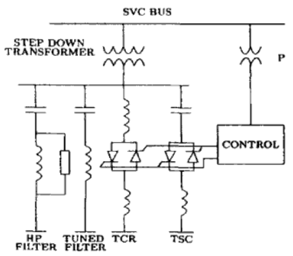
so as to maintain or control specific parameters of the electrical power system.

Table 1.FACTs Controllers

Name	Type	Main function	Controller used	Comments
SVC(Static var compensator)	shunt	Voltage control	Thyristor	Variable impedance device
TCSC(Thyristor Controlled Series Compensation)	series	Power flow control	Thyristor	Variable impedance device
TCPAR(Thyristor Controlled phase angle regulator)	Series and shunt	Power flow control	Thyristor	Phase control using series (quadrature) voltage injection
STATCON(Static Condenser)	shunt	Voltage control	GTO	Variable voltage source
SSSC(static synchronous series compensator)	series	Power flow	GTO	Variable voltage
UPFC(unified power flow controller)	Shunt and series	Voltage and power flow	GTO	Variable voltage source

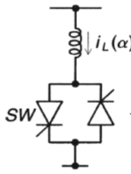
Static Var compensator (SVC)

Static Var compensator (SVC) can be considered as s "first generation" FACTS controller and uses thyristor controllers. It is a shunt reactive compensation controller consisting of a combination of fixed capacitor or thyristor-switched capacitor in conjunction with thyristor-controlled reactor (FC-TCR or TSC-TCR as in Fig 1). The SVC is a variable susceptance controller; the effective susceptance is varied by changing the conduction time of the thyristors of the TCR and/or switching in/out the shunt capacitor using a TSC. Early applications of the SVC were for load compensation of fast-changing loads like arc furnaces and steel mills for dynamic power factor improvement and load balancing in the three phases. Transmission line compensators are used not only for reactive power compensation but also for improving system stability. The control strategy usually employed is to use the SVC as a voltage regulator. In addition supplementary controls are used for damping power oscillations.



a)Thyristor-Controlled Reactor (TCR)

An elementary single-phase thyristor-controlled reactor (TCR) (Fig..2) consists of a fixed reactor of inductance *L*, and a bidirectional thyristor valve (or switch) *sw*. Currently available large thyristors can block voltage up to 4000 to 9000 volts and conduct current up to 3000 to 6000 amperes. Thus, in a practical valve many thyristors



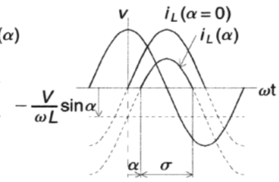


Fig.2 TCR-TSC type SVC Fig. 3 TCR & firing delay angle control waveform

(typically 10 to 20) are connected in series to meet the required blocking voltage levels at a given power rating. A thyristor valve can be brought into conduction by simultaneous application of a gate pulse to all thyristors of the same polarity. The valve will automatically block immediately after the ac current crosses zero, unless the gate signal is reapplied. The current in the reactor can be controlled from maximum (thyristor valve closed) to zero (thyristor valve open) by the method of firing delay angle control. That is, the closure of the thyristor valve is delayed with respect to the peak of the applied voltage in each half-cycle, and thus the duration of the current conduction intervals is controlled. Where the applied voltage *v* and the reactor current *iL(α)*, at zero delay angle (switch fully closed) and at an arbitrary *a* delay angle, are shown. When α = 0, the valve *sw* closes at the crest of the applied voltage and evidently the resulting current in the reactor will be the same as that obtained in steady state with a permanently closed switch. When the gating of the valve is delayed by an angle α with respect to the crest of the voltage, the current in the reactor can be expressed with *v(t)* = *V* cos *wt* as follows:

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)\,dt = \frac{V}{\omega L}(\sin \omega t - \sin \alpha)$$

$$(0 \le \alpha \le \pi/2)$$

$$\alpha \le \omega t \le \pi - \alpha.$$

Since the thyristor valve, by definition, opens as the current reaches zero, is valid for the interval For subsequent positive half-cycle intervals the same expression obviously remains valid. For subsequent negative half-cycle intervals, the sign of the terms in above equation becomes opposite.

b)Thyristor-Switched Capacitor (TSC)

A single-phase thyristor-switched capacitor (TSC) (Fig. 4) consists of a capacitor, a bidirectional thyristor valve, and a relatively small surge current limiting reactor. This reactor is needed primarily to limit the surge current in the thyristor valve under abnormal operating conditions (e.g., control malfunction causing capacitor switching at a "wrong time," when transient free switching conditions are not satisfied); it may also be used to avoid resonances with the ac system impedance at particular frequencies. Under steady-state conditions, when the thyristor valve is closed and the TSC branch is connected to a sinusoidal ac voltage source, $v = V \sin \omega t$, the current in the branch is given by

$$i(\omega t) = V\frac{n^2}{n^2-1}\omega C\cos\omega t \qquad \text{where} \qquad n = \frac{1}{\sqrt{\omega^2 LC}} = \sqrt{\frac{X_C}{X_L}}$$

The amplitude of the voltage across the capacitor is $V_C = \frac{n^2}{n^2-1}V$

The TSC branch can be disconnected ("switched out") at any current zero by prior removal of the gate drive to the thyristor valve. At the current zero crossing, the capacitor voltage is at its peak value, $V_{C,i=0} = Vn^2/(n^2 - 1)$. The disconnected capacitor stays charged to this voltage and, consequently, the voltage across the non-conducting thyristor valve varies between zero and the peak-to-peak value of the applied ac voltage.(Fig. 5)

If the voltage across the disconnected capacitor remained unchanged, the TSC bank could be switched in again, without any transient, at the appropriate peak of the applied ac voltage,(as in Fig.4). Normally, the capacitor bank is discharged after disconnection. Thus, the reconnection of the capacitor may have to be executed at some residual capacitor voltage between zero and $Vn^2/(n^2 - 1)$. This can be accomplished with the minimum possible transient disturbance if the thyristor valve is turned on at those instants at which the capacitor residual voltage and the applied ac voltage are equal, that is, when the voltage across the thyristor valve is zero.

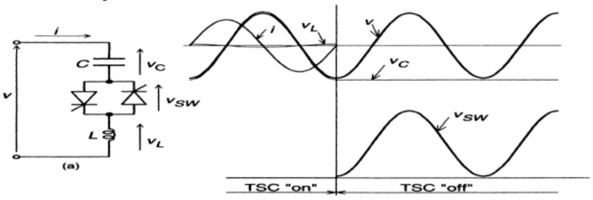
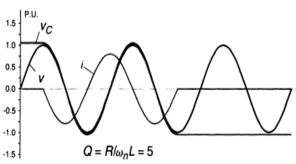


Fig. 4 Thyristor switched-reactor & associated waveforms



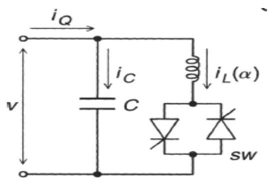
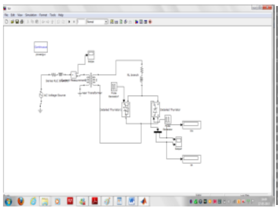


Fig. 5. Transient Free Switching By TSC

Fig. 6 FC-TCR

Fixed Capacitor, Thyristor-Controlled Reactor Type Var Generator. A basic var generator arrangement using a fixed (permanently connected) capacitor with a thyristor-controlled reactor (FC-TCR) (Fig. 6). The current in the reactor is varied by the previously discussed method of firing delay angle control. The fixed capacitor in practice is usually substituted, fully or partially, by a filter network that has the necessary capacitive impedance at the fundamental frequency to generate the reactive power required, but it provides a low impedance at selected frequencies to shunt the dominant harmonics produced by the TCR.

Simulation model: The SVC SIMULINK models are simulated and the results are as shown.



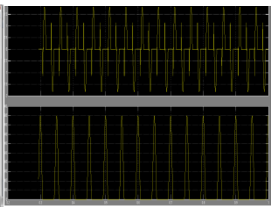
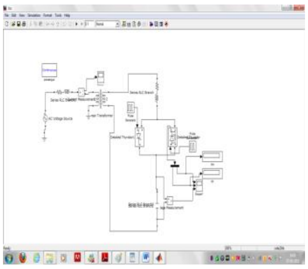


Fig.7 Model 1

Fig.8 TCR branch voltage and currents



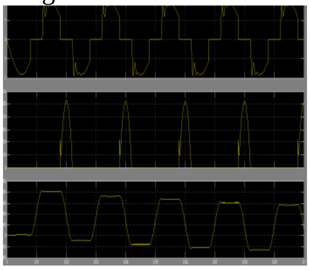


Fig.9 Model 2

Fig 10TSC branch voltage current and voltage across capacitor

Distance of Transmission line(Km)	Regulation without SVC (%)	Regulation with SVC (%)	Reactive Power without SVC(MVAR)	Reactive Power with SVC(MVAR)	%THD
500	7.3	5.3	42.5	50.47	0.43
600	8.53	6.35	41.8	49.74	0.62
700	9.63	7.61	41.3	48.97	0.92
800	10.67	8.57	40.7	48.17	1.24
900	11.64	9.26	40.33	47.34	1.51
1000	12.55	9.86	39.93	46.47	1.79
1100	13.39	10.6	39.58	45.58	2.15
1200	14.17	11.41	39.3	44.65	2.65

Conclusion

Static var compensators results in higher reactive power compensation in the transmission line reactance. Higher reactive power compensation in turn improves power quality, correcting power factor and maintaining constant distribution voltage. Thus the A C transmission network required dynamic reactive power control to maintain satisfactory profile under varying load conditions and transients**.**

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