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A Review on Reactive Power Control strategies in Compensated Transmission Line

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ABSTRACT: In the last two decades demand of power is increasing rapidly but we have limited resources of power Generation resulting transmission line getting heavily loaded and facing stability, voltage sag, reactive power issues. It is necessary to implement the FACTS devices which are better solution for power transmission problem. Static Var Compensator (SVC) is a shunt-type FACTS device, which is used in power systems primarily for the purpose of voltage and reactive power control.In this paper, overview of SVC and their controlled techniques are discussed for damping the rotor angle oscillations and to improve the stability of the power system.It is suggested that instead of using complex methods in the measuring system and voltage regulator of the SVC controller some simple but accurate methods can be employed. In this paper the Co-ordinate Transformation method is suggestedfor the measurement system and Integral droop method for the voltage regulator of the SVC controller.

KEYWORDS: reactive power compensation, STATCOM, SVC, fact controllers

I.INTRODUCTION

Large power systems have many interconnections and bulk power transmissions over long distances. Due to this, the existing transmission lines are overloaded and have become vulnerable to various faults. Theflexible ac transmissionsystem (FACTS)devices, based on power electronics, offer an opportunity to enhance controllability,stability, andpowertransfer capability of ac transmissionsystems. A static var compensator (SVC), a shunt FACTS device, has been widely used in power systems for voltage regulation and to increase transient stability in order to increase power transfer. Thus, this allows the transmission line to be compatible with the prevailing load demand [1]. A suitable supplementary external control signal to the SVC voltage control loop can provide damping and improve overall power system stability [2], [3].power system containing generators and FACTS devices is a highly nonlinear system. Some conventional methodshave been used to design supplementary damping controllers, including the classical pole placement method [4], damping torque analysis [5], linear quadratic Gaussian (LQG) [6], adaptive control [7], etc. In [8] and [9], particle swarm optimization (PSO) is applied to tune the parameters of the SVC external damping controller but based on some linearized mathematical models of power systems. In [10], a neural-network-based controller has been designed for SVC but is based on locally measured signals.Most of the methods used for designing SVC external damping controllers are based on linear control techniques where the system equations are linearized around a nominal operating point. As the operating conditions change, its performance degrades. Nonlinear controllers using neural networks such as the multilayer perceptron, radial basis function, and Elman network can provide suitable and desired control over a wide range of operating conditions. However, they require long development time and a large number of neurons to deal with complex problems. Their hardware implementations require high-speed processors and a lot of memory.The use of wide-area measurements provides better understanding of the dynamic behaviour of the entire power system. External controllers can be designed using wide-area signals based models to provide additional damping to power system oscillations.**c**onsistent efforts to make power system more efficient and reliable have seen increased use of FACTS devices intransmission systems. Most of the FACTS devices are installedon existing transmission lines to enhance their capacity and performance[1]–[8]. Distance protection relays have been widelyapplied for protecting transmission lines. This is due to theirsimple operating principle and capability to work independentlyunder most circumstances and still provide very good protectionfor the transmission line [9]. Thus there is a very high probabilitythat the transmission line where the FACTS device is beinginstalled is protected by a distance relay.

Improving power quality is the peak necessity of the age for areliable and efficient utilization of power and energyresources. FACTS devices are playing an important role inimproving the power quality in high voltage AC transmissionlines. SVC is an important FACTS device used to controlreactive power and also to regulate the voltage level. So it hasa vital role in transmission and distribution system. Therearevarious methods of connecting SVC to the bus bars. GenerallySVC is connected in high voltage transmission systemthrougha stepdown transformer but also there are some techniquesfordirect connection of SVC [5]. There are various types ofSVC depending upon the components controlling the reactivepower I.e. Fixed Capacitor-Thyristor Controlled Reactor (FCTCR)and Thyristor Switched Capacitor-Thyristor ControlledReactor (TSC-TCR) [4].The amount of reactive power to be injected or extracted from the system is decided and controlled by the SVC controller. The basic operation of the SVC controller is to measure the bus voltages, compare it with a reference voltage and then decide to inject or extract the reactive power in the system to maintain the bus voltage at a specific level. This decision is made by the voltage regulator of the SVC controller. Voltage regulator sends its output in form of susceptance (proportional to the required amount of reactive power compensation)to the gate pulse generator which in turn generates the specific pulses to activate the TCR or TSC.

Static Var Compensators (SVC) are widely used in shunt compensation of transmission lines. With the acceptability ofGate Turn Offthyristors (GTO) among the utilities, Static SynchronousCompensators (STATCOM)are also becomingpopular[2]. The location of the shunt FACTS device depends on the application for which it is installed. Shunt compensation FACTSdevices are installed at theendpoints of transmission lines (buses)when used for applications, such as, improving system stability,improvingHVDClink performance etc.However, for controllingthe power flow or increasing the power transfer capability ofvery long transmission lines (tie lines connecting two majorgrids) mid-point of the lines is the best location for shunt

II. SVC CONTROLLER

There are three major components of an SVCcontroller [6].
a. Measurement system
b. Voltage regulator
c. Gate pulse generator
All these components are discussed in the following discussion particularly the simple techniques are suggested to design the measurement system and voltage regulator are explained with details.To describe the whole system a block diagram is shown below.

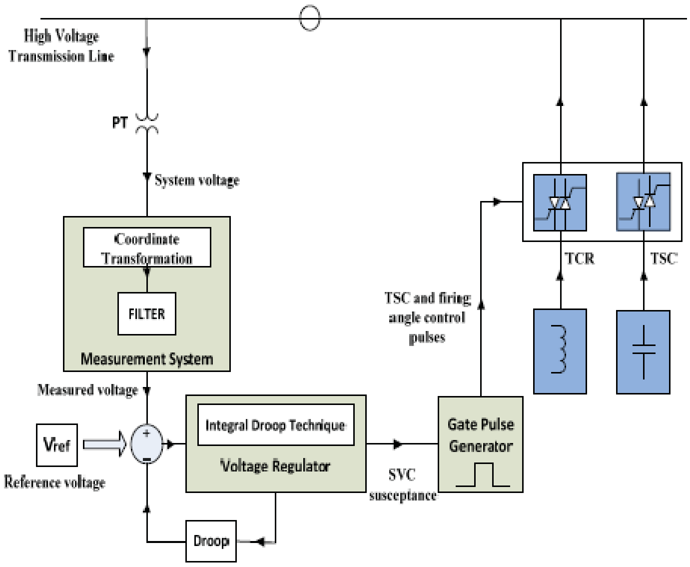

Fig. 1.Block diagram of overall system Showing the operation and techniques used in each component of SVC controller.

Fig. 1depicts the arrangement of the SVC controller system. Also it is explaining the order and technique of each component of the controller. The voltages of the system in which the SVC is connected are stepped down and then rectified via the proposed measurement technique. But this results in a pulsating DC signal which is improper to be fed to the comparator junction of the voltage regulator. So before feeding it to the voltage regulator there is a need of filtration. For that purpose a simple filter is also included in the measurement system. After the filtration a smooth DC signal is obtained and is fed to the voltage regulator through comparator. Comparator junction calculates the amount of positive or negative error then the transfer function of the voltage regulator converts this error signal to positive or negative susceptance using the integral droop method. Coordinate transformation and integral droop methods are explained in the upcoming paragraphs.

The basic purpose of the measurement system is to measure the voltages of three phase transmission system and convert it to an equivalent DC voltage signal. This DC voltage signal is then compared with a reference voltage signal and thus the error in the voltage level is calculated. For Voltage measurement we have different techniques for example AC to DC rectification, coordinate transformation, Fourier analysis technique and dq0 transformation. No matters which technique is used the purpose of measurement system is to obtain a dc signal proportional to the root mean square value of the three phase balanced voltages at fundamental frequency. Coordinate transformation is the most simple but accurate method for such type of measurement. This is just
simple algebraic calculation so very simple circuitry is required for that.This method is based on three phases to two phase scalar transformation and then from these two phases the measured voltage is obtained as shown in the following equations. Let the voltages of three phases of the system in which SVC is connected are Va, Vb and Vc respectively then

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$V_{meas} = \sqrt{V_\alpha{}^2 + V_\beta{}^2}$$

$V_{means}$is the output of the voltage measurement system which is to be fed to the voltage regulator block of the SVC controller. From this method we get a pulsating DC signal and a simple filter is required to purify it and make it able to be fed to the comparator of the voltage regulator block [2]. Output obtained by the measurement system is processed by the voltage regulator to give an output signal which isproportional to the required amount of reactive powercompensation. Different variables and parameters areused involtage regulator depending upon the mode inwhich SVC is working. The principle of basic voltageregulator is that it compares the measured voltage andthe reference voltage and then error signal is transmittedtotransfer function of the voltage regulator. The output ofvoltage regulator is per unit susceptance and it isgenerated toreduce the error signal to zero in the steadystate.A currentdroop of three to five per cent is usuallyincorporates tothe steady state characteristics of the SVC controller. Thisdroop facilitates us with some good advantages like thereduction of reactive power rating for almost the same controlobjectives, prevention of SVC from reaching its reactivepower limits too frequently and also it facilitates the sharingof reactive power when multiple compensators are operatedin parallel. The final basic voltage regulator model is shown below.

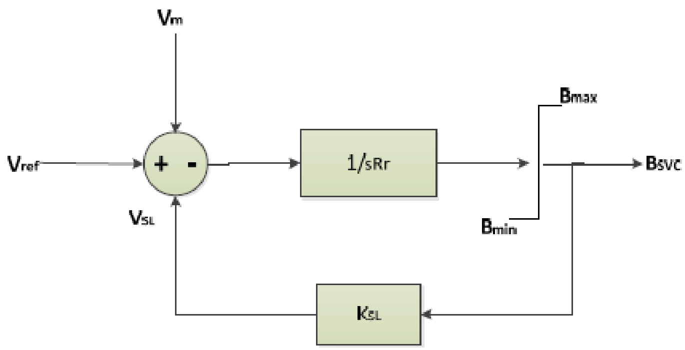

Fig. 2.Showing the Voltage regulator block of the SVC controller in which integral droop method is used.

In Fig.2 B_{min} and $B_{max}$are showing the limits of SVC susceptance V_{SL} is the susceptance droop signal obtained by multiplying the susceptanceB_{svc} and current droop K_{SL},$V_m$is the measured voltage signal obtained from the measurement system known as response rate which shows the timetaken by the SVC to move across its entire reactive power range I.e. from fully capacitive to the fully inductive state in response of a large 1 pu error. The value ofRr ranges from 2 to 20 ms/pu[2]. The output of voltage regulator in form of susceptance is transmitted to the gate pulse generator. The GPG thenproduces the appropriate firing pulses to regulate all thethyristor switched and thyristor controlled devices tomake available the required susceptance at SVC bus andthus get the required control objective. Hence GPGdetermines the number of TSC to be activated and alsocalculates the firing angle for the TCR.

III. FACTS DEVICES

Now a day as power demand increases the power system is getting more complex to fulfill the requirements within the acceptable quality and costs [4]. Generating stations are located away from the load centres because of economic and environmental issues. As the demand of power increases uncertainty occur in the system operation resulting reduction in stability and risk of blackouts. This problem can be tackle by introducing high power electronics controller in ac transmission networks. So "flexible" operation in ac transmission network comes in to role where changes can be done easily without affecting the systems. FACTS (Flexible Alternating Current Transmission System) are a family of power electronics device which improves stability, power transfer capability and controllability of ac system [5]. FACTS devices are combination of components power system (like transformers, reactors, switches, and capacitors) with power electronics components (like various types of transistors and thyristors).we are capable to deal high power application (ten, hundreds and thousands of MW) with the help of high current rating of thyristors FACTS controller also improve the transient and dynamic performance of the power system. Electronic based switches use in FACTS device have less switching time than the conventional mechanical switches. FACTS devices using electronic based switches are more flexible and fast reacting causes many advantages like enhancement of transmission capacity, control of power flow, improvement of transient stability, voltage stability and control. With using of appropriate type and rating of FACT devices transmission capacity enhance up to 40 – 50 %.

IV. FACTS CONTROLLERS USED IN REACTIVE POWER COMPENSATION TECQNICH

FACTS Controllers can be divided into four categories:[16]

- Series Controllers
- Shunt Controllers
- Combined series-series Controllers
- Combined series-shunt Controllers

A) SERIES CONTROLLERS:

It may be capacitor or reactor or power electronic based variable source. These controllers inject voltages in series with the line. When voltage and current are in 90 degree phase shift controller only supply or consume variable reactive power. For any other phase real power also considered. [15]

- Static Synchronous Series Compensator (SSSC)
- Interline Power Flow Controller (IPFC)
- Thyristor Controlled Series Capacitor (TCSC)
- Thyristor Switched Series Capacitor (TSSC)
- Thyristor Controlled Series Reactor (TCSR)
- Thyristor Switched Series Reactor (TSSR)

Among these fact devices TCSC is most commonly use for reactive power compensation which is explains below.

Thyristor controlled series compensator (TCSC)

Kinney et al. proposed the concept of TCSC in 1994 in [10]. TCSC is combination of TCR in parallel with FC (fixed capacitor). SVC and TCR are shunt connected controller where as TCSC is series connected controller. That is why TCSC is always shown in single phase form rather than three phase form. it has one or more sub module. TCSC is used when increase damping is require for large interconnecting system because it provide variable capacitive reactance. To avoid sub synchronous resonance it changes apparent impedance for sub synchronous frequency. TCSC act as a fast active power flow regulator as it changes the electrical length of transmission line with approx no delay. The circuit diagram is shown in Fig.3

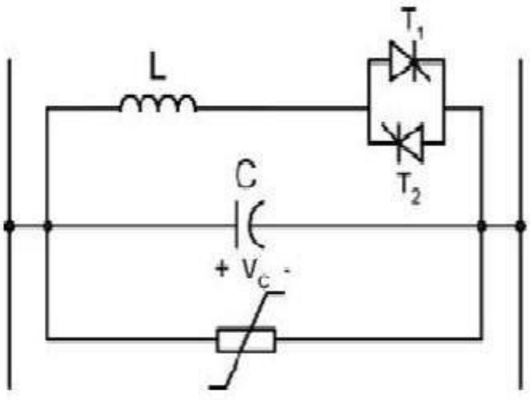

Fig.3 TCSC circuit diagram

B) SHUNT CONTROLLERS:

Like series controller shunt controller also may be capacitor or reactor or power electronic based variable source or a combination of these. Shunt controller inject current in the system. When voltage and current are in 90 degree phase shift controller only supply or consume variable reactive power. for any other phase real power also considered.

- Static Synchronous Compensator (STATCOM)
- Static Synchronous Generator (SSG)
- Battery Energy Storage System (BESS)
- Superconducting Magnetic Energy Storage (SMES)
- Static Var Compensator (SVC):
- Thyristor Controlled Reactor (TCR)
- Thyristor Switched Reactor (TSR)
- Thyristor Switched Capacitor (TSC)
- Static Var Generator or Absorber (SVG)
- Thyristor Controlled Braking Resistor (TCBR)

STATCOM, SVC and TCR are more commonly use for commercial and industrial purpose. These devices are one by one explain below. [11]

Thyristor controlled reactor (TCR)

In 1982, Miller et al. Proposed Thyristor controlled reactor [6]. It is shown in the figure it is a combination of two antiparallel thyristor. Both thyristor conducts for the alternate half cycle. It acts as a controllable susceptance. Inductance L is important sub device of TCR. TCR is also fundamental component of TCSC and SVC. It is also a shunt compensator. For lightly loaded transmission line it is use for limiting voltage rise. Circuit diagram is shown in Fig.4

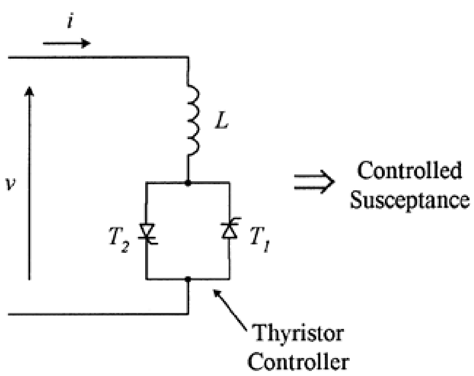

Fig.4: circuit diagram of TCR

Static VAR Compensator (SVC)

Static VAR compensator used for high voltage power system. There are many advantages using SVC like it improve system stability, reduce losses, maintain the line voltage variation within limits and better utilization of equipment. It consists of shunt capacitors and shunt reactors. Shunt reactor and TCRs is to prevent voltage rise under low load and no load condition. Static capacitor and TSCs (Thyristor switch capacitor) are to prevent voltage sag forpeak load. There are two combination uses in practise first one is TCR parallel with fixed capacitor (FC) and another one is TSC in parallel with TCR. If compare with TCR it is better than TCR as TCR only generate reactive power but SVC not only generate but also absorb reactive power. Fig 5 shows the structure of SVC.

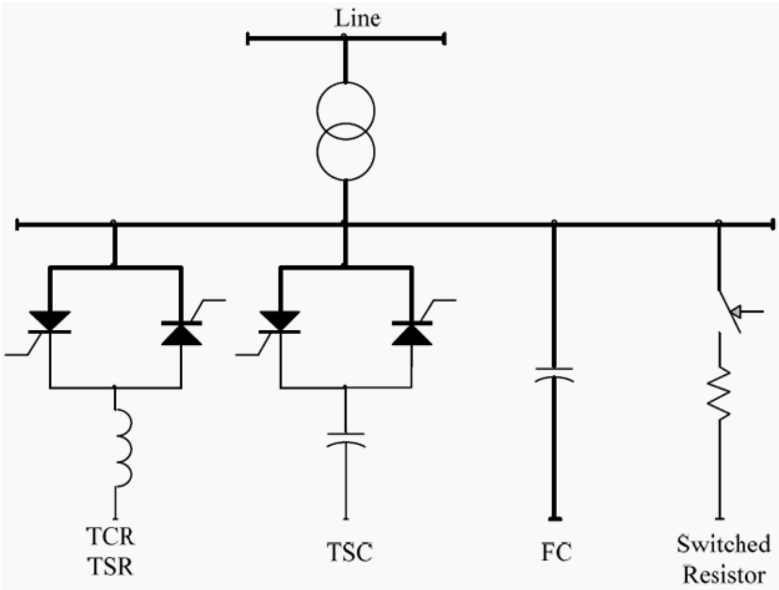

Fig.5:StaticVar Compensator

Static compensator (STATCOM)

The concept of STATCOM is proposed in [9].STATCOM consist a voltage source controller andshunt connected transformer. it is a voltage sourceconverter that dc power into ac power of variablephase angle and magnitude. It supply desire reactivepower by varying the phase angle and magnitude.For industrial application unity power factor can beobtain by using it. The basic structure of STATCOMis shown in Fig.6

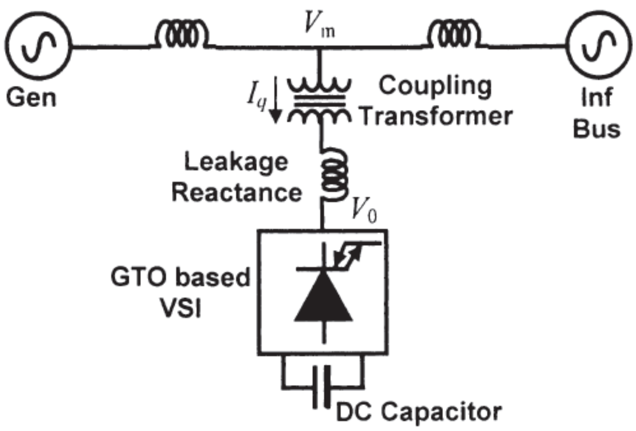

Fig.6: Basic Structure Of The STATCOM [13]

V. COMPARISON OF VARIOUS FACTS DEVICES

Table1. Shows the comparison among SVC, STATCOM, UPFC, TCSC and SSSC on the basis of their load flow, voltage control ,transient stability and dynamic stability in the form of low, medium, and high.

TABLE I. COMPARISON OF VARIOUS FACTS DEVICES

S NO	FACTS Device	Load flow	Voltage control	Transient stability	Dynamic stability
1	SVC	LOW	HIGH	LOW	MEDIUM
2	STATCOM	LOW	HIGH	MEDIUM	MEDIUM
3	UPFC	HIGH	HIGH	MEDIUM	MEDIUM
4	TCSC	MEDIUM	LOW	HIGH	MEDIUM
5	SSSC	LOW	HIGH	MEDIUM	MEDIUM

On comparison it is found that UPFC used for higher load flow and voltage control where as STATCOM is used for voltage control in small distribution system and the UPFC shows better results for power system stability improvement compared to the other FACTS devices such as SVC, TCSC, and SSSC.

VI. FUZZY LOGIC CONTROLLER

In real time applications Fuzzy logic control approach has a great potential as fuzzy logic control is characterized by its r obustness in system parameters and also changes as operating conditions changes. Fuzzy logic controllers are having the cap ability of ucertainity toleration and greater extent to imprecision these features makes the fuzzy logis controller more attract ive . The Fuzzy Logic controller is rule based controller where a control decision mechanism to counteract the effect of certai n causes in power sytem is represented by set of rule. In fuzzy logic, the fuzzy sets are definedto express five linguistic variable s that shows themembership function are suggested by rules of FC-TCR controller on the basis of practical experience an d results of simulaton observed from the behavior of the system around its stable equilibrium points and The rule of this table can be chosen Fuzzy logic is a stream of engineering that deal with the development of computer program based on the nature of human thinking and study of human intelligence. In fuzzy set based on fuzzy logic for a particular object a degree of membership in a set is given that may be anywhere in the range of 0 to 1. Fuzzy logic control is one of the control algorithm based on th e strategy of linguistic control , which is an automatic control strategy being derived from expert knowledge Principal components of Fuzzy logic controller:

1. Fuzzifier or Fuzzification block.
2. Knowledge base
3. Decision making block
4. Defuzzifier or Defuzzification block.

fuzzy controller applied with FC-TCR is able to maintain constant power factor at receiving end under normal condition as well as at load of large inductance and with the variation of load it does not get effected. The importance of fuzzy logic derives from the fact that most modes of human reasoning and especially common sense reasoning are approximate in nature. In doing so, complex closed -loop control problem are handled efficiently by the fuzzy logic approach. .Among various artificial intelligence techniques that are employed in modern power systems, fuzzy logic has emerged as the powerful tool for solving firing angle α challenging problems.For power factor correction Mamdani based fuzzy logic interfacing rule is adopted. From power measuring block Complex power is taken, in which power angle is taken as input of fuzzy controller. According to power angle controlled output (fir ing angle) is provided by fuzzy controller. When power angle is large corresponding to large value of firing angle. Controlled output is supplied to variable delay circuit and it is then supplied to thyristor. According to the variable time delay circuit output firing angle of thyristor is changed. When power angle is very small then firing angle is also very small. For medium power angle firing angle is also medium. The control concept of SVC is based on controlling of shunt susceptance (B) which can be controlled by changing the value of firing angle of thyristor. In steady-state, Ssome steady-state control of the voltage will be provided by SVC to maintain it the high-voltage bus at a predefined level. If there is a sudden increase in load the high -voltage bus begins to fall below its set point, in such a condition the SVC will inject reactive power (Qnet) into the system thereby increasing the bus voltage back to its net desired voltage level. If there is a sudden decrease in load, then bus voltage increases, the SVC (thyristor controlled reactor) will absorb reactive power, and the result will be to achieve the desired bus voltage. Therefore the magnitude of reactive power injected into the system, Qnet is controlled by the magnitude of Qind reactive power absorbed by the TCR.

VII. VOLTAGE CONTROL BY SVC TECHNIQUES

The power system stability can be known as the accurate system operation by recovering a state of operating balance after any un-preferred condition as faults, under or over voltage and etc. The recovering stability system after the abnormal condition must be controlled by very high accurate techniques. FACTS devices can overcome the power system oscillation during load variations by coupling into thetransmission system by a shunt or series techniques, which contains fixed and dynamic reactive power flow. The SVC is a consolidated technology for power quality improvement, that combined between shunt capacitor and shunt reactor. SVC module is used to control the voltage profile and their angle depending on the feedback to the control system. The control of the reactive power and the voltage value by the SVC module are depending on the thyristors firing angle [9]. The shunt capacitor module is called thyristor switched capacitors (TSC) and thyristor-controlled reactors (TCR), provides harmonic filters and/or dynamic shunt compensation. The TSC operates with series bi-directional thyristor and damping reactor to prevent the shunt resonance. SVC module is easy and more accurate to operates with the medium voltage [10]. SVC can be connected with the extra high voltage system via a step-down transformer. Fig. 1 shows the sample SVC single line diagram module to be used with the power system, which consists of VI characteristics. The current susceptance can be controlled and varied to regulate the voltage related to feedback excitation from the transmission system to the SVC control unit depending on the slope or droop characteristics.The voltage control logic of the thyristor firing angle is depending on the determination of the SVC susceptance required in the transmission system to compensate for the voltage value. At the discrepancy between the reference voltage and the system voltage, the controller logic will stay in running condition by the susceptance variation until attained equilibrium [11].

VI. CONCLUSION

In this paper we have studied about the need of reactive power compensation and the various FACTS devices and Various controller used for compensation.It has been seen that lot of work has been done for the control of reactive power. Nowadays, more interest is being giving to unified power flow control because of its wide range of applications in the development of the powersystem. This paper provides a general analysis of all the works related to SVC controller that has been done in the recent past.from above all literature reviews it has foundthat ANN-PSS has excellent dynamic performance compared with a traditional lead-lag power system stabilizer in terms ofovershoot, undershoot, and settling time. As a result, thepower system with the proposed ANN-PSS will functionmore smoothly and have greater reliability.

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