Methodology of Equipments Used in Power Quality Improvement- A Review

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Abstract:-With the increased loading and exploitation of power transmission system , the problem of power quality attracts more and more attention.Power Quality is characterized by parameters that express harmonic pollution, reactive power and load unbalance. FACTS technology reveals up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of system stability using FACTS controllers has been extensively investigated and Performance comparison of different FACTS controllers has been discussed. This paper presents a comprehensive review on the developments in the power quality enhancement using FACTS devices.

Keywords:- Power Quality (PQ), Flexible AC transmission system (FACTS), Unified power flow controller (UPFC),SVC,SSSC, TCSC, STATCOM, Interline power flow controller (IPFC).

I. INTRODUCTION

In recent years, a large demand has been placed on the transmission network, and demands will continue to increase due to an increasing number of non-utility generators and intensified competition among them. Increasing transmission capacity requirements can be achieved by either constructing new transmission lines or increasing the transfer capability of existing transmission facilities. An effective solution is, thus, to consider the use of transmission controllers (e.g. power electronics-based transmission controllers).The main objective of the power system operation is to match supply/demand, provide compensation for transmission loss, voltage and frequency regulation, reliability provision etc. The need for more efficient and fast responding electrical systems has given rise to innovative technologies in transmission using solid-state devices. These are called FACTS devices which enhance stability and increase line loadings closer to thermal limits.The involvement of a new family of FACTS devices which is based on Voltage Source Converters added the features like flexible power flow control, transient stability and power system oscillation damping enhancement. Static Synchronous (shunt) compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) are the members of family of compensators and power flow controllers based on VSC. Flexible ac transmission system (FACTS) controllers have the potential to improve the capacity of transmission networks through functional versatility and control flexibility. FACTS controllers have the capability of direct control of power flow by changing the parameters like voltage, line impedance, and power angle of transmission corridors.

In recent years, considerable attention has been devoted to the development and applications of FACTS controllers and their ability to enhance power system security. This has been done by focusing on the ability of FACTS controllers on both damping of power system oscillations and improving voltage stability.

The complexities in installing new transmission lines in a power system challenges the power engineers to research on the ways to increase the power flow with the existing transmission line without reduction in system stability and security. In this context, the concept of Flexible AC Transmission System (FACTS) introduced by N. G. Hingorani from the Electric Power Research Institute (EPRI) USA in 1986and it is based on thyristor operation techniques. FACTS controllers are broadly classified as series and shunt, both used to modify the natural electrical characteristics of ac power system.The FACTS devices control one or more of the parameters to improve system performance by using placement and coordination of multiple FACTS controllers in large-scale emerging power system networks to also show that the achieve significant improvements in operating parameters of the power systems such as small signal stability, transient stability, damping of power system oscillations, security of the power system, less active power loss, voltage profile, congestion management, quality of the power system, efficiency of power system operations, power transfer capability through the lines, dynamic performances of power systems, and the loadability of the power system network also increased. As FACTS devices are fabricated using solid state controllers, their response is fast and accurate. Thus these devices can be utilized to improve the voltage profile of the system by using coordinated control of FACTS controllers in multi-machine power systems.

Generally, the FACTs devices and technology could be divided into two generations:

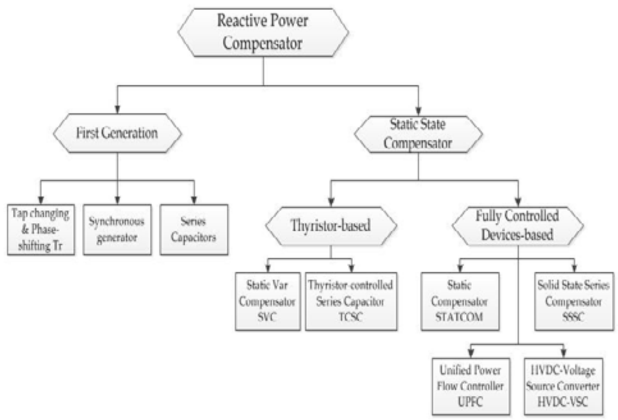

Fig.1.Power compensators

Flexible AC transmission systems (FACTS) have gained a great interest during the last few years, due to recent advances in power electronics. FACTS devices have been mainly used for solving various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement.

1.1 Benefits of FACT controllers:

The FACTS controllers provide voltage support to the system when shunt connected and regulate power flow in transmission lines when connected in series. By using combined series-shunt controller both voltage and power flow control can be achieved.

- FACTS controller helps in obtaining optimal system operation by reducing power losses and improving voltage profile of system.
- By using these controllers, the power carrying capacity of lines can be increased upto thermal limits.
- The problem of dynamic over voltages can be overcome by these controllers.
- The transient stability limit is increased thereby improving the dynamic security of the system.

II. INTRODUCTION TO VARIOUS FACTS CONTROLLERS

2.1 Thyristor Controlled Series Capacitor (TCSC):- TCSC is a series controller, the series controller may be a variable capacitor, inductor or a variable frequency source. A series controller injects a variable series voltage in the line. A voltage in series with the transmission line can control the current flow and thereby the power transfer from the sending end to receiving end.

With Series capacitors, the reactive power increases as the square of line current. The use of thyristor control to provide variable series compensation makes it attractive to employ series capacitor in long lines. Controlled series compensation can be achieved in two ways:

- Discrete control using Thyristor switched series capacitor (TSSC)

- Continuous control using Thyristor controlled series capacitor (TCSC), GTO Thyristor controlled series capacitor (GCSC).

A TCSC is 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 capacitivereactance [1].TCSC is asecond generation FACTS controller, which controls the impedance of the line in which it is connected by varying the firing angle of the thyristors. A TCSC module comprises a series fixed capacitor that is connected in parallel to a thyristor controlled reactor (TCR). A TCR includes a pair of anti-parallel thyristors that are connected in series with an inductor. In a TCSC, a metal oxide varistor (MOV) along with a bypass breaker is connected in parallel to the fixed capacitor for overvoltage protection. A complete compensation system may be made up of several of these modules.

2.2. Static VAR Compensator (SVC):- The static VAr compensator (SVC) is a first generation FACTS controller. It is a variable impedance device in which the current through a reactor is controlled by back to back connected thyristors. These thyristors are rated for lower voltages as the SVC is connected to the transmission line through a step down transformer or through the tertiary winding of a power transformer. The SVC should be located at load center or midpoint of a transmission line. SVC is a shunt connected combination which includes a separate thyristor controlled or thyristor switched reactor for absorbing reactive power and thyristor switched capacitor for supplying the reactive power. An SVC can control the voltage magnitude at the required bus thereby improving the voltage profile of the system. The primary task of an SVC is to maintain the voltage of a particular bus by means of reactive power compensation (obtained by varying the firing angle of the thyristors). It can also provideincreased damping to power oscillations and enhance power flow over a line by using auxiliary signals such as line active power, line reactive power, line current, and computed internal frequency.

Static VAR Compensator (SVC) is a shuntconnected FACTS controller whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. Basically it consists of a fixed capacitor (FC) and a thyristor controlled reactor (TCR). In SVC, theresonance phenomenon is present as similar to TCSC. So, this device cant operated in a particular zone due these phenomena. This is the drawback of SVC operations in power systems [1]. Figure 2. Shows the SVC equivalent susceptance profile.

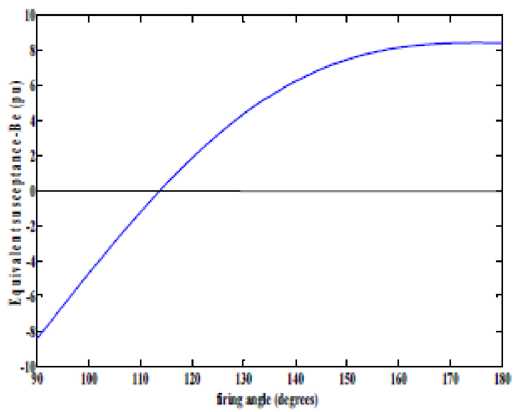

Fig.2. SVC equivalent susceptance profile

The use of SVC improves transmission capacity and steady static limit. SVC can be used for stability improvements both during small and large disturbances. Its use can also damp the sub-synchronous oscillations.

2.3. Static Synchronous Series Compensator (SSSC):- A SSSC is a static synchronous generator operatedwithout 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 transmittedelectric power. The SSSC may include transiently rated energy source or energy absorbing device to enhance the dynamic behaviour of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real voltage drop across the line [1].

An SSSC incorporates a solid state voltage source inverter that injects an almost sinusoidal voltage of variable magnitude in series with a transmission line. The SSSC has the same structure as that of a STATCOM except that the coupling transformer of an SSSC is connected in series with the transmission line. The injected voltage is mainly in quadrature with the line current. A small part of injected voltage, which is in phase with the line current, provides the losses in the inverter. Most of injected voltage, which is in quadrature with the line current, emulates a series inductance or a series capacitance thereby altering the transmission line series reactance. This emulated reactance, which can be altered by varying the magnitude of injected voltage, favorably influences the electric power flow in the transmission line. The structure of SSSC shown in Fig.3

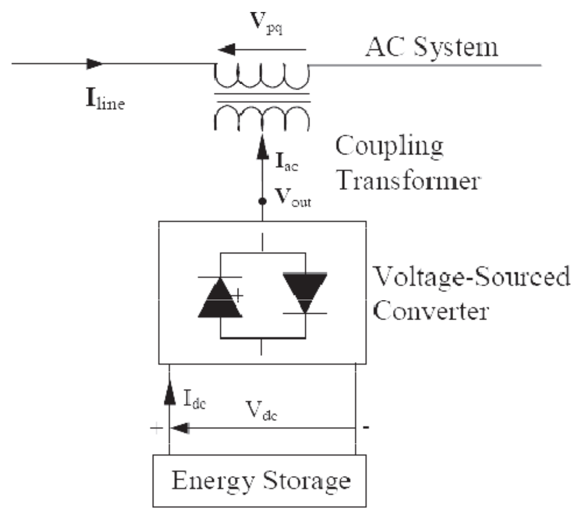

Fig.3.The basic structure of Static synchronousseries compensator (SSSC).

SSSC is a solid-state synchronous voltage source employing an appropriate DC to AC inverter with gate turn-off thyristor. It is similar to the STATCOM, as it is based on a DC capacitor fed VSI that generates a three-phase voltage, which is then injected in a transmission line through a transformer connected in series with the system. In SSSC, the resonance phenomena has been removed. So SSSC is having more superior performance as compare to TCSC.

The SSSC may be used for current control, stability improvement and for damping oscillations during disturbances.

2.4.Static Synchronous Compensator (STATCOM):- The static synchronous compensator or simply static compensator (STATCOM) is a shunt connected device developed as an advanced static VAr compensator where a voltage source converter (VSC) is used instead of controllable reactors and switched capacitors. A STATCOM is a static synchronous generatoroperated as a shunt connected static VAr compensator whose capacitive or inductive outputcurrent can be controlled independent of the ac system voltage.

The Static Synchronous Compensator (STATCOM) is a power electronic-based Synchronous Voltage Generator (SVG) that generates a three-phase voltage from a dc capacitor in synchronism with the transmission line voltage and is connected to it by a coupling transformer as shown in Fig.4. By controlling the magnitude of the STATCOM voltage, V_S, the reactive power exchange between the STATCOM and the transmission line and hence the amount of shunt compensation can be controlled.

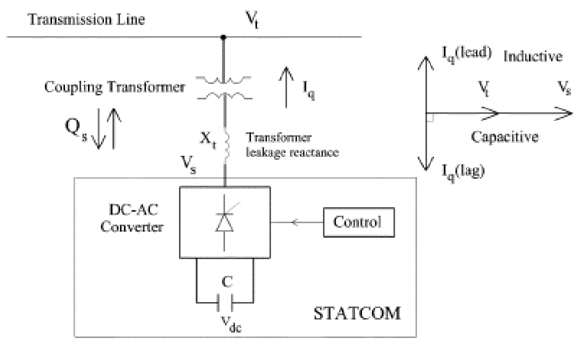

Fig. 4.The structure of Static synchronous compensator (STATCOM)

Figs.4 and 5 show the schematic diagram and terminal characteristic of STATCOM, respectively. From Fig. 4, STATCOM is a shunt-connected device, which controls the voltage at the connected bus to the reference value by adjusting voltage and angle of internal voltage source.

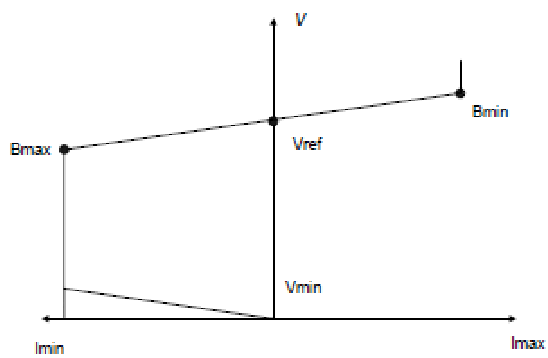

Fig.5.Terminal characteristic of STATCOM.

2.5. Unified Power Flow Controller (UPFC):- A unified power flow controller is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC). The STATCOM and SSSC are coupled y a common DC link. This DC link allows bi-directional flow of real power between series output terminals of the SSSC and the shunt output terminals of STATCOM. UPFC provides active and reactive series line compensation and also provide independently controllable shunt reactive compensation [5].

The UPFC is the most versatile and powerful FACTS device. It is also known as the most comprehensive multivariable FACTS controller. Simultaneous control of multiple power system variables with UPFC posses enormous difficulties. In addition, the complexity of the UPFC control increases due to the fact that the controlled and the variables interact with each other. The Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle.

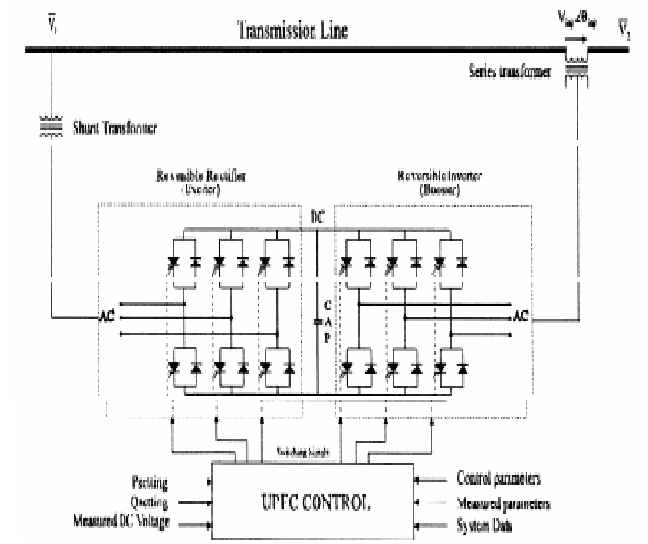

Fig.6.Schematic diagram of three phases UPFC connected to a transmission line

With the presence of the two converters, UPFC notonly can supply reactive power but also active power. Figure 7 and 8 shows the equivalent single line circuit diagram representation of UPFC in power system and UPFC model schematic. The figure 9 shows the UPFC model equivalent.

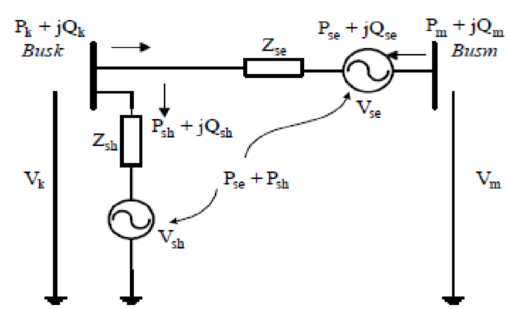

Fig.7. Equivalent single line circuit diagramrepresentation of UPFC in power systems

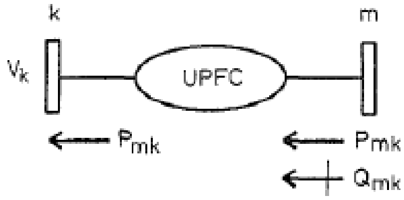

Fig.8. UPFC model schematic

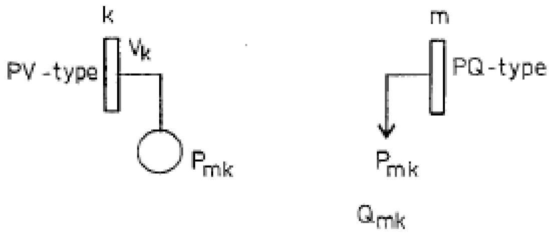

Fig.9.UPFC model equivalent

2.6. Interline Power Flow Controller:-IPFC is a series-series controller, introduced in 1998, the controller having a combination of two or more static synchronous series compensator. In its general form the inter line power flow controlleremploys a number of dc-to-ac converters each providing series compensation for a different line. In other words, the

IPFC comprises a number of Static Synchronous Series Compensators (SSSC). The simplest IPFC consist of two back-to-back dc-to-ac converters, which are connected in series with two transmission lines through series coupling transformers and the dc terminals of the converters are connected together via a common dc link as shown in Fig.10.With this IPFC, in addition to providing series reactive compensation, any converter can be controlled to supply real power to the common dc link from its own transmissionline.

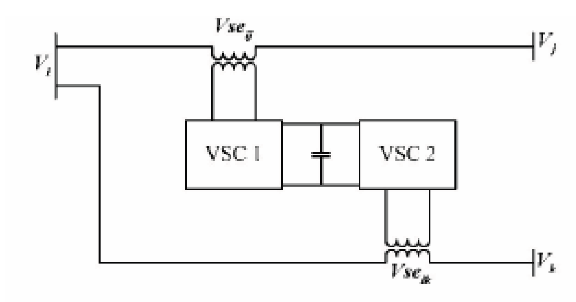

Fig.10. Schematic diagram of two converter IPFC

An IPFC with two converters compensating two lines is similar to UPFC in which the magnitude and phase angle of the injected voltage in the prime system (or line) can be controlled by exchanging real power with the support system (which is also a series converter in the second line). The basic difference with a UPFC is that the support system in the later case is the shunt converter instead of a series converter. The series converter associated with the prime system of one IPFC is termed as the master converter while the series converter associated with the support system is termed as slave converter. The master converter controls both active and reactive voltage (within limits) while the slave converter controls the DC voltage across the capacitor and the reactive voltage magnitude[2].

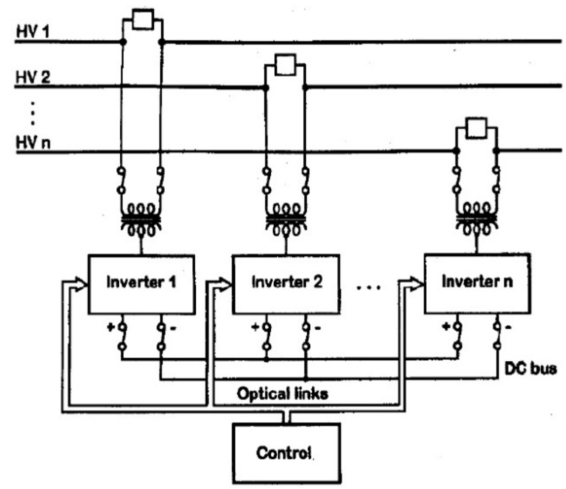

Fig.11.A Interline Power Flow Controller comprising n converters.

III. CONCLUSIONS

This paper presents the introduction of various FACTS controllers such as SVC, TCSC, SSSC, STATCOM, UPFC, IPFC, for operation, control, planning &protection from different performance point of view such as increased the loadability, improve the voltage profile, minimize the active power losses, increased the available transfer capacity, enhance the transient and steady-state stability, and flexible operations of power systems.

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