A Study of Reactive Power Compensation in Power System and Its Compensation Techniques

M.Maheshkumar
Assistant Professor
Department of Electrical & Electronics Engineering
K.G Reddy College of Engineering & Technology, Hyderabad, Telangana, INDIA

Abstract: **We always in practice to reduce reactive power to improve system efficiency. This is acceptable at some level, if system is purely resistively or capacitances it makes cause some problem in Electrical system. AC systems supply or consume two kind of power: real power and reactive power. Real power accomplishes useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system. 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. This Paper deals with what is the need of reactive power and its compensation techniques needed for any power system using FACTS devices such as SSSC, TCR, TCSC, STATCOM, UPQC and UPFC. The STATCOM and how it helps in the better utilization of a network operating under normal conditions.**

Keywords— Reactive power compensation, FACTS devices

I. INTRODUCTION

Except in a very few special situations, electrical energy is generated, transmitted, distributed, and utilized as alternating current (AC)[11]. However, alternating current has several distinct disadvantages. One of these is the necessity of reactive power that needs to be supplied along with active power. Reactive power can be leading or lagging. While it is the active power that contributes to the energy consumed, or transmitted, reactive power does not contribute to the energy. Reactive power is an inherent part of the ‘‘total power.’’ Reactive power is either generated or consumed in almost every component of the system, generation, transmission, and distribution and eventually by the loads. The impedance of a branch of a circuit in an AC system consists of two components, resistance and reactance. Reactance can be either inductive or capacitive, which contribute to reactive power in the circuit. Most of the loads are inductive, and must be supplied with lagging reactive power. It is economical to supply this reactive power closer to the load in the distribution system. Reactive power compensation in power systems can be either shunt or series.

Shunt Reactive Power Compensation: Since most loads are inductive and consume lagging reactive power, the compensation required is usually supplied by leading reactive power. Shunt compensation of reactive power can be employed either at load level, substation level, or at transmission level. It can be capacitive (leading) or inductive (lagging) reactive power, although in most cases compensation is capacitive. The most common form of leading reactive power compensation is by connecting shunt capacitors to the line.

Shunt Capacitors: Shunt capacitors are employed at substation level for the following reasons:

Voltage regulation: The main reason that shunt capacitors are installed at substations is to control the voltage within required levels. Load varies over the day, with very low load from midnight to early morning and peak values occurring in the evening between 4 PM and 7 PM. Shape of the load curve also varies from weekday to weekend, with weekend load typically low. As the load varies, voltage at the substation bus and at the load bus varies. Since the load power factor is always lagging, a shunt connected capacitor bank at the substation can raise voltage when the load is high. The shunt capacitor banks can be permanently connected to the bus (fixed capacitor bank) or can be switched as needed. Switching can be based on time, if load variation is predictable, or can be based on voltage, power factor, or line current.

Reducing power losses: Compensating the load lagging power factor with the bus connected shunt capacitor bank improves the power factor and reduces current flow through the transmission lines, transformers, generators, etc. This will reduce power losses (I2R losses) in this equipment.

Increased utilization of equipment: Shunt compensation with capacitor banks reduces kVA loading of lines, transformers, and generators, which means with compensation they can be used for delivering more power without overloading the equipment. Reactive power compensation in a power system is of two types—shunt and series. Shunt compensation can be installed near the load, in a distribution substation, along the distribution feeder, or in a transmission substation. Each application has different purposes. Shunt reactive compensation can be inductive or capacitive. At load level, at the distribution substation, and along the distribution feeder, compensation is usually capacitive. In a transmission substation, both inductive and capacitive reactive compensation are installed.

II. NEED OF REACTIVE POWER

a) Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. In general terms, decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. A voltage collapse occurs when the system try to serve much more load than the voltage can support.

b) When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further . If the current increase too much, transmission lines go off line, overloading other lines and potentially causing cascading failure.

c *Importance of Present of Reactive Power*

a) Voltage control and reactive-power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks..

b) On an alternating-current (AC) power system, voltage is controlled by managing production and absorption of reactive power. There are three reasons why it is necessary to manage reactive power and control voltage.

c) First, both customer and power-system equipment are designed to operate within a range of voltages, usually within±5% of the nominal voltage. At low voltages, many types of equipment perform poorly; light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at High voltages can damage equipment and shorten their lifetimes.

d) Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive-power flows must be minimized. Similarly, reactive-power production can limit a generator's real-power capability.

Purpose of Reactive Power: Synchronous generators, SVC and various types of other DER (Distributed energy resource) equipment are used to maintain voltages throughout the transmission system. Injecting reactive power into the system raises voltages, and absorbing reactive power lowers voltages.

Voltage-support requirements are a function of the locations and magnitudes of generator outputs and customer loads and of the configuration of the DER transmission system.

These requirements can differ substantially from location to location and can change rapidly as the location and magnitude of generation and load change. At very low levels of system load, transmission lines act as capacitors and increase voltages. At high levels of load, however, transmission lines absorb reactive power and thereby lower voltages. Most transmission-system equipment (e.g., capacitors, inductors, and tap-changing transformers) is static but can be switched to respond to changes in voltage-support requirements.

System operation has three objectives when managing reactive power and voltages.

First, it must maintain adequate voltages throughout the transmission and distribution system for both current and contingency conditions..

Profound effects of Reactive Power in Various elements of Power System:

a) Generation

An electric-power generator's primary function is to convert fuel (or other energy resource) into electric power. Almost all generators* also have considerable control over their terminal voltage and reactive-power output..

Payment for the use of this resource is the specific focus of voltage control from generation service. The ability of generator to provide reactive support depends on its real-power production. Like most electric equipment, generators are limited by their current-carrying capability. Near rated voltage, this capability becomes an MVA limit for the armature of the generator rather than a MW limitation.

Production of reactive power involves increasing the magnetic field to raise the generator's terminal voltage. Increasing the magnetic field requires increasing the current in the rotating field winding. Absorption of reactive power is limited by the magnetic-flux pattern in the stator, which results in excessive heating of the stator-end iron, the core-end heating limit.

The synchronizing torque is also reduced when absorbing large amounts of reactive power, which can also limit generator capability to reduce the chance of losing synchronism with the system.

b) Synchronous condensers[12]

Every synchronous machine (motor or generator) with a controllable field has the reactive-power capabilities discussed above..

Synchronous motors are occasionally used to provide dynamic voltage support to the power system as they provide mechanical power to their load. Some combustion turbines and hydro units are designed to allow the generator to operate without its mechanical power source simply to provide the reactive-power capability to the power system when the real-power generation is unavailable or not needed..

Synchronous machines that are designed exclusively to provide reactive support are called synchronous condensers.

Synchronous condensers have all of the response speed and controllability advantages of generators without the need to construct the rest of the power plant (e.g., fuel-handling equipment and boilers). Because they are rotating machines with moving parts and auxiliary systems, they may require significantly more maintenance than static alternatives. They also consume real power equal to about 3% of the machine's reactive-power rating.

c) Capacitors and inductors

Capacitors and inductors (which are sometimes called reactors) are passive devices that generate or absorb reactive power. They accomplish this without significant real-power losses or operating expense. The output of capacitors and inductors is proportional to the square of the voltage. Thus, a capacitor bank (or inductor) rated at 100 MVAR will produce (or absorb) only 90 MVAR when the voltage dips to 0.95 pu but it will produce (or absorb) 110 MVAR when the voltage rises to 1.05 pu. This relationship is helpful when inductors are employed to hold voltages down.

The inductor absorbs more when voltages are highest and the device is needed most. The relationship is unfortunate for the more common case where capacitors are employed to support voltages. In the extreme case, voltages fall, and capacitors contribute less, resulting in a further degradation in voltage and even less support from the capacitors; ultimately, voltage collapses and outages occur..

III. FACTS CONTROLLERS USED IN REACTIVE POWER COMPENSATION TECHNIQUES

FACTS Controllers can be divided into four categories: [13]

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

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. [9]

- 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 [4]. 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.1

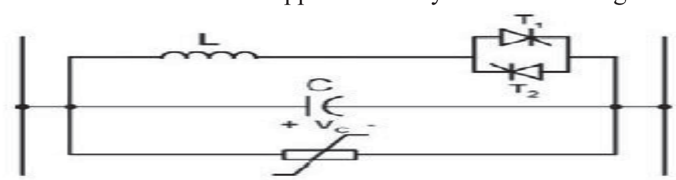

Fig.1: TCSC circuit diagram

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. [5]

Thyristor controlled reactor (TCR)
In 1982, Miller et al. Proposed Thyristor controlled reactor [1]. 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.2

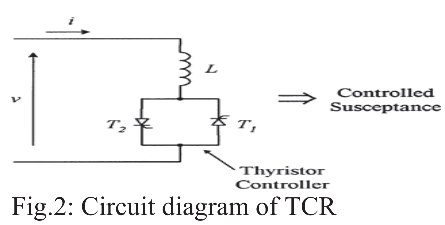

Fig.2: Circuit diagram of TCR

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 equipments.

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 for peak load. There are two combination uses in practice 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 3 shows the structure of SVC.

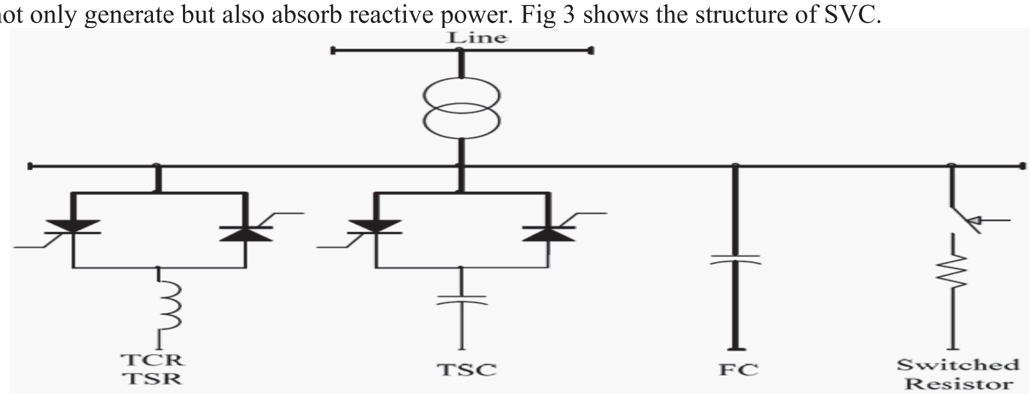

Fig.3: Static Var Compensator

Static compensator (STATCOM)

The concept of STATCOM is proposed in [3]. STATCOM consist a voltage source controller and shunt connected transformer. it is a voltage source converter that dc power into ac power of variable phase angle and magnitude. It supply desire reactive power by varying the phase angle and magnitude. For industrial application unity power factor can be obtain by using it. The basic structure of STATCOM is shown in Fig.4

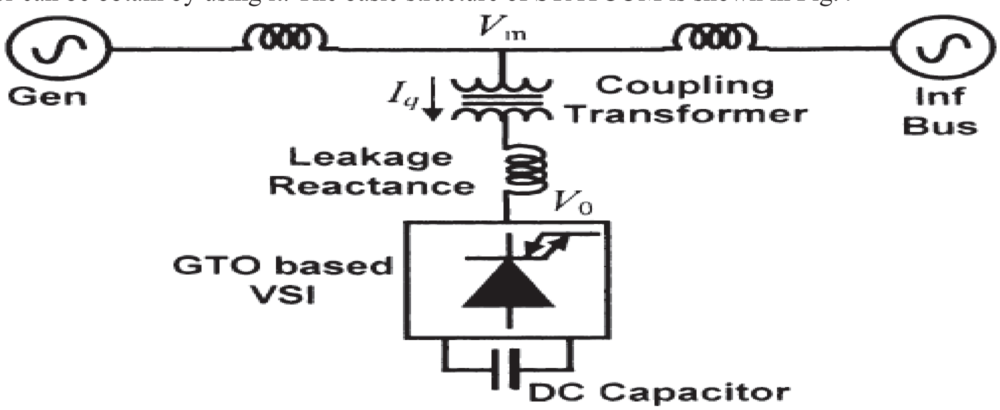

Fig.4: Basic Structure Of The STATCOM [7]

Combined series-series Controllers

It is a combination of series controller. For multiline transmission system this controller control in coordinated manner. It can be unified controller because it separately compensates the power line. It is also called “Interline Power Flow Controller” because it balances both real and reactive power. The term unified means dc terminal of controller are connected together for transfer of real power.

Combined series-shunt Controllers

It is a combination of series and shunt controller which control in a coordinated manner or it may be unified power flow controller. It injects current into system with shunt part of it and voltage with series part of the controller. When it works as unified real power exchange occurs via power link.

Example of combine series and shunt controller

Unified Power Flow Controller (UPFC): The UPFC concept was proposed by Gyugyi in 1991. It is able to control, simultaneously or selectively all the parameters affecting power flow in the transmission line (i.e., voltage, impedance and phase angle). UPFC consists of two switching converters operated from a common DC link, as shown in Fig.5 and power injection model of UPFC is shown in Fig. 4. The working range of the UPFC angle is between −180° and +180°.

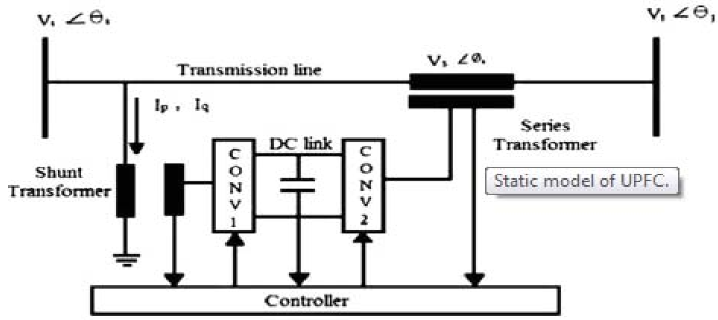

Fig.5: Static model of UPFC

Unified Power Quality Conditioner (UPQC): The unified power quality conditioner is commonly called UPQC. The design configuration is based on the connection of series and shunt inverters. In this, the design configuration is right series and left shunt with the current source converter (CSC). In this paper, UPQC-CSC is designed and analysis of the results has been done. Unified power quality conditioner (UPQC) for nonlinear and voltage sensitive load has following facilities and its circuit diagram is shown in Fig.6

- It reduces the harmonics in the supply current, so that it can improve utility current quality for nonlinear loads.
- UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase; therefore, no additional power factor correction equipment is required.
- UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag

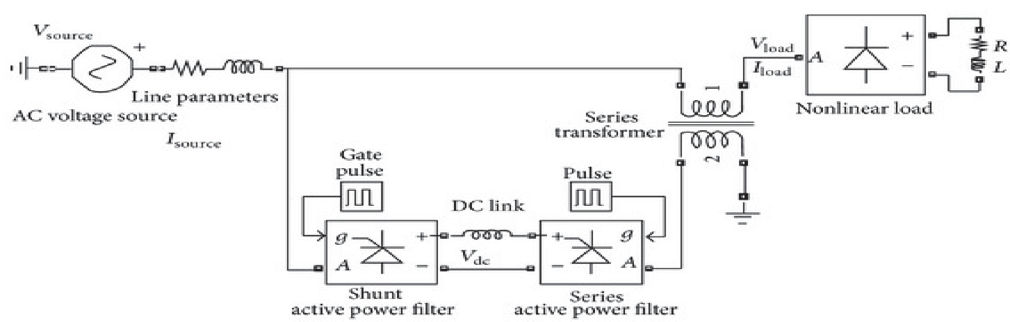

Fig.6: Basic Structure of UPQC

IV. Conclusion

In this paper we have studied about the need of reactive power compensation and the various FACTS devices used for compensation. The working principle of STATCOM, TCR, SVC, TCSC, UPQC and UPFC has been described. Finally the comparison of these fact devices is done. From the comparison it is found that UPFC is better for voltage control and lad flow but for low level application STATCOM is also shows better results. From this it can be say that FACT controller will play a very vital role for reactive power compensation in electrical power system.

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