CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 OVERVIEW

Electricity supply plays an important role in the economic development and technology advancement throughout the world. The quality and reliability of power supplies relates closely to the economic growth of a country. However, power quality disturbances such as sags, swells, flicker, harmonics, voltage imbalance etc., create a lot of problems in achieving a reliable and quality power supply. To mitigate these problems, power electronics based FACTS devices [1, 2] are used in transmission systems.

The basic applications of FACTS devices are:

- Power flow control
- Increase of transmission capability
- Voltage control
- Reactive power compensation
- Stability improvement
- Power quality improvement
- Power conditioning
- Flicker mitigation
- Interconnection of renewable and distributed generation and storage

The FACTS devices have been used to solve voltage stability problem and attain bulk power transfer. The FACTS based application of power electronic devices can also be effective for the power distribution systems to enhance the quality and the reliability of power delivered to the consumers. A compact solution to the present power quality problems as seen by the utilities and power distributors is offered in form of custom power technology. Custom power (CP) technology [3] utilizes switching equipment and controllers in order to enhance the reliability of electrical energy supplied to consumers in the form of less interruptions and small voltage variations. Hence if this technology is appropriately applied then all the industrial, commercial and domestic customers may benefit from it.

In modern power system there is a proliferation of power electronics based loads which introduces a lot of power quality problems [4, 5] such as voltage imbalance, harmonics, transients etc into the system and corrupts the system performance. To improve the performance of the system Custom Power Devices are extensively used. FACTS based controllers [6-10] provide the required change in system parameters and improve stability, voltage control and network loading control.

In recent years Power Quality [11] has become a major issue for the industrial and commercial electricity users. Now equipment are used which require high quality of power for their operation and consumers expect reliable power supply and disruption free operation. To improve the quality of power, remedies [12, 13] are suggested both at utility and customer sides.

In distribution systems power quality problems occur more frequently. Custom Power Devices [14-16] are used in distribution systems to mitigate these problems. A custom power device could be series connected, shunt connected or both simultaneously across the system. These devices are composed of a voltage source converter (VSC) and a capacitor connected at the DC link of the converter. The amount of compensation offered by the device depends on the design of VSC i.e. DC link capacitor, device rating of IGBT switches and interface inductors.

In distribution systems, there are various sensitive loads which have to be protected in case supply side voltage is unbalanced or distorted. Dynamic Voltage Restorer (DVR) is a series connected device [17, 18] which takes care of all these problems and protects the critical loads. DVR injects a voltage of required amplitude and frequency which helps in restoring the load side voltage amplitude and waveform. It can provide compensation for unbalance or distortions in source side other than outages.

Unified Power Quality Compensator (UPQC) [19, 20] is another device which takes care of power quality problems occurring in distribution systems. This device employs two voltage source inverters (VSIs) that are connected to a common dc energy storage capacitor. One of these two VSIs is connected in series with the ac line while the other is connected in shunt with the same line. The UPQC consists of both series and shunt compensators, so it can handle both voltage and current related problems. The shunt VSI is most promising to tackle the current related problems, whereas the series one is more suitable for overcoming the voltage related problems. The power quality problems which occur in distribution system are mainly current related. Hence shunt devices are generally used in distribution systems to mitigate these problems. DSTATCOM is one important shunt device which is used to deliver or absorb the required amount of reactive power and improve the power factor or voltage profile of the system.

A DSTATCOM [3, 21] consists of a three phase inverter (generally a PWM inverter) using Silicon Controlled Rectifiers (SCRs), Metal-Oxide Semiconductor Field Effect Transistors (MOSFETs) or Insulated Gate Bipolar Transistor (IGBTs), a D.C capacitor which provides the D.C voltage for the inverter, an interface reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the d.c side capacitor, three phase voltages are generated by the inverter which is synchronized to the a.c supply. The link inductor links voltage to the a.c supply side. This is the basic principle of operation of DSTATCOM.

Various control algorithms for DSTATCOM [21-23] have been proposed for load compensation. DSTATCOM control is mainly done with the help of two theories namely, Instantaneous Reactive Power Theory (IRPT) & Synchronous Reference Frame (SRF) theory. Both these theories are used to extract the compensator currents. A new Adaline based algorithm [21] is also mentioned which is quite effective for reactive power compensation. These control algorithms for DSTATCOM have been found to be effective for linear as well as non linear loads in the system under static and dynamic load conditions. DSTATCOM has been mainly employed for maintaining the source power factor to unity or for voltage regulation. Reference [24, 25] presents a number of controllers for DSTATCOM.

A comparison of shunt and series VSC based compensators [26] has been done for load voltage control in distribution systems for weak and strong ac supply system. It shows that the shunt compensator i.e. DSTATCOM works properly in case of a weak ac supply systems while the performance of DVR is better when the system is strong. Closed loop frequency control is used to check the performances of the compensators.

Load compensation using DSTATCOM in weak ac supply systems [27] has been used in distribution systems for maintaining the source currents to perfect sinusoid. Loads are connected in distribution systems through feeders, which cause voltage drop. A new switching control scheme is used which makes the source current balanced in case of unbalanced loads and makes the supply current harmonic free and of unity power factor.

DSTATCOM has many applications in distribution systems [28-32]. It can improve the voltage profile of the system and power factor under unbalanced and distorted load conditions. Flicker in case of arc furnace can be suppressed with the help of DSTATCOM [33]. Battery Energy Storage System (BESS) increases the flexibility of control [34, 35] such that different aspects of a system could be controlled at the same time.

1.2 FACTS CONTROLLERS

The IEEE Power Engineering Society (PES) Task Force of the FACTS Working Group [1] has defined FACTS and FACTS Controllers as given below:

Flexible AC Transmission System (FACTS*)*: Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability.

FACTS Controller*:* A power electronic-based system and other static equipment that provide control of one or more AC transmission system parameters.

The term “other static Controllers” used in this definition of FACTS ensures that there can be other static Controllers which are not based on power electronics. The general symbol for

FACTS Controller is shown in Fig. 1.1a. FACTS Controllers are broadly categorized into four types:

(a) Series FACTS Controllers
(b) Shunt FACTS Controllers
(c) Combined Series-Series FACTS Controllers
(d) Combined Series-Shunt FACTS Controllers

(i) **Series FACTS Controllers**: - These FACTS Controllers could be variable impedance such as capacitor, reactor or a power electronic based variable source, which in principle injects voltage in series with the line as illustrated in Fig. 1.1b. When the voltage is in phase quadrature with the line current, the series Controllers only supplies or consumes variable reactive power. Any other phase relationship involves handling of real power as well.

(ii) **Shunt FACTS Controllers**: - The shunt Controllers may be variable impedance such as capacitor, reactor or power electronic based variable source, which is shunt connected to the line in order to inject variable current, as shown in Fig. 1.1c. When the injected current is in phase quadrature with the line voltage, the shunt Controllers only supplies or consumes variable reactive power. Any other phase relationship involves handling of real power as well.

(iii**) Combined Series-Series FACTS Controllers**: - These Controllers are the combination of separate Series FACTS Controllers, which are controlled in a coordinated manner in a multiline transmission system, as illustrated in Fig. 1.1d. This configuration provides independent series reactive power compensation for each line but also transfers real power among the lines via power link. The presence of power link between series controllers names this configuration as "Unified Series-Series Controller".

(iv) **Combined Series-Shunt FACTS Controllers**: - These are combination of separate shunt and series controller, which are controlled in a coordinated manner (Fig. 1.1e) or a Unified Power Flow Controller with series and shunt elements (Fig. 1.1f). When the Shunt and Series

FACTS Controllers are unified; there can be a real power exchange between the series and shunt controllers via power link.

Although series FACTS Controllers for a given MVA size is several times more powerful than Shunt FACTS Controllers, they have to be designed to ride through contingency and dynamic overloads, and ride through or by-pass short circuit currents. Therefore, shunt FACTS controllers are more popular in order to control voltage at and around the point of connection through injection of reactive current (lagging or leading) or a combination of active and reactive current for a more effective voltage control and damping of voltage oscillations.

Shunt connected FACTS Controllers have also found wide applications in the distribution and transmission systems for many years since they present simple, cost effective solutions in load compensation. The most common Shunt connected FACTS Controllers are static shunt compensators: Static VAR Compensator (SVC) and STATCOM. STATCOM with a converter based var generator functions as a shunt connected synchronous voltage source while the SVC with thyristor controlled reactors and thyristor switched capacitors functions as a shunt connected controllable reactive admittance. This basic operational difference (voltage source versus reactive admittance) accounts for the STATCOM's overall superior functional characteristics, better performance, and greater application flexibility than those attainable with the SVC. The capability of providing maximum compensating current at reduced system voltage enables the STATCOM to perform in a variety of applications the same dynamic compensation as an SVC of considerably higher rating and makes it more stable in transient conditions. The response time of STATCOM is less than 200µs to 350 µs which is faster than SVC time of 2.5 to 5.0 ms which is an additional advantage of STATCOM over SVC.

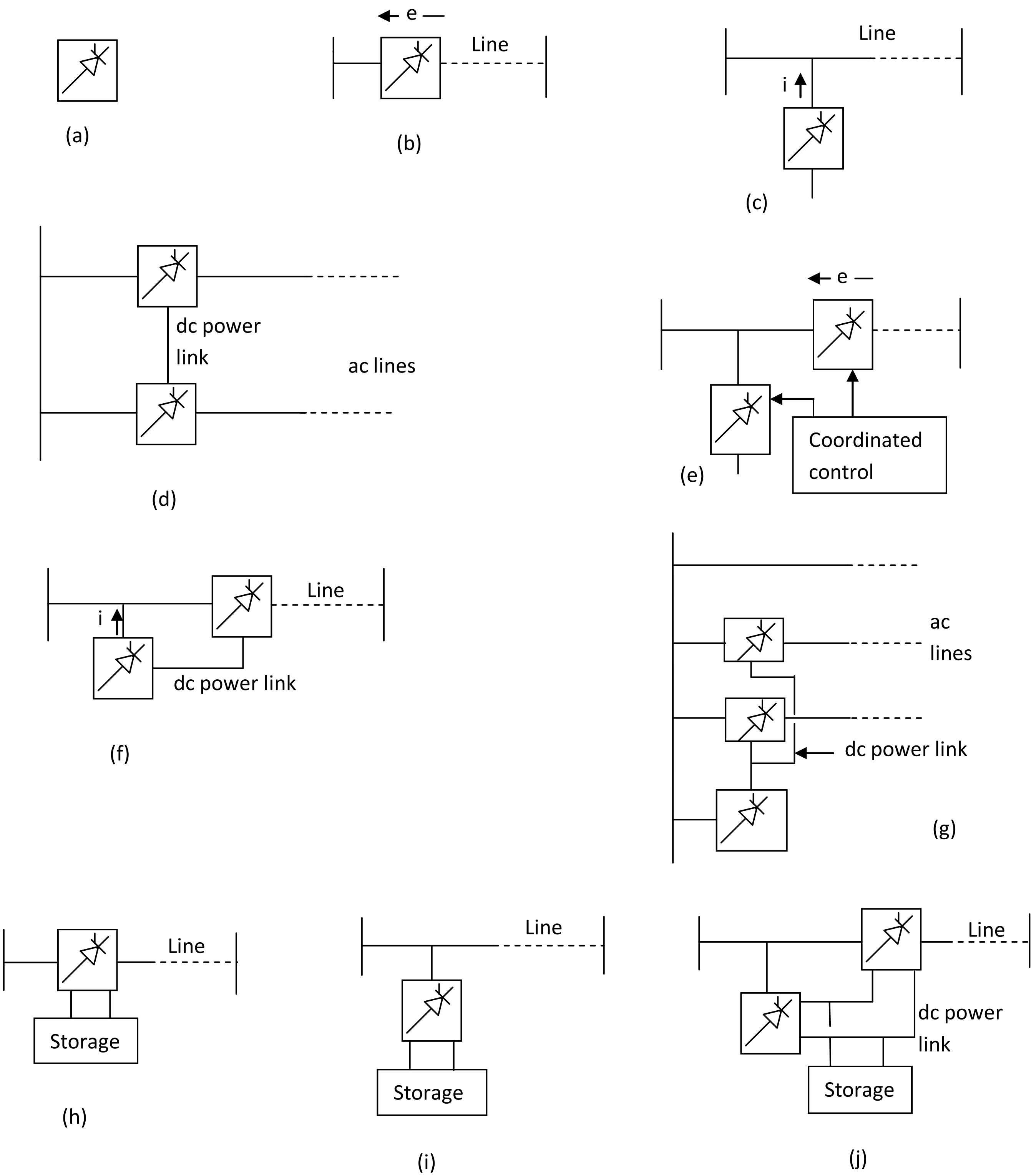

Fig. 1.1 Basic Types of FACTS Controllers (a) General symbol for FACTS Controller, (b)Series FACTS Controller, (c) Shunt FACTS Controller, (d) Unified Series-Series FACTS Controller, (e) Coordinated Series and Shunt Controller, (f) Unified Series-Shunt Controller, (g) Unified Controller for multiple lines,(h) series Controller with storage, (i) shunt Controller with storage, (j) unified series-shunt Controller with storage.

1.3 Custom Power Devices

The concept of custom power was introduced by N.G. Hingorani [14]. Like flexible ac transmission systems (FACTS) for transmission systems, the term custom power (CP) pertains to the use of power electronic controllers for distribution systems. The FACTS technology improves the reliability and quality of power transmission by simultaneously enhancing both power transfer and stability, the custom power devices at distribution level enhance the quality and reliability of power delivered to customers. These devices ensure that a customer receives a prespecified quality power [15, 16].

There are many custom power devices. The compensating power electronic devices are either connected in shunt or in series or a combination of both. In addition there are current breaking devices which are based on power electronics. Any one or combination of two or more of these devices is used to mitigate problems such as voltage sag, voltage swell, low phase unbalance etc.

Custom power devices can be classified into two major categories [3], network configuring type and compensating type. The former changes the configuration of the power system network for power quality enhancement. SSCL (Solid State Current Limiter), SSCB (Solid State Circuit Breaker) and SSTS (Solid State Transfer Switch) are the most representative in this category. SSCL is a GTO based device that inserts an inductor in series with a power system and limits the fault current. The inductor is removed from the circuit once the fault is cleared. SSCB acts as a protection device. It isolates the faulted circuit from the system. SSTS performs rapid transfer of the load from a faulted line to an alternative line to protect a sensitive load. All of these devices use GTO or thyristor switches. Therefore these devices are called “solid state” devices.

The compensating type devices are used for active filtering, load balancing, power factor correction and voltage regulation. The family of compensating devices includes DSTATCOM (Distribution Static compensator), DVR (Dynamic voltage restorer) and Unified power quality conditioner (UPQC). DSTATCOM has a similar structure and function to STATCOM in the transmission system. DSTATCOM is connected in shunt with the power system. DVR is a series connected device that injects a controllable series voltage to compensate for the disturbances in the supply voltage. UPQC has a structure similar to that of Unified Power Flow Controller (UPFC). It can inject controllable series voltage and shunt currents to the system.

1. Distribution Static Compensator (DSTATCOM)

The simplest DSTATCOM configuration consists of a two-level VSC, a dc energy storage device, and a coupling transformer connected in shunt with the ac system. Fig 1.2 shows the schematic representation of the DSTATCOM. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled to the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effective control of active and reactive power between the DSTATCOM and the ac system.

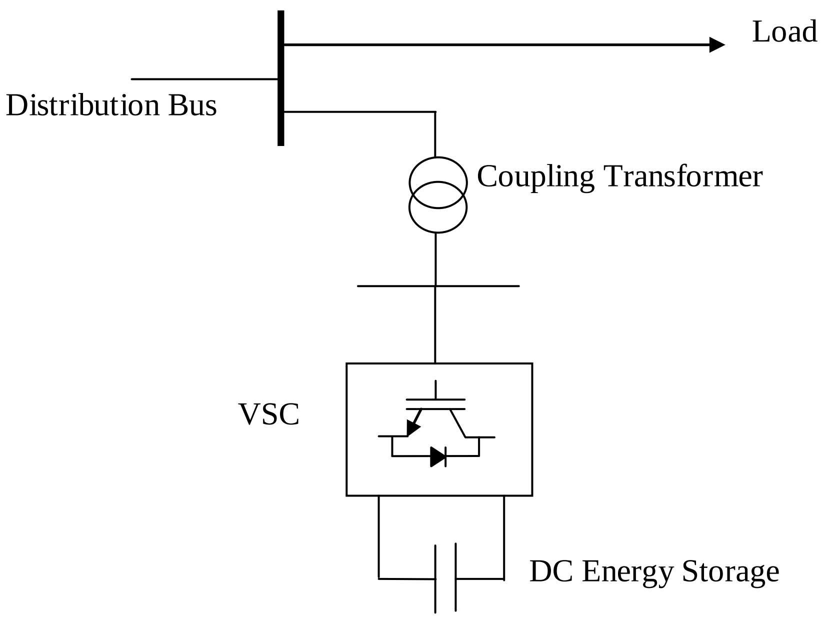

Fig 1.2 Basic Configuration of DSTATCOM

The VSC connected in shunt with the ac system provides a multiple benefits such as:

1) Voltage regulation and compensation of reactive power

2) Correction of power factor

3) Elimination of current harmonics

2. Dynamic Voltage Restorer

The DVR [3] is a powerful controller that is commonly used for voltage sags mitigation at the point of connection. The DVR has the same construction as the DSTATCOM, but in this application the coupling transformer is connected in series with the ac system, as illustrated in Fig.1.3. The main functions of DVR are:

(a) Reactive Power Compensation

(b) Voltage Regulation

(c) Compensation for Voltage sags and Swells

(d) Unbalance Voltage Compensation (for 3-phase systems)

The VSC generates a set of three phase ac output voltages which are controllable in phase and magnitude. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference.

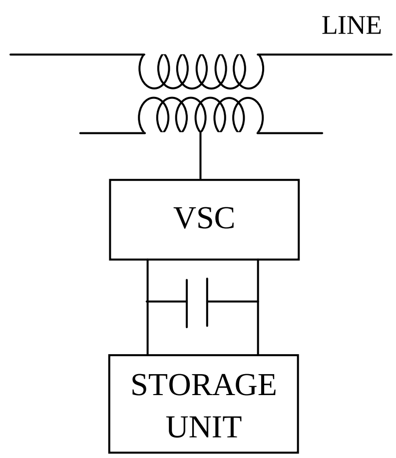

Fig 1.3 Basic Configuration of DVR

3 .Unified Power Quality Conditioners

Unified power quality conditioners (UPQC) allow the mitigation of voltage and current disturbances that could affect sensitive electrical loads while compensating the load reactive power. Unified power quality conditioners UPQC consist of combined series and shunt connected custom power devices for simultaneous compensation of voltage and current disturbances and reactive power.

The function of UPQC includes:

(a) Reactive Power Compensation

(b) Voltage Regulation

(c) Compensation for Voltage sags and swells

(d) Unbalance Compensation for current and voltage (for 3-phase systems)

(e) Neutral Current Compensation (for 3-phase 4-wire systems)

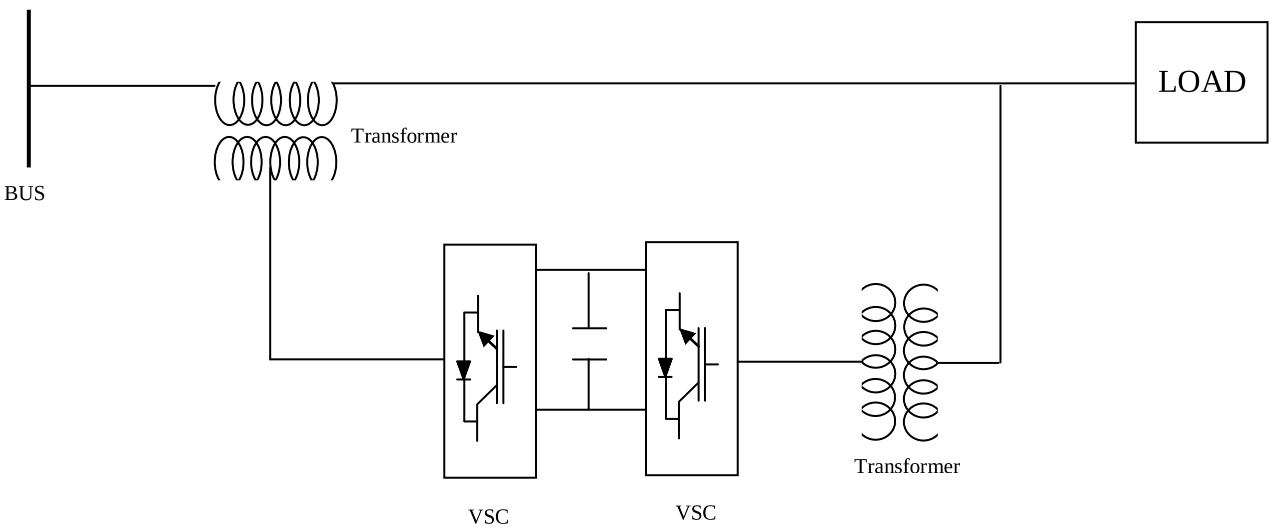

Fig 1.4 Basic Configuration of UPQC