CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

In this section, the survey of literatures that are reported by various researchers are discussed. The literature survey is made on the three types of compensators namely, Shunt Active Filter, Series Active Filter and Unified Power Quality Conditioner.

Ideally, all power utilities should provide their customers with a quality supply which has constant magnitude and frequency of sinusoidal voltage. Unfortunately it is a hard task to maintain this quality supply for constant magnitude and frequency of sinusoidal voltage. Poor power quality may result either from transient conditions developing in the power circuit or from the installation of non-linear loads.

Due to the increasing use of loads sensitive to power quality, e.g. communications and medical equipment, variable speed drives, rectifiers, Uninterruptible Power Supplies(UPS), Personal computers (PC), Television (TV) sets etc, the issue of power quality has gained renewed interest over the last two decades. Nowadays, power quality is an even more complex problem than in the past because the new loads are not only sensitive to power quality but also responsible for affecting adversely the quality of power supply.
Although transmission power systems may have an impact on the quality of power, most power quality problems occur in distribution systems. The power quality becomes significantly worse at the points where the loads are connected to the distribution grid. A single customer may cause significant reductions in power quality for many other customers. The presence of harmonics and reactive power in the grid is harmful, because it will cause additional power losses and malfunctions of the grid components.

Some types of the power quality problems are voltage sag/swell, interruption, voltage fluctuation, voltage unbalance, current harmonic, current unbalance and current unbalance. Among them, voltage sags/swells and current harmonics are the most common power quality problems. Some PQ reports indicate that poor PQ can cause large financial losses to different types of industries. The limits of PQ problems are generally set by IEEE and IEC standards. Custom Power is a concept based on the use of power electronic controllers in the distribution system to supply value-added, reliable and high quality power to its customers by eliminating PQ problems.

2.2 LITERATURE SURVEY OF SHUNT ACTIVE FILTER

Power electronics based devices/equipments are a major key component of today’s modern power processing, at the transmission as well as the distribution level because of the numerous advantages offered by them. These devices, equipments, nonlinear load including saturated transformers, arc furnaces and semiconductor switches and so on, draw non-sinusoidal currents from the utility. Therefore a typical power distribution system has to deal with harmonics and reactive power support (Khadkikar et al 2009).

When a Static Synchronous Compensator is employed at the distribution level or at the load end for power factor improvement, active harmonic filtering, dynamic load balancing, flicker mitigation and voltage
regulation alone it is called as DSTATCOM (Distributed Static Compensator). DSTATCOM is a fast-compensating reactive power source that’s applied on the transmission or distribution system to reduce voltage variations such as sags, surges and flicker, along with instability caused by rapidly varying reactive power demand. DSTATCOM can also help provide quick recovery for the transmission system after contingency events such as loss of part of the system or individual equipment. DSTATCOM is well suited to Integration of renewable energy sources, such as wind, concentrated solar and tidal power generation. It allows these renewable energy sources to meet utility interconnection requirements, as well as the power factor, voltage output and low voltage ride-through requirements of various worldwide grid codes. When it is used to do harmonic filtering and reactive power compensation, it is called as Active Power Filter (Bhuvaneshwari et al 2008).

Passive filters are used to provide a low impedance path for current harmonics so that they flow in the filter and not the supply. Passive filters are suited only to particular harmonics, the isolating transformer being useful only for triple-N harmonics and passive filters only for their designed harmonic frequency. In some installations the harmonic content is less predictable. (Fujtha et al 1998).

Power Factor Correction (PFC) techniques include both passive and active solutions for eliminating harmonic distortion and improving power factor. The passive approach uses inductors, transformers, capacitors and other passive components to reduce harmonics and phase shift. The passive approach is heavier and less compact than the active approach, which is finding greater favor due to new technical developments in circuitry, superior performance and reduced component costs. Specially corrected transformers are effective only for certain harmonic frequencies and most passive filters,
once installed and tuned, are difficult to upgrade and may generate harmful system resonance. As for active PFC techniques, they must be applied to each individual power supply or load in the system, which complicates architecture and results in high system cost (Singh et al 1999).

APF supplies only the harmonic and reactive power required to cancel the reactive currents generated by nonlinear loads. In this case, only a small portion of the energy is processed, resulting in greater overall energy efficiency and increased power processing capability (Fujtha et al 1998).

APF utilizes harmonic or current injection to achieve PFC. APF determines the harmonic distortion on the line and injects specific currents to cancel the reactive loads. This technique has been used for years in high power, three phase systems, but high costs and complicated high speed circuitry made it impractical for low level power systems. However, new techniques that utilize simpler circuitry are making active power filtering more attractive and advantageous for low power, single phase systems. APF is connected in parallel to the front end or AC input of the system and corrects all loads directly from the AC line. This type of APF provides excellent harmonic filtering that complies with international harmonic regulations.

The basic representation of DSTATCOM is shown in Figure 2.1. APF system can be divided into two sections as: The control unit and the power circuit. Control unit consists of reference signal generation, gate signal generation, and capacitor voltage balance control and voltage/current measurement.
Figure 2.1. Basic representation of DSTATCOM

Power circuit of APF is generally comprised of energy storage unit, DC/AC converter, harmonic filter and system protection. Active power filters are generally designed to compensate current harmonic, reactive power, voltage harmonic and to balance the supply current and supply voltage. Control strategy is based on the overall system control, extraction of reference signal and capacitor voltage balance control.

The converter types of APF can be either Current Source Inverter or Voltage Source Inverter (VSI) bridge structure. VSI structures with Insulated Gate Bipolar Transistor (IGBTs) or Gate Turn Off Thyristor (GTO) have become more dominant, since it is lighter, cheaper and expandable to multilevel and multi step versions, to enhance the performance with lower switching frequencies. IGBTs are generally used up to 1 MVA rating, GTO thyristors are generally used higher than 1 MVA rating (Aredes et al 1998).

The presence of harmonics and reactive power in the grid is harmful, because it will cause additional power losses and malfunctions of the grid components. Conventionally, passive filters composed of tuned L-C components have been widely used to suppress harmonics because of their low initial cost and high efficiency. However, passive filters have many
disadvantages, such as large size, mistuning, instability and resonance with load and utility impedances (Aredes et al 1998).

Active Power Filters have now become an alternative solution for controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power and/or voltage control at high voltage distribution level (Afonso et al 2000). APF such as shunt APFs, series APFs, hybrid APFs, UPQC and other combinations have made it possible to mitigate some of the major power quality problems (Khadkikar et al 2009).

Control strategy in the frequency domain is based on the Fourier analysis of the distorted voltage or current signals to extract compensating current/voltage reference (Akagi et al 1984). Frequency domain approaches are suitable for both single and three-phase systems. The frequency domain algorithms are sine multiplication technique, conventional Fourier and Fast Fourier Transform (FFT) algorithms and modified Fourier series techniques (Das et al 2004).

Control methods of APF’s in the time domain are based on instantaneous derivation of compensating commands in the form of either voltage or current signals from distorted and harmonic polluted voltage or current signals (Chen et al 2004).

Time domain approaches are mainly used for three-phase systems. The time domain algorithms are dq method, synchronous flux detection algorithm, fictitious power compensation algorithm, constant active power algorithm, constant power factor algorithm, Instantaneous active and reactive Power theory (Agaki et al 1984) and neural network (George et al 2007). A component that has a frequency between the two frequencies is called an interharmonic. A method for real-time detection and extraction of
interharmonic components in a power signal with potentially time-varying characteristics (Fujitha et al 1998).

Classification according to current/voltage reference estimation techniques can be made as time domain control and frequency domain control that are processed by the open loop or closed loop control techniques. Active Power Filters have now become an alternative solution for controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power and voltage control at high voltage distribution level.

APFs are used in low power (<100 kVA), medium power (100 kVA-10 MVA) and high power (>10 MVA) applications. For low power applications, APFs can be applied for single-phase and three-phase systems. For single-phase systems, APFs generally mitigate the current harmonics. For three phase systems, APFs generally provide acceptable solution for unbalanced load currents and mitigate the current harmonics. For medium and high power applications, the main aim is to eliminate or reduce the current harmonics (Ghosh et al 2002).

Because of economic considerations, reactive power compensation using active filters at the high voltage distribution level is not generally regarded as viable. For high power applications, the harmonic pollution in high-power ranges is not such a major problem as in lower-power systems. One of the few applications of active filters in high power systems is the installation of parallel combination of several active filters because the control and co-ordination requirements of these filters are complicated (Karimi et al 2003).

Power circuit configuration of APFs can be parallel active filter, series active filter and combination of series and parallel filters. The purpose of parallel active filters is to cancel the load current harmonics fed to the supply. It can also perform the reactive power compensation and balancing of
three-phase currents. The series active filter produces a PWM voltage waveform which is added or subtracted from the supply voltage to maintain a purely sinusoidal voltage waveform across the load. However, series active filters are less common industrially than their rivals, parallel active filters (Ghosh et al 2002).

Combinations of several types of filter can achieve greater benefits for some applications. The examined combinations are combination of both parallel and series active filters, combination of series active and parallel passive filters, combination of parallel active and passive filters and active filter in series with parallel passive filters. Seven-level APF configuration is also examined in (Jindal et al2005).

Multilevel three-leg center-split VSIs are more preferable in medium and large capacity applications due to lower initial cost and fewer switching devices that need to be controlled. The series stacked multilevel converter topology, which allows standard three phase inverters to be connected with their DC busses in series (Gunther et al 1995). This converter has both regenerated energy generation and active power filtering capabilities. An inductance for output filtering of VSI is used to eliminate the harmonic at different frequencies. The different combinations of L and C filters to attenuate the switching ripple currents (Zhilli et al 2010).

A rectifier employing phase control with extra low inductance characteristic or load which high frequency input current, may affect APF and causing it to malfunction or shutdown. While APF is being applied to this type of load, a reactor (3% to 5%) is recommended to install at the input side of the load to reduce the rising rate of load input current. LC passive filter is used for harmonic elimination and reactive power compensation. LCL filter is used in (Rong et al2009) that gives advantages in costs and dynamic
performance since smaller inductors can be used compared to L-filter in order to achieve the necessary damping of the switching harmonics.

APFs are basically categorized into four types, namely, single phase two-wire, three-phase three wire, three-phase three-wire with Zig-Zag transformer and three-phase four wire configurations to meet the requirements of the three types of nonlinear loads on supply systems. (Fujita et al 1998).

The power circuit of APF generally consists of DC energy storage unit, DC/AC converter and passive filter. DC capacitor serves two main purposes: (1) it maintains a DC voltage with a small ripple in steady state and (2) it serves as an energy storage element to supply the real power difference between load and supply during the transient period (Jayanthi et al., 2009).

DC link voltage can be controlled using proportional-integral (PI) controller, proportional-integral-derivative controller(PID) and fuzzy logic controller(FLC). DC link is fed from separate voltage supply to stabilize DC-side voltage within a certain range (Singh et al 2009). Switched capacitor APF that brings new dimension to APF as it reduces components and ratings while performing at low switching frequency is evaluated. DC link, instead of a capacitor, is used as a battery pack, which is charged from a photovoltaic array.(Razaeipour et al 2009).

The switching signals for the solid state devices of APF are generated using PWM, space vector modulation, fuzzy logic based control techniques, sliding-mode controller, hysteresis controller and multiresonant controller or dead beat controller (Fujita et al 2009).

The basic of the hysteresis current control is based on an error signal between an injection current ($I_{inj}$) and a reference current of APF ($I_{ref}$) which produces proper control signals. The hysteresis band current controller
decides the switching pattern of APF. The conventional hysteresis band current control scheme used for the control of APF is shown in Figure 2.2. There are bands above and under the reference current. When the error reaches to the upper limit, the current is forced to decrease. When the error reaches to the lower limit, the current is forced to increase.

![Figure 2.2 Voltage and current waveforms of hysteresis band controller](image)

The switching logic is formulated as follows:

- If $I_{inj} < (I_{ref} - hb)$ upper switch is OFF and lower switch is ON.
- If $I_{inj} > (I_{ref} + hb)$ upper switch is ON and lower switch is OFF as shown in Figure 2.2.
Some significant advantages of hysteresis controllers over other types of controllers designed with linear or nonlinear control techniques for APF applications are as follows,

- Switching behavior of the power inverter can be directly taken into account at the design level,
- Robustness to load parameters variation can be proved. Almost static response is achieved (the dynamics are obviously bounded by the DC-link voltage and by the actual switching frequency),
- Simple hardware implementation, based on logical devices, is possible according to Boolean nature of controller input/output variables.

2.3 LITERATURE SURVEY OF SERIES ACTIVE FILTER

Tap changing transformer is takes care of a limited range of voltage sag. The disadvantages of tap-changing transformer are slow in response, exhibits contact erosion, needs routine maintenance of its parts, has an uneconomical size and requires frequent replacement of transformer oil (Singh et al 1999). Compared to the other devices, DVR (Dynamic Voltage Restorer) is clearly considered to be one of the best economic solutions for its size and capabilities.

DVR also known as Static Series Compensator is a series-connected custom power device which is to protect sensitive loads from supply side disturbances. Also, the DVR can act as a series active filter, isolating the source from harmonics generated by loads.
The DVR consists of a voltage-source PWM converter equipped with a dc capacitor and connected in series with the utility supply voltage through a low pass filter (LPF) and a coupling transformer. This device injects a set of controllable three-phase ac voltages in series and synchronism with the distribution feeder voltages such that the load-side voltage is restored to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. Also it is used to compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the point of common coupling (Zhilli et al 2006).

During standby operation, DVR neither absorbs nor delivers real power. However, when voltage sag/swell occurs in the system, DVR delivers/absorbs real power transiently to/from DC link. Many loads facilitated in industrial plants such as adjustable speed drives and process control equipments are able to detect voltage faults as minimal as a few milliseconds. Due to the sensitivity of the loads, DVR is required to response in a very high speed (Chen et al 2004). Basic representation of DVR is shown in Figure 2.3.

![Figure 2.3 Basic representation of DVR](image)
The inverter circuits convert DC power to AC power. The types of inverter are voltage source inverter (VSI) and current source inverter (CSI). Current source inverter is easy to limit over current conditions but the value of output voltage varies widely with changes in load. In the voltage source inverter, the values of output voltage variations are relatively low due to capacitor but it is difficult to limit current because of capacitor. Some types of this inverter are Cyclo converter based inverter, 6-bridge inverter, H bridge inverter and Multilevel inverter. VSIs have its drawbacks, such as a rather slow control of converters (LC filter) output voltage and current protection problems, DC bus voltage oscillations can be observed.(Zhilli et al 2010).

DVR is almost always in standby mode and conduction losses will account for the bulk of converter losses during the operation. The voltage rating of the transformer depends on the grid voltage level and the depth of voltage sag which will be compensated. The rated current multiplied by the injection voltage level gives the VA rating of each phase. The filter unit eliminates the dominant harmonics produced by inverter circuit. Filter unit consists of inductor (L) and capacitor (C). (Bhim Singh et al 1999).

The effect of harmonics generated by the inverter can be minimized using the inverter side or line side filtering. Inverter side filtering scheme has the advantage of being closer to the harmonic source thus high order current harmonics are prevented to penetrate into the series injection transformer but this scheme has the disadvantages of causing voltage drop and phase angle shift in the fundamental component of the inverter output. In line side filtering scheme, current harmonics penetrate into the series injection transformer but the voltage drops and phase shift problems do not disturb the system (Basu et al 2008).

The protection of a DVR against voltage surges and short circuit conditions to prevent its malfunction or destruction is discussed in (Peng et al
The use of the transformer is eliminated applying the voltage boosting functions and a dynamic energy replenishing charging circuit. DVR is implemented using a multilevel inverter topology allowing the direct connection of DVR to the distribution network without using a bulky and costly injection transformer (Axente et al. 2010).

DVR is most of time in standby mode and conduction losses will account for the bulk of converter losses during the operation. Its main tasks are connecting DVR to the distribution network via the high voltage windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage (Ghosh et al. 2008).

In standby mode, the injection transformer works like a secondary shorted current transformer using bypass switches delivering utility power directly to the load. Alternatively, during standby operation of DVR, two upper IGBTs in each phase of the inverter remain turned off while the two lower IGBTs remain turned on. A short circuit across the secondary (inverter side) windings of the series transformer through L filter is obtained eliminating the use of bypass switches (Han et al. 2006).

Voltage reference generation is achieved using dq method, instantaneous active and reactive Power theory, artificial neural network, sliding mode, fuzzy logic and software Phase Locked Loop. Most of DVR controllers are using open-loop feed forward control in order to meet the fast compensation requirement. However, the presence of the switching harmonic LC filter would introduce voltage oscillations in transients. These oscillations increase damping response time of the system (Ghosh et al. 2004).

Different topologies for DVR are transformerless, multilevel, four-leg DVR, H bridge and interline. Power circuit of DVR generally
consists of DC link, DC/AC converter, LC filter and injection transformer. DVR can be used for low voltage, medium voltage and high voltage applications. DVR is generally designed as single phase, three phase three wire and three phase four wire.

DC link (energy storage unit) supplies required power for compensation of load voltage during voltage sag/swell or harmonics. For most DVR applications, the energy source can be an electrolytic capacitor bank. The selection of the optimum topology and DVR ratings is related with the distribution of the remaining voltage, the outage cost and investment cost. The topology of storage systems with auxiliary supply is applied to increase the performance when the grid of DVR is weak. In the topology of storage systems with grid itself, the remaining voltage on supply side or load side is used to supply necessary power to the system if DVR is connected to the strong grid (Ghosh et al 2004).

When the DC link is fed from the rectifier, the rectifier can be controlled using hysteresis or PI controllers. The saturation of the series injection transformer and the voltage drop across the inductor in steady state operation are other factors that affect the performance of DVR in open loop control. The load voltage may not be compensated to the desired value in open loop feed forward control. The problems stated above shows that closed loop control can reduce the damping oscillations coursed by the switching harmonic LC filter and the load voltage can track closer to the reference load voltage under varying load condition. Multi loop control and closed loop state variable control are closed loop control strategies of DVR. The performance of these control strategies are investigated with its dynamic and damping performance. These control schemes can reduce the damping oscillations, but cannot catch up with the fast dynamic response. (Ghosh et al 2001).
The generated reference signal is used to produce gate switching signals of the inverter. The main modulation techniques used in DVR are space vector PWM modulation, dead beat control, PWM control and hysteresis control.

The hysteresis control has the advantages of quick controllability, easy implementation and variable switching frequency. PWM control has a great impact on its transient performance and higher operating frequency capability. PWM method is widely used for gate signal generation in custom power applications. The deadbeat controller has very fast transient response. (Ghosh et al 2004).

The space vector PWM technique can generate output voltages and currents with less harmonic Distortion. In phase advance method, decreasing the power angle between the remaining voltage and the load current minimizes real power consumed by DVR. In pre-sag compensation, the supply voltage is continuously tracked and the load voltage is compensated. On the other hand, in phase compensation, DVR voltage is always in phase with the measured supply voltage regardless of the load current and presag voltage.

In voltage tolerance with minimum energy injection method, the phase angle and magnitude of corrected load voltage within the area of load voltage tolerance are changed. The small voltage drop and phase angle jump on load can be tolerated by load itself and the size of the energy storage is minimized.(Rezaeipour et al 2008).
2.4 LITERATURE SURVEY OF UNIFIED POWER QUALITY CONDITIONER

The unified power quality conditioner is a power electronics based compensator which works on the principle of active filtering. The UPQC is a custom power device that integrates the series and shunt active filters, connected back-to-back on the dc side and sharing a common DC capacitor as shown in Figure 2.4. It 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 feeder and the other is connected in parallel to the same feeder. Each compensator of the UPQC consists of an IGBT based full bridge inverter, which may be operated in a voltage or a current controlled mode depending on the control scheme. Series Compensator is connected in series with the supply voltage through a low pass LC filter and a transformer.

Shunt Compensator is connected in parallel to the load through a smoothing link inductor. Series Compensator operates as a controlled voltage source and compensates for any voltage disturbance in the network. Shunt Compensator operates as a controlled current source and compensates for reactive or harmonic elements in the load. It also acts as a real power path and maintains the DC link voltage at a constant value by charging the DC link capacitor continuously.
The main advantage of UPQC is that it does not require any energy storage. It can be designed to mitigate any sag above a certain magnitude, independent of its duration. This could result in a device that is able to compete with the uninterruptible power supply (UPS) typically used for the protection of low-power and low-voltage equipment. UPQC is much more flexible than separately configured DSTATCOM. (Kolhatkar et al 2007).

UPQC is also known as the universal power quality conditioning system, universal active power line conditioner and universal active filter. UPQC is a combination of a shunt (Active Power Filter) and a series compensator (Dynamic Voltage Restorer) connected together via a common DC link capacitor, which facilitates the sharing of the active power (Aredes et al 1998). A wide diversity of solutions to power quality problems is available for both the distribution network operator and the end user. The power processing at supply, load and for reactive and harmonic compensation by means of power electronic devices is becoming more prevalent due to the vast advantages offered by them. (Singh et al 1999).
Various topologies of UPQC are multilevel topology, single-phase UPQC with two half-bridge converters, single-phase UPQC with three legs, H bridge topology (Ghosh et al 2004) and UPQC is connected between two independent feeders to regulate the bus voltage of one of the feeders while regulating the voltage across a sensitive load in the other. A new configuration, named multiconverter unified power quality conditioner (MC-UPQC), for simultaneous compensation of voltage and current in adjacent feeders (Khadkikar et al 2012).

To generate reference signals for shunt converter, Instantaneous reactive power theory is generally preferred for reference current calculation (Fujita et al 1998). An extended method based on Instantaneous reactive power theory in a rotating reference frame is used to suppress the harmonics and to correct the power factor. Adaptive detection technique is evaluated in (Karimi et al 2003) that minimizes the affects of noise or parameter variations.

To generate reference signals for series converter, fuzzy control (Singh et al 1999), finite impulse response filter (Chen et al 2004), using band pass filter and positive sequence calculation, dq transform, using peak detector and averaging method, vector template generation method (Khadkikar et al 2011), sinusoidal template vector algorithm, PI controller method (Basu et al 2008), adaptive detection (Rong et al 2009), are used.

Least squares algorithm, wavelet transform (Forghani et al 2007), neural network, positive sequence component method, linear quadratic regulator, unit vector template generation method, multi variable regulator based with kalman filters, artificial intelligence method (George et al 2007), pole shift control (Jindal et al 2005) and abc-dq transform method (Lee et al 2010) are employed to generate reference signals for both series and shunt converter simultaneously.
To generate gating signals for only shunt converter, predictive current regulation current controller and hysteresis controller (Basu et al 2008) are employed. Sinusoidal PWM (Basu et al 2008) and hysteresis controller (Khadkikar et al 2004) methods are employed to generate gating signals for only series converter. Space vector PWM, fuzzy hysteresis control and SPWM strategy are preferred for both series and shunt side inverter signal generation (Lee et al 2010).

The overall power balance of UPQC is maintained through DC-link capacitor (Jayanti et al 2009). DC voltage control can be fulfilled by the traditional DC voltage feedback or PI control (Basu et al 2008) and composite control (Salam et al 2006).

Depending upon the location of the shunt compensator with respect to series compensator, UPQC model can be named as right shunt-UPQC or left shunt-UPQC. Typically the active power generated in one unit is consumed in the other unit maintaining the energy balance overall characteristics of the right shunt-UPQC are superior to those of the left shunt-UPQC (Ghosh et al 2002).

The protection of a UPQC against voltage surges and short circuit conditions to prevent its malfunction or destruction is discussed in (Zhili et al 2010). The power circuit of UPQC generally consists of common energy storage unit, DC/AC converter, LC filter and injection transformer. The effect of harmonics generated by the inverter can be minimized using inverter side and line side filtering. Inverter side LC filtering is generally preferred for both series sides (Basu et al 2008) and inverter side L filtering is generally preferred for shunt side (Axente et al 2010).

UPQC can be used for medium voltage and low voltage applications. In case of low power applications, it is not convenient to install a
UPQC, since DVR spends most of its time in standby mode. UPQC is generally designed as 3-phase 3-wire (3P3W) systems. 3-phase 4-wire (3P4W) system is also realized from (3P3W) system where the neutral of series transformer used in series part UPQC is considered as the fourth wire for 3P4W system (Khadkikar et al 2009).

UPQC is a Custom Power device and consists of combined series active power filter that compensates voltage harmonics, voltage unbalance, voltage flicker, voltage sag/swell and shunt active power filter that compensates current harmonics, current unbalance and reactive current (Khadkikar et al 2011).

Series converter of UPQC is most of time in standby mode and conduction losses will account for the bulk of converter losses during the operation. In this mode, the series injection transformer works like a secondary shorted current transformer using bypass switches delivering utility power directly to the load. UPQC without injection transformer has been designed (Basu et al 2002). A novel configuration of UPQC which can be connected to the distribution system without series injection transformers is presented in (Han et al 2006).

The shunt APF is usually connected across the loads to compensate for all current related problems such as the reactive power compensation, power factor improvement, current harmonic compensation and load unbalance compensation, whereas the series active power filter is connected in a series with a line through series transformer. It acts as controlled voltage supply and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc (Khadkikar et al 2008).
2.5 CONCLUSION

Widespread applications of power electronic based devices/equipments in industry have increased the importance and application of power quality studies. Custom Power (CP) devices including DVR, APF and UPQC are showing tremendous development. These devices have become very popular in recent years in both low voltage and medium voltage applications. The comprehensive reviews of articles concerning CP devices are presented to show the advantages and disadvantages of each possible configuration and control techniques. The literature survey reveals that new control algorithms and topologies for CP devices have been developed to minimize the power losses, increase the system flexibility and efficiency.