Chapter 1

Introduction

1.1 General

The capabilities and economy of power electronics system are determined by the active devices that are available. Their characteristics and limitations are a key element in the design of power electronics systems As technology grows everyday, the study of power systems has shifted its direction to power electronics to produce the most efficient energy conversion. Power electronics is the study of processing and controlling the flow of electric energy by supplying voltages and currents in a form that is suited for user loads . The goals of using power electronics are to obtain the benefit of lower cost, small power loss and high energy efficiency. Because of high energy efficiency, the removal of heat generated due to dissipated energy is lower. Other advantages of power electronics are reduction in size, weight, and overall cost. Like other technologies, power electronics has certain disadvantages. One major shortcoming is the generation of harmonic voltages and currents. To filter out harmonics, more components and complex system would be needed. Having harmonics produced by power electronics will result in upstream losses in windings and in transformers in the system.

The proliferation of power electronics based equipment in the power system has a profound impact on the quality of power supply world over. High power industrial loads, such as adjustable speed drives, uninterrupted power supply (UPS), thyristor converters etc., which are the prerequisites for realizing energy efficiency and productivity benefits and low power domestic loads such as television sets, fax machines, computers, domestic inverters, small power supplies, etc., draw strongly distorted currents resulting in non sinusoidal supply voltages across power system network. Further more, conventional loads such as large arc furnaces and single phase welding machines also contribute significantly to the fluctuation, unbalance and flicker in supply voltages. By looking towards the recent development in the different types of power electronics converters and their industrials applications, growth rate of industries, automation in the industry, its is expected that the use of equipment based on power electronics technology would further increase in future and the distortion problem in the supply become a more and more sevier.

The quality of electrical power in commercial and industrial installation is undeniably decreasing. With the increasing use of solid-state circuit equipment, harmonic distortion in supply systems becomes more frequent and severe due to non-linear characteristics of such circuits. The voltage or current distortions may cause unsafe and unreliable electrical power supplies, malfunction of equipment, overheating of conductors and can reduce the efficiency, and life of most connected loads. Therefore, harmonic distortion is an undesirable effect for electrical systems. Clean power refers to voltage and current waveforms that represent pure sine waves and are free of any distortion. Dirty power refers to voltage and current waveforms that are distorted and do not represent pure sine waves [1]. Alternating current power supply has always suffered from the effects of harmonics. In an electrical power system, there are various kinds of power quality problems / disturbances like voltage sag, voltage swell, interruption, under voltage, over voltage, transient, harmonics, inter-harmonics, voltage imbalance etc. Since the rapid development of the semiconductor industry, power electronics devices have gained popularity in our daily used electrical house-hold appliances. Although these power electronics devices have benefited the electrical and electronic industry, these devices are also the main source of power harmonics in the power system. These power harmonics are called electrical pollution which will degrade the quality of the power supply. As a result, filtering process for these harmonics is needed in order to improve the quality of the power supply [2].

Use of multi pulse converters has become a common practice in order to minimize the harmonics in applications with large non-linear loads where the harmonics must be kept under certain limits. The harmonics mitigation performance of multiple drive is far superior to the well-known 6- pulse drive even the cost is high. So the proper assessment of harmonics performance is necessary before put into the utility. 12-pulse converter is used for large DC drives in the industry. The converter is consists of two 6- pulse converters connected in series or in parallel. The supply current harmonics in the 12-pulse converter is when both the converter is working in equal firing angle. But normally the 12-pulse converter is connected to a transformer having a two 30-degree phase shifted secondary winding. Looking to the difference in leakage inductance of the transformer secondary and the source inductance, there is a possibility of presence of 5^{th} and 5^{th} harmonics in the supply. When the converter works in unequal firing angle mode, the supply current harmonics is in the order of $(6n \pm 1)$.

The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. Harmonic contamination has become a major concern for power system specialists due to its effects on sensitive loads and on the power distribution system. Harmonic current components

1. Increase power system losses,
2. Cause excessive heating in rotating machinery,
3. Can create significant interference with communication circuits that share common right-of-ways with AC power circuits,
4. And can generate noise on regulating and control circuits causing erroneous operation of such equipment.

Passive filter have already been considered a good alternative for a current harmonic compensation and displacement power factor correction. Shunt passive filter exhibits lower impedance at a tuned harmonic frequency than the source impedance to reduce the harmonic current flowing into the source. In principle, filtering characteristics of the shunt passive filter are determined by the impedance ratio of the source and the shunt passive filter. For an increasing number of applications, conventional equipment is proving insufficient mitigation of power quality problems. The level of harmonics distortion has traditionally been dealt with the bank of passive tuned filters. Their application for harmonic reduction has many limitations. Therefore, the active power filtering has been researched over past one decade and is being developed in order to overcome the limitations of passive filters. The application of active filter is capable to obviate most of the problems created by non-linear loads and further more these filters offer flexibility in control of reactive and harmonic power, with good dynamic performance. This thesis presents the operation of 12 pulse converter for constant active and reactive power operation. 12 pulse converter consists of two six pulse converter connected in series. To get constant active or constant reactive power operation, converter should be operated in equal and/or unequal firing angle mode. In this thesis operation of of converter for unequal mode and effect of source inductance on the region of operation has been analysed. Supply current harmonics have been investigated for equal and unequal firing angle mode. Active power and reactive power demanded by converter has been studied for different combination of firing angle and so, the combination of firing angle has been investigated to operate converter in constant active power and constant reactive power operation. This thesis also presents the analysis and control of Hybrid Series Active Filter and its potential use to alleviate power quality problems for the demand-side power systems. Hybrid Series Active Filter is a combination of a series type active filter and a shunt-type passive filter. It can be connected at the point of common coupling (PCC) between the utility distribution line and the customer loads and provides complete compensation and isolation for load reactive power, load harmonics, utility harmonics, utility disturbances and utility imbalance

1.2 Power quality problems

Power quality is a describing term which narrates the aspects of electric utility supply to customers at industrial and domestic load sites. A power quality problem is any anomaly occurring in voltage, current or frequency that results in failure, misoperation,and interruption of electrical equipment. A severe power quality problem may lead to shutdown of processes and services, causing economical losses to utility consumers. The recent technical publications manifest that the power quality problem is a major issue in electric utilities and its large industrial or commercial clients. The major development for this growing concern on power quality problems can be
1. Microelectronics and VLSI technology have produced modern chips with faster and complex components. These modern chips are designed to operate in low power levels and require a stable power supply for proper operation. However, the lower voltage levels of the power are easier to be disturbed

2. Power electronics has produced various low-cost supplies aod high capacity devices and their applications are ever expanding. Many of these power electronic devices are also responsible for injecting harmonic currents and switching transients which deteriorate the power quality.
3. Modern electrical devices are designed for high efficiency and their design and components are kept to their limits. This makes the electrical equipment succumb to any small power quality variations.
4. With these contemporary changes in progress, more capacitor banks are installed by electric utilities and industries for power factor correction and loss reductions. These capacitor alter the characteristics of the power system and can improve or worsen the power quality.
5. The increase in the power demand owing to the growth in the load is not equally met by an increase in power generation. Consequently, the number of disturbances in the power system has gone up.. With the proliferation of electrical loads, and the power-quality-induced downtime for industrial process and the associated cost, the quality and the reliability of power supplied to utility customers are now increasing concems. The deregulation of electric utility and the choice for the consumers to choose and pick the suppliers to buy power above certain level of quality have also an impact on this issue.

1.3 Power Quality Problem Identification

Although the power produced by electric utilities may be of a good quality, the Distribution environment is always disturbed and the power offered at the customer end may not be of rich in quality. The kind of electric activities that contribute to the anomaly in the power quality and its reliability are identified below, in association with (1) the voltage supplied by the electric utility and (2) the current drawn by the consumers. These electrical disturbances and their source can be summarised as follows :
1 The diode or thyristor rectifier and cyclo-converter loads generate harmonic currents, and the Total Harmonic Distortion(THD) levels in the line current drawn by these loads are normally more than 40%. The high frequency harmonic currents can cause electromagnetic interference with the communication networks and the maloperation of microprocessors and relays.
2 The large induction motors used in the steel rnills and hoists draw reactive current.

Due to this, the RMS value of the line current and the power is increase. The reactive current also causes the reduction in supply voltage.

3 Domestic consumer loads normally represent single-phase loads and present an unbalanced loading to the power system. The unbalanced loading causes the circulation of negative and zero sequence currents in the networks.

4 Voltage unbalance [4] describes a state in which the three phase voltages are not equal either in magnitude, or in the phase difference (120^0). The unbalance condition is harmful for the motors and other devices that depend upon a balanced supply voltage.

5 The starting of induction motors used in hoists/industrial loads momentarily draws a large amount of reactive current, which produces voltage flicker and fluctuations. The voltage flicker is also caused by the sub-harmonic currents drawn by arc-furnaces. The voltage fluctuations are harmful for the sensitive digital and electronic loads.

6 Harmonics are introduced in the system voltage due to the load harmonic currents flowing into the network. Because of the presence of the voltage harmonics, a resonance network is formed along the installed LC filters with the line inductance, which again increases the voltage distortion levels.

7 Voltage sags are short voltage depressions caused by fault currents and may also appear during the starting of large motors. An industrial survey on voltage sags reports that voltage sag up to 30 %, ranging from 0.6 cycles to 150 cycles exists during sag conditions. These voltage sag related problems are one of the main issues in the power quality problems, because of the process interruptions caused by the voltage sags. Although the frequency of the voltage sags in a year may be less than 20 times (from the survey), the disturbance causes the loss of millions of dollars for industries.

8. Voltage swells normally accompany voltage sags. They are also introduced during the light loading conditions. The voltage swells seriously undermine the insulation levels in electric equipment.

9. Voltage impulsive or oscillatory transients are caused by lightning or load/capacitor switching. The notching (voltage waveform may cross zero potential line more than twice in a cycle) are introduced during the transients, are troublesome for the electronic circuits based on zero-crossing detection.

1.4 Power Quality

There can be completely different definitions for power quality, depending on ones frame of reference. For example, a utility may define power quality as reliability and show statistics demonstrating that its system is 99.98 percent reliable. Criteria established by regulatory agencies are usually in this vein. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly. These characteristics can be very different for different criteria. Power quality is ultimately a consumer-driven issue, and the end users point of reference takes precedence. Therefore, the following definition of a power quality problem is
Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment.

There are many misunderstandings regarding the causes of power quality problems. The charts in Figure 1.1 show the results of one survey conducted by the Georgia Power Company in which both utility personnel and customers were polled about what causes power quality problems. While surveys of other market sectors might indicate different splits between the categories, these charts clearly illustrate one common theme that arises repeatedly in such surveys: The utilitys and customers perspectives are often much different. While both tend to blame about two-thirds of the events on natural phenomena (e.g., lightning), customers, much more frequently than utility personnel, think that the utility is at fault. When there is a power problem with a piece of equipment, end users may be quick to complain to the utility of an outage or glitch that has caused the problem. However, the utility records may indicate no abnormal events on the feed to the customer. We recently investigated a case where the end-use equipment was knocked off line 30 times in 9 months, but there were only five operations on the utility substation breaker. It must be realized that there are many events resulting in end-user problems that never show up in the utility statistics. One example is capacitor switching, which is quite common and normal on the utility system, but can cause transient over voltages that disrupt manufacturing machinery. Another example is a momentary fault elsewhere in the system that causes the voltage to sag briefly at the location of the customer in question. This might cause an adjustable-speed drive or a distributed generator to trip off, but the utility will have no indication that anything was amiss on the feeder unless it

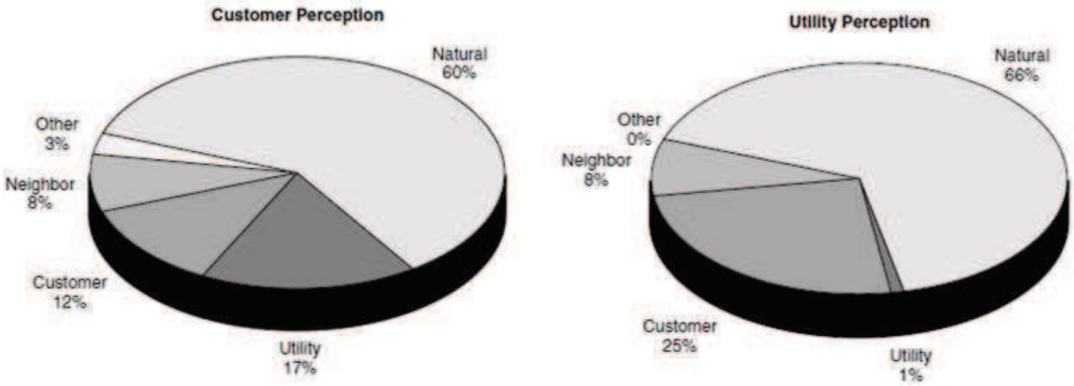

Figure 1.1: Results of a survey on the causes of power quality problems. (Courtesy of Georgia Power Co.)

has a power quality monitor installed. In addition to real power quality problems, there are also perceived power quality problems that may actually be related to hardware, software, or control system malfunctions. Electronic components can degrade over time due to repeated transient voltages and eventually fail due to a relatively low magnitude event. Thus, it is sometimes difficult to associate a failure with a specific cause. It is becoming more common that designers of control software for microprocessor-based equipment have an incomplete knowledge of how power systems operate and do not anticipate all types of malfunction events. Thus, a device can misbehave because of a deficiency in the embedded software. This is particularly common with early versions of new computer-controlled load equipment. One of the main objectives of this book is to educate utilities, end users, and equipment suppliers alike to reduce the frequency of malfunctions caused by software deficiencies. In response to this growing concern for power quality, electric utilities have programs that help them respond to customer concerns. The philosophy of these programs ranges from reactive, where the utility responds to customer complaints, to proactive, where the utility is involved in educating the customer and promoting services that can help develop solutions to power quality problems. The regulatory issues facing utilities may play an important role in how their programs are structured. Since power quality problems often involve interactions between the supply system and the customer facility and equipment, regulators should make sure that distribution companies have incentives to work with customers and help customers solve these problems.

The economics involved in solving a power quality problem must also be included in the analysis. It is not always economical to eliminate power quality variations on the supply side. In many cases, the optimal solution to a problem may involve making a particular piece of sensitive equipment less sensitive to power quality variations. The level of power quality required is that level which will result in proper operation of the equipment at a particular facility.

Power quality, like quality in other goods and services, is difficult to quantify. There is no single accepted definition of quality power. There are standards for voltage and other technical criteria that may be measured, but the ultimate measure of power quality is determined by the performance and productivity of end-user equipment. If the electric power is inadequate for those needs, then the quality is lacking. Perhaps nothing has been more symbolic of a mismatch in the power delivery system and consumer technology than the blinking clock phenomenon. Clock designers created the blinking display of a digital clock to warn of possible incorrect time after loss of power and inadvertently created one of the first power quality monitors. It has made the home-owner aware that there are numerous minor disturbances occurring throughout the power delivery system that may have no ill effects other than to be detected by a clock. Many appliances now have a built-in clock, so the average household may have about a dozen clocks that must be reset when there is a brief interruption. Older-technology motor-driven clocks would simply lose a few seconds during minor disturbances and then promptly come back into synchronism.

Power Quality = Voltage Quality

The common term for describing the subject of this book is power quality; however, it is actually the quality of the voltage that is being addressed in most cases. Technically, in engineering terms, power is the rate of energy delivery and is proportional to the product of the voltage and current. It would be difficult to define the quality of this quantity in any meaningful manner. The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits. AC power systems are designed to operate at a sinusoidal voltage of a given frequency [typically 50 or 60 hertz (Hz)] and magnitude. Any significant deviation in the waveform magnitude, frequency, or purity is a potential power quality problem. Of course, there is always a close relationship between voltage and current in any practical power system. Although the generators may provide a near-perfect sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage. For example,

1. The current resulting from a short circuit causes the voltage to sag or disappear completely, as the case may be.
2. Currents from lightning strokes passing through the power system cause high-impulse voltages that frequently flash over insulation and lead to other phenomena, such as short circuits.
3. Distorted currents from harmonic-producing loads also distort the voltage as they pass through the system impedance. Thus a distorted voltage is presented to other end users. Therefore, while it is the voltage with which we are ultimately concerned, we must also address phenomena in the current to understand the basis of many power quality problems.

1.5 The Power Quality Evaluation Procedure

Power quality problems encompass a wide range of different phenomena. Each of these phenomena may have a variety of different causes and different solutions that can be used to improve the power quality and equipment performance. However, it is useful to look at the general steps that are associated with investigating many of these problems, especially if the steps can involve interaction between the utility supply system and the customer facility. Figure 1.2 gives some general steps that are often required in a power quality investigation, along with the major considerations that must be addressed at each step. The general procedure must also consider whether the evaluation involves an existing power quality problem or one that could result from a new design or from proposed changes to the system. Measurements will play an important role for almost any power quality concern. This is the primary method of characterizing the problem or the existing system that is being evaluated. When performing the measurements, it is important to record impacts of the power quality variations at the same time so that problems can be correlated with possible causes.

Solutions need to be evaluated using a system perspective, and both the economics and the technical limitations must be considered. Possible solutions are identified at all levels

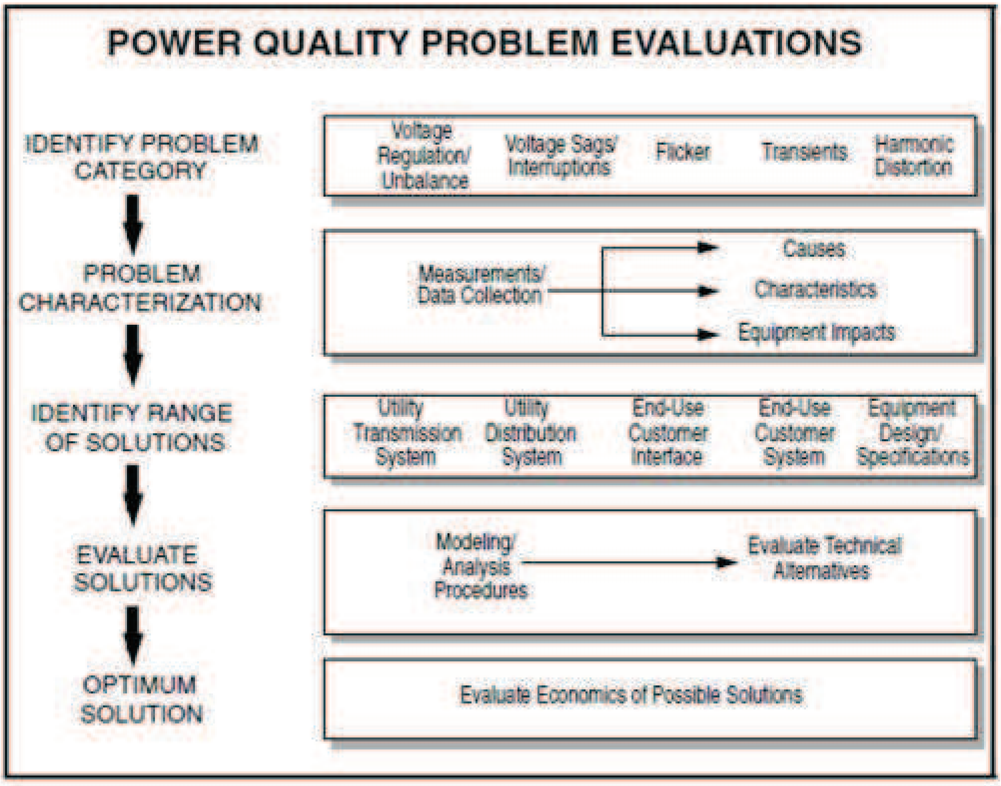

Figure 1.2: Basic steps involved in a power quality evaluation.

of the system from utility supply to the end-use equipment being affected. Solutions that are not technically viable get thrown out, and the rest of the alternatives are compared on an economic basis. The optimum solution will depend on the type of problem, the number of end users being impacted, and the possible solutions[93].

1.6 Harmonic Mitigation Techniques

There are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is made less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line-conditioning systems that suppress or counteract the power system disturbances. Among the different new technical options available to improve power quality, active power filters (line conditioning) have proved to be an important and flexible alternative to compensate for current and voltage disturbances in power distribution systems [3][4]. In order to maintain the quality and the reliability of the offered power, the disturbance and distortion in the supplied voltage and the line current must be eliminated or suppressed to tolerable Limits. This can be achieved by power electronics devices such as various compensator and active filters. The objectives of these devices can be defined as follows:

1. The voltage at the load end is regulated such that a balanced, constant, sinusoidal voltage is presented to the consumers, irrespective of the utility conditions. This implies that compensation or isolation is achieved for,

(a) voltage harmonics or waveform distortion,

(b) voltage swells, sags and imbalances,

(c) voltage fluctuations and flicker,

(d) voltage impulsive and oscillatory transients.

2. The load current is compensated such that a unity power factor load is presented to the electric utility, which implies a flow of only active power from the electric utility. This enhances the power transmission and the capacity of the existing system can be utilised to the maximum. The compensation or isolation is generally achieved for,

(a) reactive load currents,

(b) harmonics load currents,

(c) unbalanced loading.

Power electronics and micro-controller development have made possible to solve the many power system related problems. Over the last decade, the advent of fast switching devices with the Pulse Width Modulation (PWM) techniques has spurred remarkable development in this area. The advancement in DSP has dso made possible to utilize the modern control techniques for this area and various compensation techniques have been developed for selective applications to generalised ones. The existing compensation techniques are primarily classified into passive filters, VAR compensator, static compensator for transmission systems, active filters, and combined active filter systems. The passive filters are basic L-C tuned filters. On the other hand, the VAR compensator and active filters use power converters to achieve the filtering characteristics. The existing compensation techniques are discussed in the following sections.

1.6.1 Passive filters for Harmonic Compensation

Passive filters have been most commonly used to limit the flow of harmonic currents in distribution systems. They are usually custom designed for the application. However, their performance is limited to a few harmonics, and they can introduce resonance in the power system. They consist of capacitors, inductors, and damping resistors. Passive filters have some advantages such as simplicity, reliability, efficiency, and cost. However, passive filters have many disadvantages, such as

1. Resonance problem
2. Large size
3. Fixed compensation character
4. Possible overload
5. Poor dynamic behavior

1.6.2 VAR Compensator

The VAR compensator are primarily for the reactive power compensation, and they can be classified into (1) Static VAR compensator, and (2) Advanced static VAR compensator. (a) Static VAR Compensator (SVC): The use of thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC) is a well established practice in power system for reactive power compensation [10]. Static VAR compensator overcome the drawbacks faced by the shunt capacitors for reactive power compensation due to the resonance phenomena. When the SVC's are installed for power transmission applications, they increase the steady-state power transfer and the voltage profile along the transmission line. Despite their ability to provide variable VAR compensation, SVC's produce undesirable harmonic currents during the generation of the reactive current, for which LC filters need to be installed.

(b) Advanced Static VAR Compensator (ASVC): The advanced static VAR compensator are essentially solid-state synchronous voltage sources (SVS) [19] and are precursors to the active filters. The solid-state synchronous voltage sources are basic inverters driven to perform the hinction of static VAR compensator with the additional features for dynamic compensation and real-time control of power flow in transmission systems. The SVS, when operated as a shunt reactive power compensator, exhibits similar operating and performance characteristics of a rotating synchronous condenser and therefore it is aiso called Stutic Condenser or STATCON. The SVS has the significant advantage over the SVC's in providing fast dynamic reactive power compensation and control, and hence it finds the application in both the industrial and transmission system for reactive power compensation and voltage regulation.

1.6.3 Static Compensator for Transmission Systems

The application of switching converters is also well found for the transmission lines. The static compensator control the power transmission parameters such as voltage, impedance, and transmission angle. The existing static compensator are described as follows:
(a) Static Synchronous Series Compensation (SSSC): In the past, Thyristor- Contmlled Series Capacitors (TCSC) [20] were used for the compensation of transmission lines. In a nutshell, the effect of adding the series capacitor reduces the effective line impedance and it enhances the maximum transmittable power. However, the series capacitor causes the phenomenon of sub-synchronous resonance. A solid-state synchronous source by using PWM converters is made to accomplish the objective of a series capacitor [20]. The synchronous voltage source injects a voltage at the fundamental frequency which is locked in quadrature (lagging) with the line current.The amplitude of this injected voltage is

made in proportional to the line current and hence the series compensation is achieved to that provided by a series capacitor at the fundamental frequency. In addition, it is immune to the sub-synchronous resonance. The approach to the use of the synchronous voltage source also offers additional advantages. With the additional control dynamics equipped, the series source cm also be made to develop damping for the power systems oscillations and sub-synchronous resonance phenomenon due to any series capacitors that are connected in the system. In addition with the series compensation, the SSSC cm also compensate for the resistive voltage drop in the transmission line.

(b) Phase Shifters for Transmission Angle Control: Conventional thyristor controlled tap changing transformer provides the necessary phase shifting by the injection of quadrature voltage with the line to neutral system voltage. The phase shifting changes the effective transmission angle, which controls the real power tram. fer between the sending and the receiving ends. The use of a solid-state synchronous voltage source offers cornpleteiy different approach to the transmission angle control, because of its capability to exchange the real power with the AC system, and provides a comprehensive dynamic control of transmission system under transients.

(c) Unified Power Flow Controller: The concept of unified power flow controller was proposed for real-time control and dynamic compensation of AC transmission system and it is an important tool in the implementation of Flexible AC Transmission Systems(FACTS) [92]. The unified power flow controller consists of two switching converters which perform the functions of a series synchronous voltage source and a shunt current source. The control of the sources provides the multi-functional flexibilities for power flow control such as

(1) voltage regulation,

(2) series compensation,

(3) phase angle regulation and

(4) reactive power compensation. The unified power flow controller configuration has the capability to exchange both the real and reactive powers with the AC system that it provides an absolute control over the power that is negotiated between the sending and the receiving end of the transmission. The unified power flow controller is a powerful tool for concurrent control of voltage, line impedance and transmission angle for the increased effective damping of power oscillations and the transients.

1.6.4 Active Filters

Active filters with switching devices and their basic compensation principles were proposed in the 1970's [12, 27, 34]. The development of fast switching devices over the last two decades, has made possible to realize the active filters which have been a popular research topic since then. The active filters are primarily classified into shunt active filter and series active filter, they are used for the compensation of disturbances in load current and utility voltage. The research on active filters is now advanced to the development of the combined systems, such as a series active filter with a shunt passive filter, and the integration of series and shunt active filters. The active filters are described in the following:

(a) Shunt Active Filters: Shunt active filters are basic PWM converters commonly, realised as non-linear current source for the compensation of reactive power, harmonic currents, imbalance, and flicker produced by the industrial loads]. The PWM converter of the shunt active filter is connected in parallel with the load and is made to generate a compensating current with the help of a current control scheme. The popular control techniques such as hysteresis, predictive, and sliding-mode controller have been proposed to use for the line current control scheme. Irrespective of the current control scheme, the shunt active filter generates a compensating current which is equal in magnitude but out of phase by 180^0 to the unwanted component of the load current. Thus the shunt active filter supplies the reactive power, harmonic currents and unbalance to the load so that the utility line current is compensated. A unity power factor condition is ultimately presented to the utility. The shunt active filters, in general, have the following disadvantages : Since the load is directly connected to the utility, it is still subjected to the utility power quality problems such as distortions, sags,transients and imbalance. The shunt active filters require large ratings for PWM converters when they are installed for the compensation of reactive and harmonic currents generated by the loads. The accompanying initial costs are high compared to the passive filters. There have been approaches to reduce the rating of the shunt active filters by the combination of active filter and passive elements such as capacitors and reactors

(b) Series Active Filters:

Series active filters are also basic PWM converters commonly realised as non-linear voltage sources and are connected in series with the utility. The series active filter injects a compensating voltage in series with the utility voltage which is equal in magnitude but out of phase by 180^0 to the unwanted component in the utility voltage. Thus the unwanted components are compensated, and the voltage supplied to the load is regulated to a constant magnitude low THD sinusoidal voltage. The series active filters generally provide compensation for voltage harmonies, unbalance, transients and sags. The ratings of the series active filter depends on the nature of the compensation. The compensation for utility voltage is indirect and the series active filter requires protection from the line faults. Furthermore, the reactive power and harmonic currents injected by the load are transferred to the utility side without compensation.

(c) Combined System of Series Active and Shunt Passive Filters: A compensator for harmonic currents generated by large rectifier and arc furnace loads requires a large shunt active filter systern. The combined system with a series active filter and a shunt passive filter has been developed as a suitable alternative for this specific purpose. The combined system utilises the collective advantages both in active filter and passive filter. The passive filter is connected in pardlel to the load and the active filter is connected between the utility and the combined passive filter and load. The passive filter provides a shunt path for the harmonic currents,while the active filter isolates the passive filter from the power system network. The active filter exhibits high impedance at harmonic frequencies and effectively prevents any formation of resonance between the utility and the passive filter. The active filter does not involve in the actual filtering of harmonic currents, therefore, the size of the active filter is very small. The combined system is primarily developed for the harmonic current compensation only. However, the application of the combined systems can also be found for the compensation of utility voltage unbalance in addition to the harmonic current compensation.

1.6.5 Combined Series and Shunt Active Filters

The combined Series and Shunt Active filter systems are aimed to provide a comprehensive isolation of disturbances between the utility and the load. More specifically, with the combined series and shunt active filters, it is possible to supply a constant magnitude, low-THD, balanced sinusoidal load voltage while simultaneously presenting a unity-power factor condition to the utility. The application of the combined systems can be of two types: One is a general compensator for power distribution systems and industrial power systems. The other is the specific compensator with low power ratings which can be installed on the premises of an electric power consumer. In any case, the combined system consists of a series active filter and a shunt active filter and has the capability to improve the power quality at the point of installation on demand-side power systems.

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2 The control on the load voltage and the utility line current is direct.
3 Direct isolation between utility and industrial loads is providence for harmonic currents, harmonic distortions, reactive power, and unbalanced conditions. Although, the active filter is a popularity area of research, the research works on the combined active filter systems are limited. The following combined active filter systems can be found in the literature:
a) Unified Power Quality Conditioner
b) Line Voltage Regulator/Conditioner
c) Universal Power Filters

1.6.6 Harmonic Sources from Commercial Loads

Commercial facilities such as office complexes, department stores, hospitals, and Internet data centres are dominated with high-efficiency fluorescent lighting with electronic ballasts, adjustable-speed drives for the heating, ventilation, and air conditioning (HVAC) loads, elevator drives, and sensitive electronic equipment supplied by single-phase switch-mode power supplies. Commercial loads are characterized by a large number of small harmonic-producing loads. Depending on the diversity of the different load types, these small harmonic currents may add in phase or cancel each other. The voltage distortion levels depend on both the circuit impedances and the overall harmonic current distortion. Since power factor correction capacitors are not typically used in commercial facilities, the circuit impedance is dominated by the service entrance transformers and conductor impedances. Therefore, the voltage distortion can be estimated simply by multiplying the current by the impedance adjusted for frequency. Characteristics of typical non-linear commercial loads are detailed in the following sections.

1.6.6.1 Single-phase power supplies

Electronic power converter loads with their capacity for producing harmonic currents now constitute the most important class of nonlinear loads in the power system. Advances in semiconductor device technology have fueled a revolution in power electronics over the past decade, and there is every indication that this trend will continue. Equipment includes adjustable-speed motor drives, electronic power supplies, dc motor drives, battery chargers, electronic ballasts, and many other rectifier and inverter applications.

A major concern in commercial buildings is that power supplies for single-phase electronic equipment will produce too much harmonic current for the wiring. DC power for modern electronic and microprocessor based office equipment is commonly derived from single-phase full-wave diode bridge rectifiers. The percentage of load that contains electronic power supplies is increasing at a dramatic pace, with the increased utilization of personal computers in every commercial sector. There are two common types of single-phase power supplies. Older technologies use ac-side voltage control methods, such as transformers, to reduce voltages to the level required for the dc bus. The inductance of the transformer provides a beneficial side effect by smoothing the input current waveform, reducing harmonic content. Newer-technology switch-mode power supplies (see

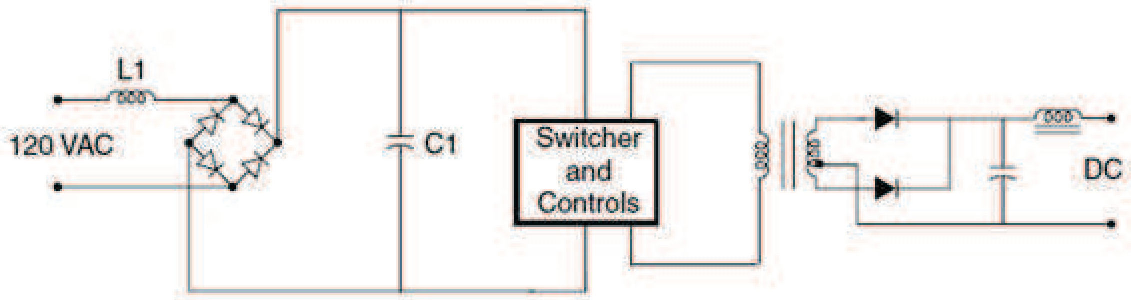

Figure 1.3: Switch-mode power supply.

Figure 1.3) use dc-to-dc conversion techniques to achieve a smooth dc output with small, lightweight components.

The input diode bridge is directly connected to the ac line, eliminating the transformer. This results in a coarsely regulated dc voltage on the capacitor. This direct current is then converted back to alternating current at a very high frequency by the switcher and subsequently rectified again. Personal computers, printers, copiers, and most other single-phase electronic equipment now almost universally employ switch-mode power supplies. The key advantages are the light weight, compact size, efficient operation, and lack of need for a transformer. Switch-mode power supplies can usually tolerate large variations in input voltage. Because there is no large ac-side inductance, the input current to the power supply comes in very short pulses as the capacitor C1 regains its charge on each half cycle. Figure 1.4 illustrates the current waveform and spectrum for an entire circuit supplying a variety of electronic equipment with switch-mode power supplies. A distinctive characteristic of switch-mode power supplies is a very high third-harmonic content in the current. Since third-harmonic current components are additive in the neutral of a three-phase system, the increasing application of switch-mode power supplies causes concern for overloading of neutral conductors, especially in older buildings where an undersized neutral may have been installed. There is also a concern for transformer

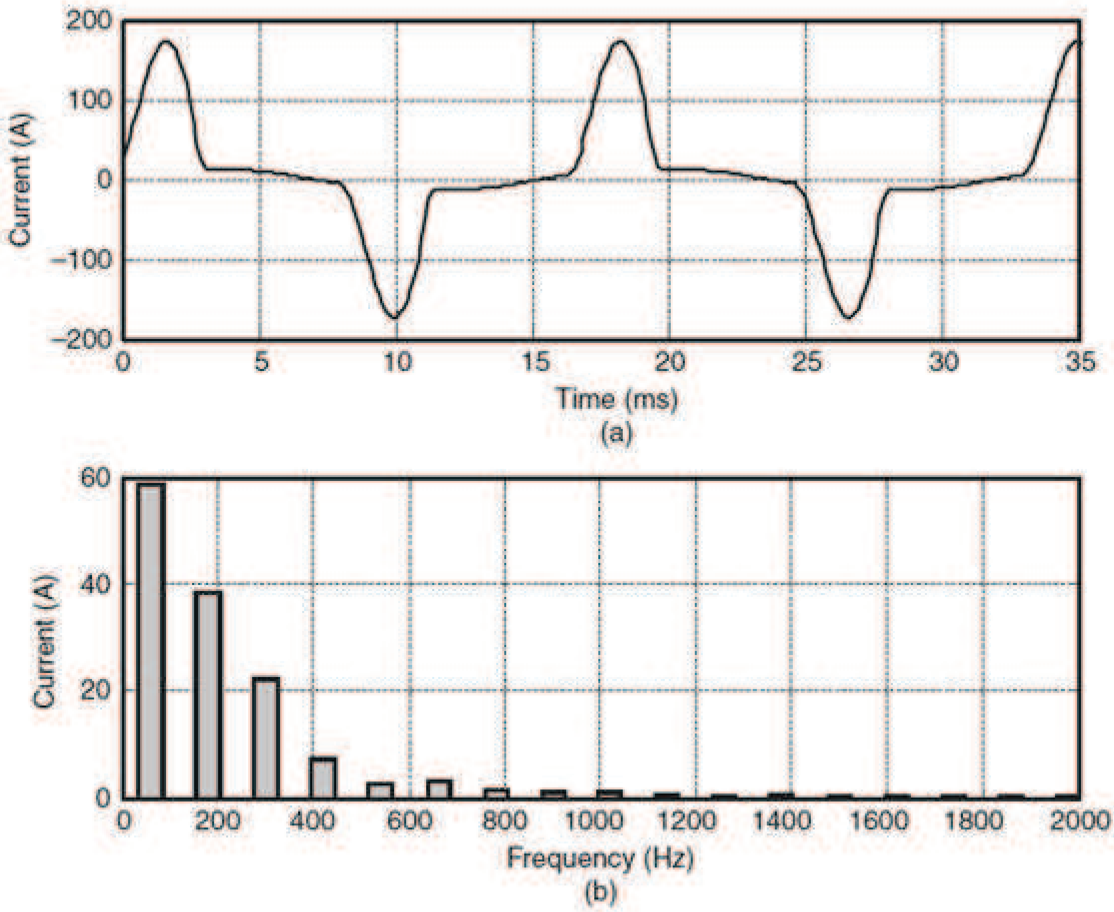

Figure 1.4: SMPS current and harmonic spectrum.

overheating due to a combination of harmonic content of the current, stray flux, and high neutral currents[93].

1.6.6.2 Fluorescent lighting

Lighting typically accounts for 40 to 60 percent of a commercial building load. According to the 1995 Commercial Buildings Energy Consumption study conducted by the U.S. Energy Information Administration, fluorescent lighting was used on 77 percent of commercial floor spaces, while only 14 percent of the spaces used incandescent lighting.1 Fluorescent lights are a popular choice for energy savings. Fluorescent lights are discharge lamps; thus they require a ballast to provide a high initial voltage to initiate the discharge for the electric current to flow between two electrodes in the fluorescent tube. Once the discharge is established, the voltage decreases as the arc current increases. It is essentially a short circuit between the two electrodes, and the ballast has to quickly reduce the current to a level to maintain the specified lumen output. Thus, a ballast is also a current-limiting device in lighting applications. There are two types of ballasts, magnetic and electronic. A standard magnetic ballast is simply made up of an iron-core transformer with a capacitor encased in an insulating material. A single magnetic ballast can drive one or two fluorescent lamps, and it operates at the line fundamental frequency, i.e., 50 or 60 Hz. The iron-core magnetic ballast contributes additional heat losses, which makes it inefficient compared to an electronic ballast. An electronic ballast employs a switch-modetype power supply to convert the incoming fundamental frequency voltage to a much higher frequency voltage typically in the range of 25 to 40 kHz. This high frequency has two advantages. First, a small inductor is sufficient to limit the arc current. Second, the high frequency eliminates or greatly reduces the 100- or 120-Hz flicker associated with an iron-core magnetic ballast. A single electronic ballast typically can drive up to four fluorescent lamps.

Standard magnetic ballasts are usually rather benign sources of additional harmonics themselves since the main harmonic distortion comes from the behavior of the arc. Figure 1.5 shows a measured fluorescent lamp current and harmonic spectrum. The current THD is a moderate 15 percent. As a comparison, electronic ballasts, which employ switch-mode power supplies, can produce double or triple the standard magnetic ballast harmonic output. Figure 1.6 shows a fluorescent lamp with an electronic ballast that

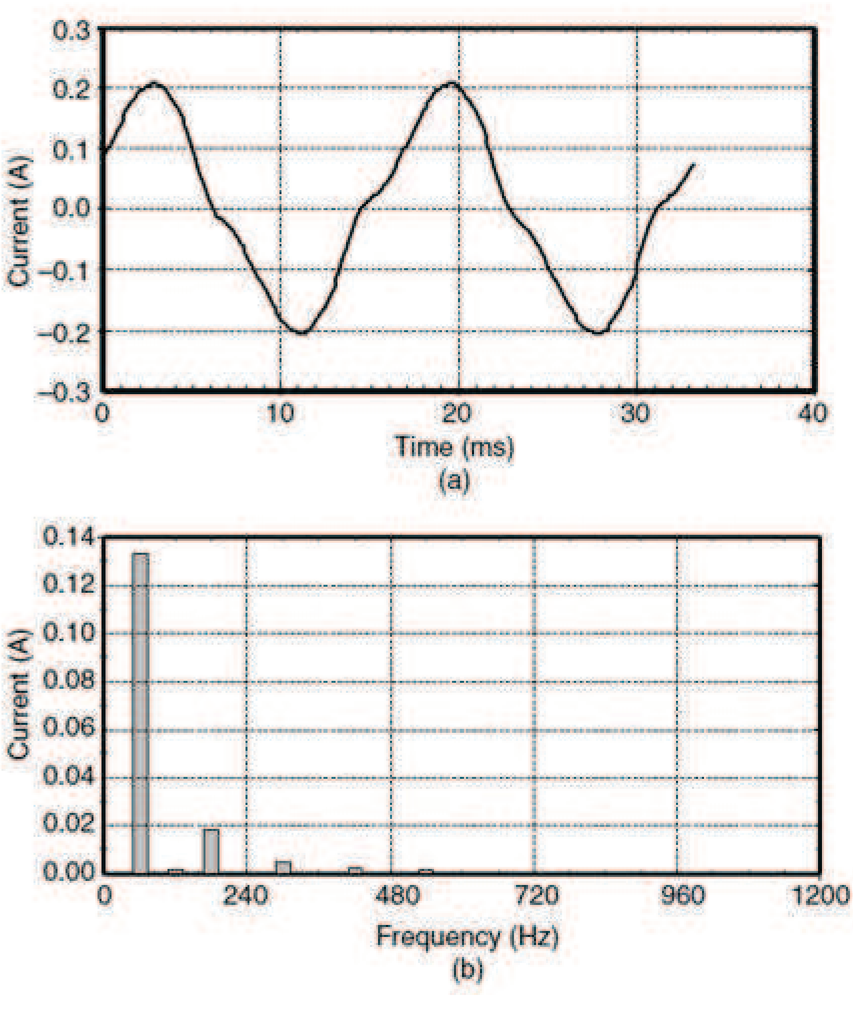

Figure 1.5: Fluorescent lamp with (a) magnetic ballast current waveform and (b) its harmonic spectrum.

has a current THD of 144. Other electronic ballasts have been specifically designed to minimize harmonics and may actually produce less harmonic distortion than the normal magnetic ballast-lamp combination. Electronic ballasts typically produce current THDs in the range of between 10 and 32 percent. A current THD greater than 32 percent is considered excessive according to ANSI C82.11-1993, High-Frequency Fluorescent Lamp Ballasts. Most electronic ballasts are equipped with passive filtering to reduce the input current harmonic distortion to less than 20 percent.

Since fluorescent lamps are a significant source of harmonics in commercial buildings, they are usually distributed among the phases in a nearly balanced manner. With a delta-connected supply transformer, this reduces the amount of triple n harmonic currents flowing onto the power supply system. However, it should be noted that the common wye-wye supply transformers will not impede the flow of triple n harmonics regardless of how well balanced the phases are. to match the application requirement such as slowing a pump or fan. ASDs also find many applications in industrial loads.

1.6.6.3 Adjustable-speed drives for HVAC and elevators

Common applications of adjustable-speed drives (ASDs) in commercial loads can be found in elevator motors and in pumps and fans in HVAC systems. An ASD consists of an electronic power converter that converts ac voltage and frequency into variable voltage and frequency. The variable voltage and frequency allows the ASD to control motor speed.

1.7 Harmonic Sources from Industrial Loads

Modern industrial facilities are characterized by the widespread application of nonlinear loads. These loads can make up a significant portion of the total facility loads and inject harmonic currents into the power system, causing harmonic distortion in the voltage. This harmonic problem is compounded by the fact that these nonlinear loads have a relatively low power factor. Industrial facilities often utilize capacitor banks to improve the power factor to avoid penalty charges. The application of power factor correction capacitors can potentially magnify harmonic currents from the nonlinear loads, giving rise to resonance conditions within the facility. The highest voltage distortion level usually occurs at the facilitys low-voltage bus where the capacitors are applied. Resonance conditions cause

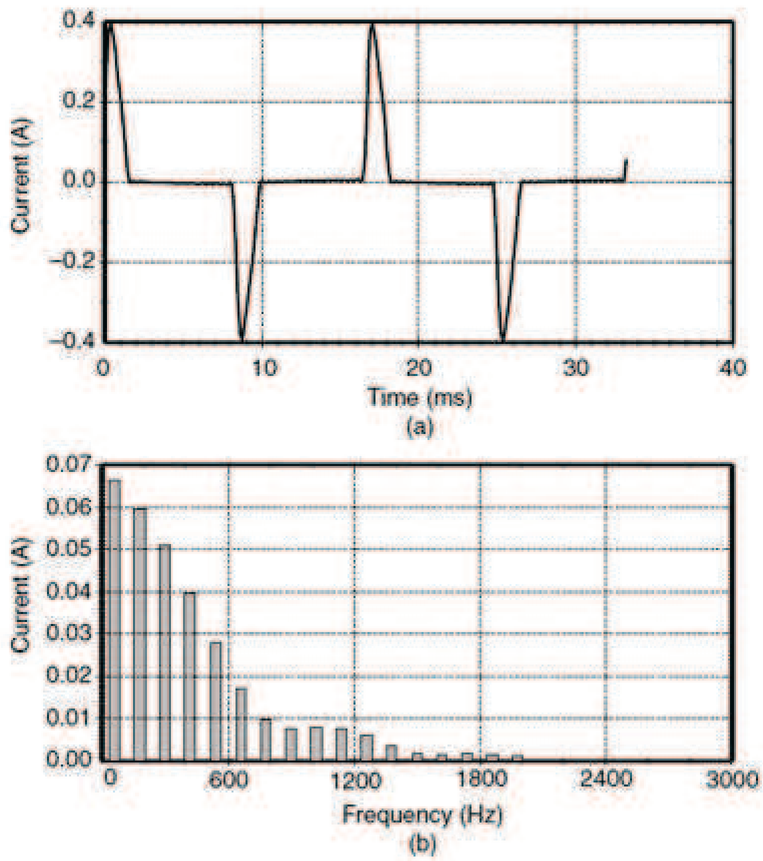

Figure 1.6: Fluorescent lamp with (a) electronic ballast current waveform and (b) its harmonic spectrum.

motor and transformer overheating, and misoperation of sensitive electronic equipment. Nonlinear industrial loads can generally be grouped into three categories: three-phase power converters, arcing devices, and saturable devices.

1.7.1 Three-phase power converters

Three-phase electronic power converters differ from single-phase converters mainly because they do not generate third-harmonic currents.This is a great advantage because the third-harmonic current is the largest component of harmonics. However, they can still be significant sources of harmonics at their characteristic frequencies, as shown in Figure 1.7. This is a typical current source type of adjustable-speed drive. The harmonic spectrum given in Figure 1.7 would also be typical of a dc motor drive input current. Voltage source inverter drives (such as PWM-type drives) can have much higher distortion levels as shown in Figure 1.8

The input to the PWM drive is generally designed like a three-phase version of the switch-mode power supply in computers. The rectifier feeds directly from the ac bus to a large capacitor on the dc bus. With little intentional in ductance, the capacitor is charged in very short pulses, creating the distinctive rabbit ear ac-side current waveform with very high distortion. Whereas the switch-mode power supplies are generally for very small loads, PWM drives are now being applied for loads up to 500 horsepower (hp). This is a justifiable cause for concern from power engineers.

DC drives Rectification is the only step required for dc drives. Therefore, they have the advantage of relatively simple control systems. Compared with ac drive systems, the dc drive offers a wider speed range and higher starting torque. However, purchase and maintenance costs for dc motors are high, while the cost of power electronic devices has been dropping year after year. Thus, economic considerations limit use of the dc drive to applications that require the speed and torque characteristics of the dc motor. Most dc drives use the six-pulse rectifier shown in Figure 1.9. Large drives may employ a 12-pulse rectifier. This reduces thyristor current duties and reduces some of the larger ac current harmonics.

The two largest harmonic currents for the six-pulse drive are the fifth and seventh. They are also the most troublesome in terms of system response. A 12-pulse rectifier in this application can be expected to eliminate about 90 percent of the fifth and seventh

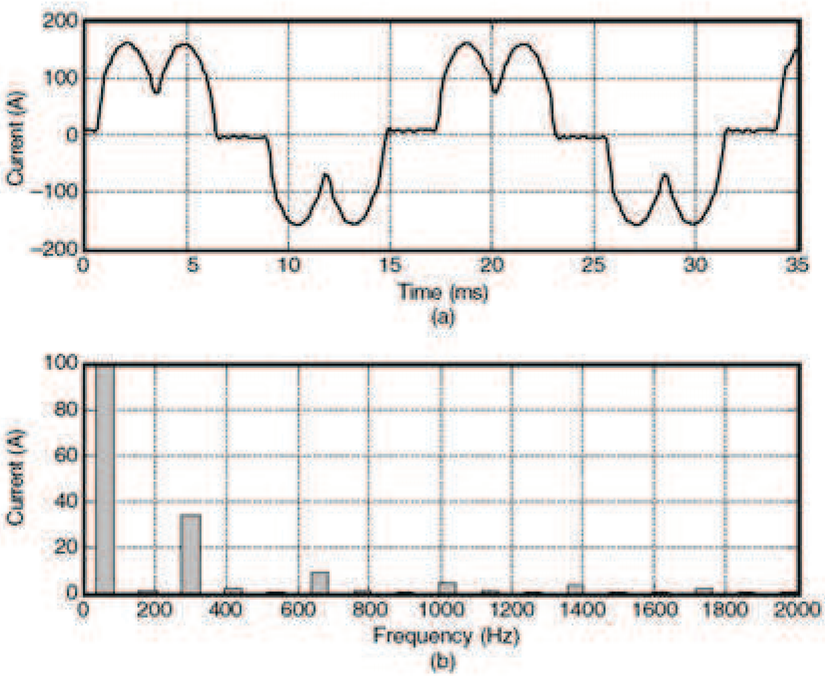

Figure 1.7: Current and harmonic spectrum for CSI-type ASD.

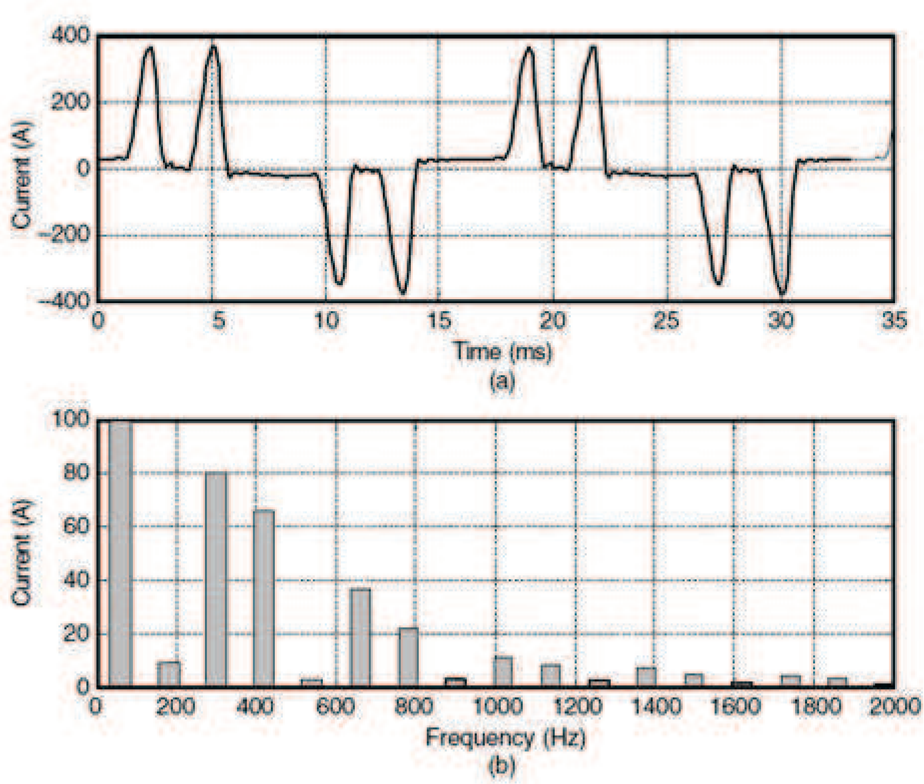

Figure 1.8: Current and harmonic spectrum for PWM-type ASD.

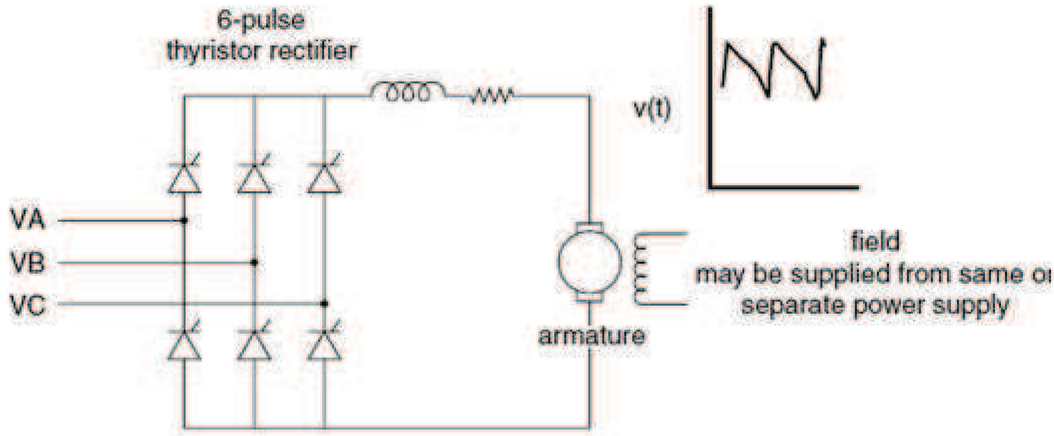

Figure 1.9: Six-pulse dc ASD.

harmonics, depending on system imbalances. The disadvantages of the 12-pulse drive are that there is more cost in electronics and another transformer is generally required.

AC drives In ac drives, the rectifier output is inverted to produce a variable-frequency ac voltage for the motor. Inverters are classified as voltage source inverters (VSIs) or current source inverters (CSIs). A VSI requires a constant dc (i.e., low-ripple) voltage input to the inverter stage. This is achieved with a capacitor or LC filter in the dc link. The CSI requires a constant current input; hence, a series inductor is placed in the dc link. AC drives generally use standard squirrel cage induction motors. These motors are rugged, relatively low in cost, and require little maintenance. Synchronous motors are used where precise speed control is critical. A popular ac drive configuration uses a VSI employing PWM techniques to synthesize an ac waveform as a train of variable-width dc pulses (see Figure 1.10).

The inverter uses either SCRs, gate turnoff (GTO) thyristors, or power transistors for this purpose. Currently, the VSI PWM drive offers the best energy efficiency for applications over a wide speed range for drives up through at least 500 hp. Another advantage of PWM drives is that, unlike other types of drives, it is not necessary to vary rectifier output voltage to control motor speed. This allows the rectifier thyristors to be replaced with diodes, and the thyristor control circuitry to be eliminated.

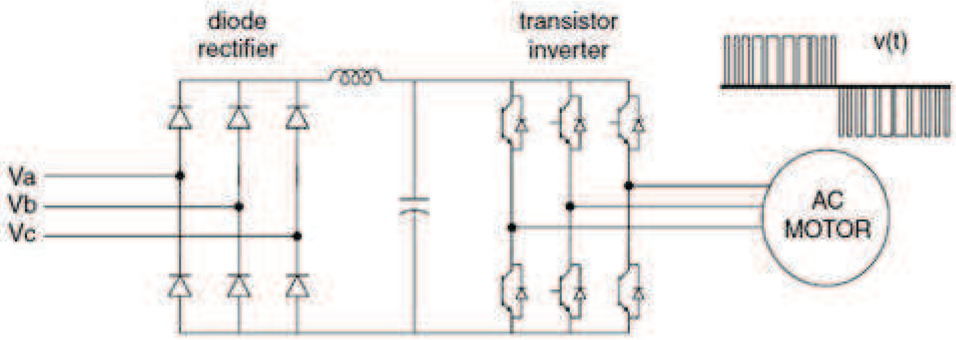

Figure 1.10: PWM ASD

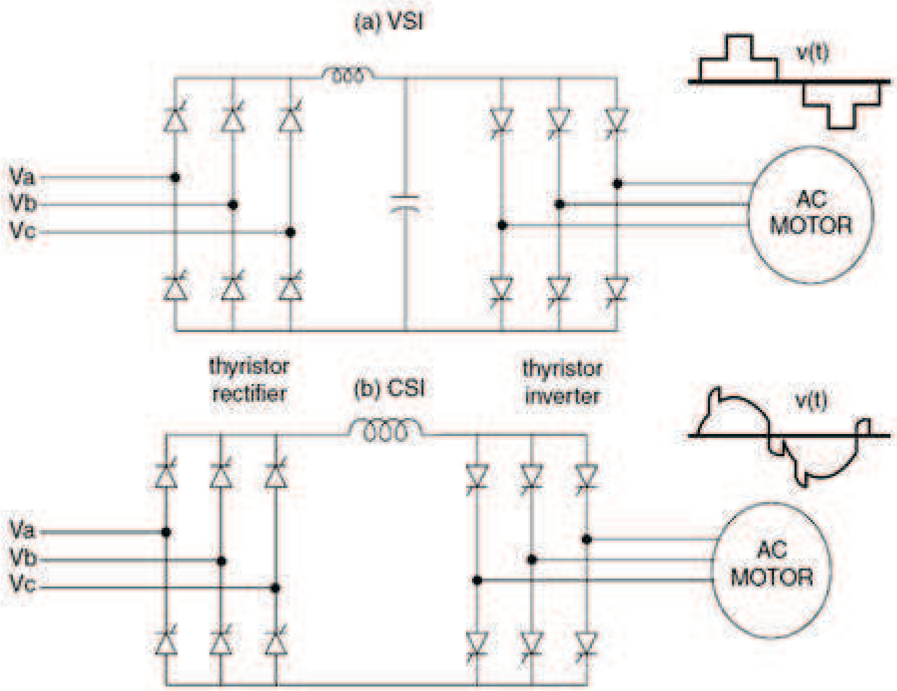

Figure 1.11: Large ac ASDs

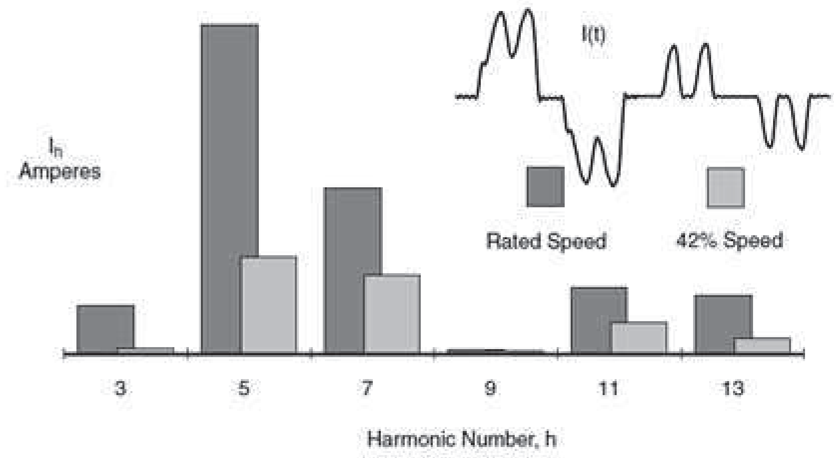

Figure 1.12: Effect of PWM ASD speed on ac current harmonics.

Large ASDs Very high power drives employ SCRs and inverters. These may be 6-pulse, as shown in Figure 1.11, or like large dc drives, 12-pulse. VSI drives (Figure 1.11) are limited to applications that do not require rapid changes in speed. CSI drives (Figure 1.11) have good acceleration/deceleration characteristics but require a motor with a leading power factor (synchronous or induction with capacitors) or added control circuitry to commutate the inverter thyristors. In either case, the CSI drive must be designed for use with a specific motor. Thyristors in current source inverters must be protected against inductive voltage spikes, which increases the cost of this type of drive.

Impact of operating condition The harmonic current distortion in adjustable-speed drives is not constant. The waveform changes significantly for different speed and torque values. Figure 1.12 shows two operating conditions for a PWM adjustable speed drive. While the waveform at 42 percent speed is much more distorted proportionately, the drive injects considerably higher magnitude harmonic currents at rated speed. The bar chart shows the amount of current injected. This will be the limiting design factor, not the highest THD. Engineers should be careful to understand the basis of data and measurements concerning these drives before making design decisions.

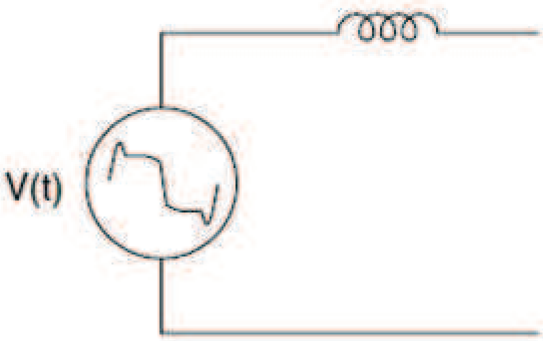

Figure 1.13: Equivalent circuit for an arcing device.

1.7.2 Arcing devices

This category includes arc furnaces, arc welders, and discharge-type lighting (fluorescent, sodium vapor, mercury vapor) with magnetic

(rather than electronic) ballasts. As shown in Figure 1.13, the arc is basically a voltage clamp in series with a reactants that limits current to a reasonable value. The voltage-current characteristics of electric arcs are nonlinear. Following arc ignition, the voltage decreases as the arc current increases, limited only by the impedance of the power system. This gives the arc the appearance of having a negative resistance for a portion of its operating cycle such as in fluorescent lighting applications. In electric arc furnace applications, the limiting impedance is primarily the furnace cable and leads with some contribution from the power system and furnace transformer. Currents in excess of 60,000 A are common. The electric arc itself is actually best represented as a source of voltage harmonics. If a probe were to be placed directly across the arc, one would observe a somewhat trapezoidal waveform. Its magnitude is largely a function of the length of the arc. However, the impedance of ballasts or furnace leads acts as a buffer so that the supply voltage is only moderately distorted. The arcing load thus appears to be a relatively stable harmonic current source, which is adequate for most analyses. The exception occurs when the system is near resonance and a Thevenin equivalent model using the arc voltage waveform gives more realistic answers. The harmonic content of an arc furnace load and other arcing devices is similar to that of the magnetic ballast shown in Figure 1.13. Three phase arcing devices can be arranged to cancel the triplen harmonics

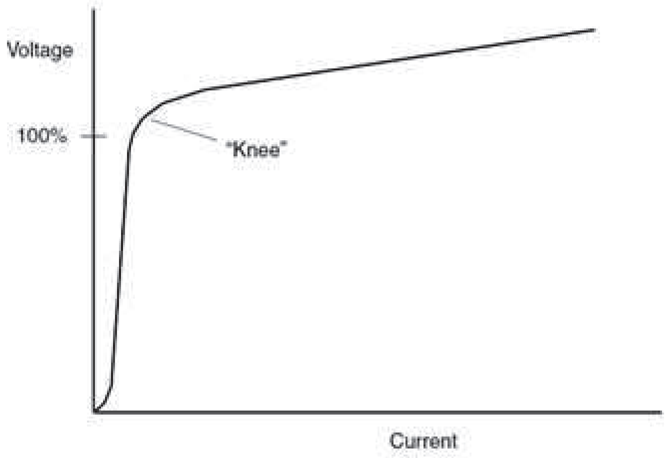

Figure 1.14: Transformer magnetizing Characteristic

through the transformer connection. However, this cancellation may not work in three-phase arc furnaces because of the frequent unbalanced operation during the melting phase. During the refining stage when the arc is more constant, the cancellation is better.

1.7.3 Saturable devices

Equipment in this category includes transformers and other electromagnetic devices with a steel core, including motors. Harmonics are generated due to the nonlinear magnetizing characteristics of the steel (see Figure 1.14). Power transformers are designed to normally operate just below the knee point of the magnetizing saturation characteristic. The operating flux density of a transformer is selected based on a complicated optimization of steel cost, no-load losses, noise, and numerous other factors. Many electric utilities will penalize transformer vendors by various amounts for no-load and load losses, and the vendor will try to meet the specification with a transformer that has the lowest evaluated cost. A high-cost penalty on the no-load losses or noise will generally result in more steel in the core and a higher saturation curve that yields lower harmonic currents.

Table 1.1: IEEE-519 Maximum odd-harmonic current distortions. % Limits of Harmonic Currents (Bus voltage at PCC <69KV)

$\mathbf{\frac{I_{sc}}{I_1}}$	**h<11**	**11<h<17**	**17<13**	**23<h<35**	**35<h**	**THD**
<20	4.0	2.0	1.5	0.3	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	15.0	7.0	6.0	2.5	1.4	20.0

1.7.4 Harmonic Standards and Recommended Practices.

In view of the proliferation of the power electronic equipment connected to the utility distribution system, various international agencies have proposed limits on the magnitude of harmonic current injected into the supply to maintain acceptable power quality. The resulting guidelines and standards specify limits on the magnitudes of harmonic currents and harmonic voltage distortion at various harmonic frequencies. The most widely known are the IEEE-519 guidelines [2] in North America and the IEC-61000 Standard (formerly IEC 555) [3] prepared by the International Electrical Commission (in effect since 1996). However, the approach taken in these documents is drastically different. The IEC Standard imposes limits on individual equipment (up to 15 A, 220 V) connected to the supply, whereas the IEEE Recommended Practice addresses the issue of harmonic distortion at the point of common of coupling (PCC). Complying with the IEC Standard usually requires special design of the equipment itself [5] [6] [7]. However, meeting the IEEE guidelines can be achieved by means of filter, particularly active filters. Therefore, reference in this work will only be made to the IEEE guideline. IEEE 519 proposes to designers of industrial plants harmonic limits as given in Table 1.1 and 1.2. For existing installations, harmonic mitigation techniques may have to be used to reduce distortion to the specified limits[93].

I_{sc} is the maximum short-circuit current at PCC. I_1 is the maximum fundamental frequency load current at PCC.

HD_v = Individual harmonic voltage distortion.

Table 1.2: IEEE-519 Voltage distortions limits

Bus Voltage at PCC	$HD_v(\%)$	$THD_v(\%)$
69 kV and below	3.0	5.0

1.8 Review papers

Various researchers have been worked to meet the requirements of the IEEE 519 standards at the point of common coupling by implementing the passive and active filters In a various combinations like a shunt filter, series filter and the combination of the both i.e. hybrid filter. They have proposed various control schemes includes instantaneous P-Q theory, Synchronous reference frame based theory and notch filter based control algorithms. But all the research has been done with six-pulse rectifier.

A large number of publications have appeared in the field of hybrid filters, many giving simulation and experimental results and also new concepts. The available literature on hybrid active filters can thus be broadly classified based on:

H.Akagi gives the comparison between the series active and shunt active filter. Also author discussed about the shunt passive filters. Author has used active power line conditioner instead of that of active power filters because active line conditioners would cover a wider sense than active filters. His intent is to present PWM inverters for line conditioners. Fang Zheng Peng discussed about the types of harmonics sources and its equivalent circuits. Active shunt filter and series filter configuration with transfer function discussed. And compare the series active filter with parallel active filter configurations.

Bhattacharya addresses cost effectiveness of various active filter topologies based on the application. Pure active filter solutions and hybrid active filter solutions are both seen to have merit in realizing a harmonic free utility interface for industrial loads rated at 100 kW to several MW. The objective of this paper is to present a methodology, for both the Industrial user and the utility, to match the optimal active filter solution to their application.

The proposed strategy is general and applicable to six-pulse rectifier loads and 12-pulse rectifier loads. Small-rated active filter inverters, (1%2%) of the load rating, provide a practically viable and cost-effective solution for high power nonlinear loads up to 100 MW.

Rastogi has demonstrated by means of simulation of control of proposed hybrid system under transient conditions such as start up and during steady state. Results from a scaled down hardware prototype are presented to verify the simulation.

Active series filter is controlled as sinusoidal current source instead of harmonic voltage source to simplify the control strategy for active filters by Dixon[11]. This approach presents many advantages eg. it controls the voltage at node allowing excellent regulation characteristics. It offers unity power factor operation.

Sitaram , has given the results of the digital simulation of the hybrid system presented in the paper. They have also used a 5th harmonic tuned filter to compensate for the dominant harmonic by six pulse rectifier load. The harmonic filtering required a low rated series active power filter in series with the passive filter. The dc capacitor voltage control of the active filter is done using the PI controller. Control scheme adapted in this paper is based on synchronous reference frame theory.

C. E. Lin , presents calculating approaches to obtain compensating components for reactive and harmonic current compensator. The synchronous detection method is applied to calculate proper compensating components by monitoring the line currents and voltages. H. L. Jou proposes a new active power filter algorithm. Its performance is simulated and compared with that of instantaneous reactive power algorithm and a synchronous detection algorithm under ideal and non ideal conditions. A prototype is also developed to demonstrate the performance of the proposed algorithm.

G. Myoung Lee and Dong Choon Lee propose a novel control scheme compensating source voltage unbalance and current harmonics for hybrid active filters. The reference voltage for the compensation is derived from the differences between the fundamental source and load voltages and their instantaneous values.

D.A. Deib and H.W. Hill had proposed the operation of An asymmetrical firing strategy for the cascaded converters of a HVDC link, resulting in minimum reactive power compensation at both ends of the DC link. Both 6- and 12-pulse converters, in unipolar and bipolar operation, was considered.

W. Mc Murray the study of asymmetrical gating phase controlled converters. The low power factor of phase-controlled converters when the output voltage is less than the maximum is of-concern in high-power equipment. In a converter consisting of two commutating groups in cascade, the usually low power factor can be improved by firing or gating the thyristors in the two groups asymmetrically. One of the groups is fully advanced (or retarded) to minimize its reactive power, while the other group is controlled to give the desired dc Output. The technique is not recommended for single three-phase bridge converters because of third-hannonic output ripple, second-harmonic line current distortion, and danger of commutation failure. These objections were overcome by combining pairs of three-phase bridges. When regeneration was not required, half of the thyristors could be replaced by diodes, reducing the cost. The method should offer substantial improvement in the power factor of cycloconverter ac motor drives as well as dc motor drives.

Dahono P.A proposed new hysteresis current controller for single-phase full-bridge inverters. The proposed hysteresis current controller combines the advantages of both symmetrical unipolar PWM and hysteresis techniques. As the proposed hysteresis current controller has a capability to ensure equal switching frequencies among the switching devices, the capability of inverter switching devices can be fully utilised to improve the output current waveform. The proposed hysteresis current controller was compared with conventional single-band and double-band hysteresis current controllers.

J.C.Das, PE stated that n ew topologies for harmonic mitigation and active filters have come a long way and these address the line-harmonic control at the source. These mitigate some of the disadvantages of passive filters, however, for nonliner loads above 1 MW the passive filters are an economical choice. The paper discussed two types of filters: band pass filters and damped filters, which are commonly applied. The operation of these filters is described with respect to the design and system limitations. The operating constraints are then superimposed. The development of this approach shows that there are design limitations and large system changes or modifications can result in higher distortion or even damage to filters in extreme cases. The constraints and limitations that a designer faces in implementing an effective filter design with modern tools of harmonic analysis, measurements and system analysis are discussed. The paper shows that in most distribution systems it was practical and economical to implement passive filter designs, provided the required safeguards were considered.

B.O. Slim, Braha A. and Ben saoud s stated that industrial and domestic equipment actually uses a large variety of electronic circuits, which have nonlinear impedance. They provide into the network non-sinusoidal currents which outcomes include higher losses for transformer or possible overheating or over-voltage. The parallel active filtering presents one of the adequate solutions to eliminate the harmonic pollution generated by inductive loads on the electrical supply networks.in this pape, they r presented the implementation of a digitally controlled parallel active filter for a three-phase rectifier with inductive load.

Ching-Tsai Pan and Ting-Yu Chang presented, an improved invertor hysteresis current controller. It coordinates the switching of the three-phase switches in the d-q phase plane. In addition to the current error, information of the current error derivative is further employed so that one can take more advantage of adding the zero voltage vector for reducing the switching frequency. A simple hardware implementation of the improved hysteresis current controller is also proposed such that merits of the conventional hysteresis current controller can still be kept.

Kim Y.S., Kim, J.S., Ko S.H. proposed a new control algorithm for a three-phase three-wire series active power filter. With the proposed control algorithm, the series active power filter compensates for the harmonics and reactive power that are generated by non-linear loads, such as diodes or thyristor rectifiers. The proposed control algorithm is based on the generalised p-q theory. It may be applied to both harmonic voltage sources and harmonic current sources. In this algorithm, the compensation voltage references are extracted directly. Therefore, the calculation of the compensation voltage reference will be much simpler than for other control algorithms.

Sangsun Kim, Enjeti P.N presented w hybrid active power filter topology is presented. A higher-voltage, low-switching frequency insulated gate bipolar transistor (IGBT) inverter and a lower-voltage high-switching frequency metal oxide semiconductor field effect transistor (MOSFET) inverter were used in combination to achieve harmonic current compensation. The function of the IGBT inverter is to support utility fundamental voltage and to compensate for the fundamental reactive power. The MOSFET inverter fulfills the function of harmonic current compensation.

V. S. C. Raviraj and P. C. Sen presented a comparative evaluation of the proportionalintegral, sliding mode and fuzzy logic controllers for applications to power converters. The mismatch between the characteristics which lead to varying performance was outlined.

C. N. Bhende, S. Mishra, and S. K. Jainper described the application of TakagiSugeno (TS)-type fuzzy logic controller to a three-phase shunt active power filter for the power-quality improvement and reactive power compensation required by a nonlinear load

S.Hansen, P. Nielsen, F. Blaabjerg worked on Harmonic Cancellation by Mixing Non Linear single phase and Three Phase Loads. The voltage on the distribution line is, in most cases, distorted even at no load of the transformer. This was due to the background distortion on the medium-voltage line caused by the large number of single-phase nonlinear loads, such as PCs, TVs, VCRs, etc. This paper proposeed a method to mix single-phase and three-phase nonlinear loads and reduce the harmonic currents significantly. The dependence of the phase angle of the harmonic currents as a function of the short-circuit impedance was investigated using SABER for the three-phase and the single-phase diode rectifier both with and without DC-link inductance.

Bor-RenLin, Chun-Hao Huang, Bor-Ren Yang, worked on control scheme of hybrid active filter with integrated series active filter and parallel passive filter for power quality improvement . The system was capable of compensating the current and voltage harmonics and voltage sag in distribution system. The line current was controlled to be sinusoidal in phase with mains voltage and load terminal voltage was controlled to be fixed under a wide range of distorted line voltage.

P. T. Cheng, S. Bhattachaarya, and D. M. Divan presented Harmonic filter re quired for 12 pulse rectifier-utility interface to meet IEEE 519 harmonic current limits. Passive filter techniques employ tuned L-C filters at dominant 11th and 13th harmonic frequencies. However, they also require 5th and 7th tuned filters to avoid series and parallel resonance conditions.

T.C. Green and J.H. Marks, shows that the fitting of an active power filter (APF) to mitigate the effects of a diode or thyristor bridge-rectifier can be predicated on the assumption that the rating of the filter was reasonable (i.e. small) compared with the rating of the existing bridge rectifier or of a replacement active rectifier. The ratings of both shunt and series APFs are analysed in a variety of operating conditions. Ratings are assessed through peak voltage and mean current as appropriate for junction semiconductor devices. RMS ratings also given because of their familiarity. The series APF, appropriate for the compensation of harmonic voltage sources, is of a generally higher rating than the shunt APF, appropriate for harmonic current sources.

S. Rechka, E. Ngandui, J.Xu and P. Sicard, presented the performance of three harmonic detection methods which wae evaluated in term of precision, speed of convergence and calculation complexity. The algorithms are respectively based on the recursive discrete Fourier transform (RDFT), Kalman filtering approach and the instantaneous reactive power theory.

Wei P, Zhan Z, Chen H worked on DSP-based active power filter for three phase power distribution systems.T his paper presents a digital signal processor (DSP)-based control method for shunt active power filter (SAF) for three-phase power distribution systems. Compared to conventional analog-based methods, the DSP-based solution provides a flexible and cheaper method to control the SAF.

Ping W, Houquan C, Zhixiong Z , also worked on Three-phase active power filter based on DSP for power distribution systems. With the use of nonlinear loads increasing rapidly, which inject undesired harmonic currents into power distribution systems, shunt active power filters (SAF) being considered as a potential candidate for solving harmonic problems in order to meet harmonic standards and guidelines. They presented digital signal processor (DSP)-based control method for a three-phase shunt active power filter. Compared to conventional analog-based methods, the DSP-based solution provides a flexible and cheaper method to control the SAF.

Chapter 1 introduce the application of multi pulse converter and configuration of different converters which presents a brief state-of-art survey of research work carried out in the areas 12 pulse converter and mitigation of harmonics. The various control algorithms are presented for the harmonics mitigation.

Chapter 2 gives the detailed operation of 12 pulse converter operating under asymmetrical and symmetrical firing angle mode. The effect of source inductance is a major limitation for operating a converter under constant active / reactive power control. The region of operation is generated for constant active / reactive power operation. The harmonic pattern for different order of harmonics and Total Harmonic Distortion is carried out.

Chapter 3 gives the detail design of passive filter and simulation of converter with passive filter. The converter is analysed with passive filter. The harmonic pattern for different order of harmonics and Total Harmonic Distortion is carried out.

Chapter 4 gives the necessity of active filter. The hybrid series active filter is simulated The SRF and P.-Q theory is simulated. The waveform is compared for without, with passive and with hybrid active filter. The combined hybrid series active filter is simulated and results are compared.

Chapter 5 shows the experimental verification of 12 pulse converter analysis operating under asymmetrical firing angle operation with and without passive filter for constant Active / reactive power operation . It also covers detail experimental results and analysis of 12 pulse converter using passive and hybrid active filter. The input current harmonics has been analysed for different firing angle operation of 12 pulse converter.

Chapter 6 gives the conclusion of the work carried out and importance of this industry to keep required reactive power constant when more than one power electronic equipments are connected and using 12 pulse converter it can be possible with mitigation of harmonics. It also include possible ways for future expansion.