CHAPTER 1

INTRODUCTION

1.1 POWER QUALITY

Recent advances in the power electronic technologies have estimated that about 50-60 percent of the electric power in industrialized countries is flowing through some kind of power electronic systems (non-linear loads) and the percentage is growing. These loads distort the supply voltage as well as supply current from its pure sinusoidal form. It defines the quality of the supply by two characteristics, stable voltages and undistorted waveforms. Interest in Power Quality has increased significantly over the last decade. The main reason for the awareness of the power quality problems is this: the load equipment is more sensitive to power quality variations. Modern load devices contain microprocessor based controls and power electronic devices that are sensitive to power disturbances. Many things are now interconnected in a network and any failure in the components has much more important consequences.

This thesis starts with a brief description of power quality and the existing standards specified by IEEE, IEC, and ANSI etc. Various power quality issues are addressed and their effects are discussed. Before discussing quality and how it pertains to the supply, an ideal supply must first be defined. An ideal supply voltage is a three phase voltage which is symmetrical, sinusoidal and has a constant RMS value. Sags, swells and transients will affect the RMS value, while harmonics and noise will cause the supply
voltage to be non-sinusoidal. Power quality is the deviation in the incoming power supplied to the electrical equipment from the steady, 50Hz, sinusoidal waveform of voltage or current. These deviations may affect the safe or reliable operation of equipment connected to the power system. The term “poor power quality” means that there is a sufficient deviation from standards that can cause equipment mis-operation and/or failure. Such deviations are due to non-linear loads in the system.

Since Indian Railways has introduced AC traction, it has expanded its traction network and locomotive manifold and these locomotives use thyristor-controlled devices. Harmonics produced by these devices are large and often accompanied by phase unbalance Rajesh Kumar et al (1998). This may cause malfunctioning of electronic and protective devices. Central Power Research Institute (CPRI) has carried out harmonic measurements on substations feeding traction loads in India and the result confirms the presence of power quality problems by these loads. In 1991, the Canadian Electrical Association (CEA) took a proactive approach to power quality problems and initiated a three year “Canadian National Power Quality Survey” involving 22 utilities Koval et al (1998). The results of the national survey provide a guide to the number of the various types of utility and industrial site disturbances. An analysis of steel rolling mill Lalli and Paul (1998) loads, consisting of induction and arc furnace, is very useful in identifying power quality problems. Induction and arc furnaces produce significant harmonics Ahmad Esfandiari and Mostafa Parniani (2004) which leads to additional heating, resulting in the rise of temperature of the transformer. This leads to the deterioration of insulation and consequent reduction in the life of the transformer.
1.2 VARIOUS POWER QUALITY PROBLEMS

The various power quality problems are categorized in the following types.

1) Transients
   a) Impulsive Transient
   b) Oscillatory Transient

2) Long duration voltage variations
   a) Overvoltage
   b) Under voltage
   c) Sustained interruptions

3) Short duration voltage variation

4) Waveform distortion

   Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency. The primary types of waveform distortion are
   a) DC offset
   b) Harmonics
   c) Inter-harmonics
   d) Notching
   e) Noise

5) Flicker and

6) Power frequency variations
1.3 HARMONICS

Harmonics refers to all sinusoidal voltages and currents that are integral multiples of the basic (fundamental) power system frequency. Any cyclic waveform can be deconstructed into a sinusoid at the fundamental frequency plus number of sinusoids at odd multiples of frequencies. Figure 1.1 shows a fundamental sine wave with the third harmonics. Harmonic distortions are caused by non-linear loads, which draw currents that are not proportional to the applied voltage. Even if the power supplied is a purely sinusoidal voltage of constant magnitude and frequency, the current drawn by the load may be in spurts and therefore not sinusoidal. The voltage distortion is the result of distorted current passing through the linear, series impedance of the power delivery system. The harmonic current passing through the impedance of the system causes a voltage drop for each harmonic and results in voltage harmonics appearing in the load bus. The amount of the voltage distortion depends on the impedance and the current.

![Figure 1.1 Fundamental Sine Wave with Third Harmonic](image-url)
1.4 SYMPTOMS OF HARMONIC DISTORTION

- Unusual noise in magnetic devices such as motors and transformers
- Unusual hum from ceiling fans
- High neutral and earth voltage
- Equal line voltage but high variations in phase voltage
- Large neutral currents
- Periodic lamp flicker (more perceptible in fluorescent lamp)
- Large variations between energy values recorded by electronic energy meters and electro-mechanical energy meters

1.5 SOURCES OF HARMONICS

A brief review of these harmonics producing loads is presented by Subjak and McQuilkin (1990).

- Static Power Converters - Thyristor and/or diode based power converters are the largest non-linear loads connected to the power system. These are extensively used in the industry to convert power from ac-to-dc, dc-to-ac, dc-to-dc, and ac-to-ac. The current commutation phenomenon results in voltage notching and the poor Displacement Power Factor (DPF) draws additional VAR from the source.

- Arc furnaces, mine hoists loads – The harmonics produced by these loads are highly unpredictable because of cycle-by-cycle variation of the mechanical torque. The line current is non-periodic. The harmonic spectrum will have both integer and non-integer order of frequencies.
Switch Mode Power Supplies (SMPS) – Most electronic equipment uses a SMPS to provide the stabilized voltage to the equipment. It feeds the capacitor that supplies voltage to the equipment. Since the load, as seen from the power system, is a capacitor, the current to the power supply is discontinuous, producing line harmonics.

PWM Drive – The dc link drive has a diode at the input and a large capacitor on the dc link to regulate the dc voltage. For light loads (30-50%), the current only flows when the voltage output of the diode rectifier is above that of the capacitor. Thus at light loads current in the ac circuit is discontinuous.

Utility Interface with Distributed Energy Sources – With the increasing use of distributed energy sources such as fuel cells, wind generators, micro-turbines, and solar cells, there are various topologies available to connect these sources to the utility. These interfacing power converters may act as current sources attached to the electric utility or as voltage sources tied to the utility through series impedance. Depending on the topology used, the outputs of these power converters may contain harmonics of various orders and power factors that may cause unacceptable power quality for the utility grid.

1.6 PROBLEMS DUE TO HARMONICS

Due to the presence of the harmonics, problems can occur both on the customer side and on the utility side.
1.6.1 Problems on the Customer Side

- Many home appliances are very sensitive to the power quality problems (lighting flicker, blinking of VCR, digital clocks)
- Automated manufacturing process can shut down in case of short voltage dips
- Increased losses and temperature in Induction and Synchronous machines
- Computers and communication systems are very much sensitive to power system disturbances which can lead to loss of data

1.6.2 Problems on the Utility Side

- Increased Transmission and Distribution losses
- Dangerous overheating in cables and additional stressing of cable insulation
- Higher earth fault currents
- Errors in Energy meters which are calibrated to operate under sinusoidal conditions
- Incorrect operation of protective relays particularly in solid static and microprocessor controlled systems

1.6.3 Effect of Harmonics on Equipment

Most power equipment is designed to operate at fixed frequency sinusoidal voltages and currents. The presence of harmonics will naturally have unwarranted effects on these equipment. The degree to which harmonics can be tolerated depends on the type of load consuming these harmonics. The
following Table 1.1 summarizes the consequences of harmonic distortion on industrial electrical equipment.

### Table 1.1 Consequences of Harmonic Distortion on Equipments

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Equipment</th>
<th>Consequences of Harmonics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Circuit Breakers</td>
<td>False tripping</td>
</tr>
<tr>
<td>2.</td>
<td>Capacitors for PF correction</td>
<td>Blowing of fuses, overheating, Bursting, Series and Parallel resonance. Overvoltage and high circulating current</td>
</tr>
<tr>
<td>3.</td>
<td>Telecommunication lines</td>
<td>Interference</td>
</tr>
<tr>
<td>4.</td>
<td>Induction type energy meters (Electro mechanical)</td>
<td>Reads high</td>
</tr>
<tr>
<td>5.</td>
<td>Average reading energy meters</td>
<td>Reads low</td>
</tr>
<tr>
<td>6.</td>
<td>Fluorescent lamps</td>
<td>High peak voltage value due to harmonics, reduces life</td>
</tr>
<tr>
<td>7.</td>
<td>Protective relays</td>
<td>Incorrect Operation</td>
</tr>
<tr>
<td>8.</td>
<td>Fan motors</td>
<td>Electronic regulators produce a hamming</td>
</tr>
<tr>
<td>9.</td>
<td>Neutral if 3 phase 4 wire system</td>
<td>Increased zero sequence current. Neutral conductor size to be increased.</td>
</tr>
<tr>
<td>10.</td>
<td>Rotating machines</td>
<td>Increased loss and insulation failure</td>
</tr>
<tr>
<td>11.</td>
<td>Transformers</td>
<td>Saturation and increased copper and iron loss</td>
</tr>
<tr>
<td>12.</td>
<td>Drive power supplies</td>
<td>Increased noise, device failure, mechanical fatigue, mis-operation due to zero cross over</td>
</tr>
<tr>
<td>13.</td>
<td>Electronic/SMPS devices</td>
<td>Generates high third harmonics, if uncorrected causes erratic operation, even shut down</td>
</tr>
<tr>
<td>14.</td>
<td>Computers</td>
<td>Malfunctions in disks and drive motors</td>
</tr>
<tr>
<td>15.</td>
<td>Sags</td>
<td>Fuse overheating to the extent that even minor spikes causes them to blow</td>
</tr>
<tr>
<td>16.</td>
<td>Cables</td>
<td>Insulation failure due to heating effects of high frequency harmonics corrosion of Aluminum cables with even harmonics and DC component, heating losses</td>
</tr>
<tr>
<td>17.</td>
<td>Lighting</td>
<td>Ballast failure due to circuit resonance. Irritating flicker especially on fluorescent lamps.</td>
</tr>
</tbody>
</table>
1.7 HARMONIC DISTORTION STANDARDS

These problems have resulted in standards being developed by bodies such as the IEEE and IEC to limit the amount of harmonic current that can be injected into the distribution system based on the type of equipment. Key and Jih-Sheng Lai (1993). The standards with regards to harmonic considerations are summarized as follows:

- IEEE standard 519, 1981 Duffey and Stratford (1989) gave the first guidelines for system harmonic limitations. Below 69 kV it was recommended in that document that the voltage distortion needs to be kept less than 5%.

- IEEE standard 519 was revised in 1992. The 5% voltage limitations remain while there is a limitation on current distortion at the point where the utility and customer tie together. This limit on current distortion is in the range of 2.5% to 20% depending upon the size of the customer and the system voltage.

- ANSI/IEEE standard 18 gives limitations for shunt capacitor banks that allow for significant harmonic distortion.

- ANSI/IEEE standard C 57.110 gives the limitations for current distortion in transformers at 5% of full load.

- ANSI/IEEE standard C 57.110 gives a recommended practice for establishing transformer capability when the current distortion exceeds 5%.

- A 1992 draft revision of ANSI C 82.1 “Specifications for high frequency lamp ballasts” recommends a maximum current THD of 32%.
The IEEE recommended practices and harmonic control guidelines limit the harmonic contents and the distortions caused by them in the waveform to a certain level. The distortion level is gauged in terms of the THD, defined in Equation (1.1),

\[
\text{THD}_I = \sqrt{\sum_{n=2}^{\infty} \frac{i_n^2}{i_1^2}}
\]  

(1.1)

where, the $I_n$ is the rms value of the current harmonics and $I_1$ is the rms value of the fundamental current component. However, this can be often misleading. To account for the loading effect for characterizing the harmonic currents in a consistent fashion, the IEEE Standard 519-1992 defines an additional term, the Total Demand Distortion (TDD). This term is the same as THD except that the distortion is expressed as a percent of rated fundamental load current rather than of the fundamental current magnitude at the instant of measurement. TDD is therefore given by Equation (1.2),

\[
\text{TDD}_I = \sqrt{\sum_{n=2}^{\infty} \frac{i_n^2}{i_L^2}}
\]  

(1.2)

where, the $I_n$ is the rms value of the current harmonics and $I_L$ is the rated demand of the fundamental current component. Therefore, IEEE Standard 519-1992 recommended harmonic current limits, shown in Table 1.2. It is expressed in terms of current TDD, rather than current THD. The $I_{sc}/I_L$ ratio is the short circuit ratio at PCC. As $I_L$ is previously defined, $I_{sc}$ is the short circuit current available at the input of the nonlinear load. The short circuit ratio defines the TDD limit that applies to a distribution transformer output, and therefore to the loads connected to it. The IEEE Standard 519-1992 recommended harmonic voltage limits, shown in Table 1.3. It is given for the maximum harmonic components and for the voltage THD. These values are expressed as the percentage of the fundamental voltage.
Table 1.2 IEEE 519 Harmonic Current Limits

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>I_{sc}/I_{L}</th>
<th>&lt;11</th>
<th>11≤h&lt;17</th>
<th>17≤h&lt;23</th>
<th>23≤h&lt;35</th>
<th>35≤h</th>
<th>TDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>&lt;20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>2.</td>
<td>20-50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>3.</td>
<td>50-100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>4.</td>
<td>100-1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>5.</td>
<td>&gt;1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Table 1.3 IEEE 519 Harmonic Voltage Limits

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Bus Voltage at PCC</th>
<th>Maximum Individual Harmonic Component %</th>
<th>Maximum THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>69kV and Below</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>2.</td>
<td>69.001kV through 161kV</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>3.</td>
<td>161.001kV and Above</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

In this thesis, the THD index is used for both current and voltage. They will be distinguished by using THD_I and THD_V for current and voltage harmonics measurement, respectively.

1.8 POSSIBLE SOLUTIONS FOR HARMONIC PROBLEMS

Various harmonic reduction techniques have been developed to meet the requirements imposed by the harmonic standards. The intent of these techniques is to make the input current a pure sinusoidal waveform, so as to reduce the overall current THD. The following are the possible solutions for the harmonic related problems.

Transformer connections: Transformer connections can be employed to reduce harmonics in three phase systems. Phase-shifting half of
the 6 pulse power converters in a plant load by 30 degrees can approximate the benefits of 12 pulse loads by dramatically reducing the fifth and seventh harmonics. Delta connected transformers can block the flow of zero sequence harmonics from the line. Zigzag and grounding transformers can shunt the triplets off the line. Transformers need to be rated or derated to handle the high harmonic currents. Filters can be applied at the loads to reduce harmonics throughout the system. This may reduce the k-factor of the transformer needed as well as the neutral current requirement.

**Using capacitor banks:** In medium and low voltage systems where harmonic distortion is excessive, capacitor banks can be applied to reduce the harmonic distortion. When determining the optimum filter requirements, power factor should also be considered in the evaluation.

**Passive filters:** In passive filters, the flow of the undesired harmonic currents into the power system can be prevented by the usage of a high series impedance to block them or divert them to a low impedance shunt path. These two methods represent the concept of the series passive filters and the shunt passive filters, respectively. Series passive filters can be purely inductive type or LC tuned type. AC line reactor filter and DC link inductor filter are the two purely inductive type filters. Both AC line and DC link inductance insertion methods provide a limited amount of THD reduction that is not sufficient to comply with the IEEE 519 standards shown in Figure 1.2.

![Figure 1.2 AC Line Reactor and DC Line Inductance Based Passive Filtering](image)
The tuned series passive filter, shown in Figure 1.3, is connected in series with the load. The filter consists of parallel inductance and capacitance that are tuned to provide high impedance at a selected harmonic frequency. At fundamental frequency, the filter is designed to yield low impedance, thereby allowing the fundamental current to flow. For blocking multiple harmonics, multiple series filters are needed. They must be designed to carry a full rated load current as they are connected in series to full line voltage. Therefore, they can create significant losses at the fundamental frequency.

In contrast, shunt passive filters carry only a fraction of the current that a series filter must carry. Given the higher cost of a series filter, and the fact that shunt filters may supply reactive power at the fundamental frequency, the most practical approach usually is the use of shunt filters. A shunt filter offers very low impedance path at the frequency to which it is tuned and it shunts most of the harmonic current at that frequency. Most common shunt filter types are the single tuned filters and high-pass filters. These two filters are relatively simple to design and implement among the other shunt types. The layout of common shunt filter types is shown in Figure 1.4.
They are relatively inexpensive when compared with other types of filters used for reducing harmonics. The limitations of passive filter are as explained by Das (2004)

1) The design of L and C is very difficult and it is bulky in size.

2) Source impedance, which is not exactly known, strongly influences the filter characteristics.

3) Change of series resonance with the source impedance.

4) It generates high noise.

5) The performance of a passive filter is strongly dependent on the system impedance at the harmonic frequencies. The system impedance depends on the distribution network configuration and the loads.

6) Therefore, design of passive filters involves thorough system analysis in order to obtain adequate filtering performance of the filter.

**Power Electronics Based Active Filters:** Although advancements in semiconductor device technology have led to an increase of harmonic pollution in distribution systems, they have also provided potential solutions
to the problem. Active harmonic compensation (filtering) method is relatively a new technique for eliminating current harmonics from the line. The basic idea of Active Filter (AF) is to inject equal magnitudes of the current/voltage harmonics generated by the nonlinear load with 180 degrees phase difference to the line so that they cancel each other. These AFs offer solutions to some of the shortcomings of passive compensation. Theoretically, a SAF can dynamically adjust the impedance it presents to the system to act as a short circuit to the system at the harmonic frequencies. This would allow the filter to shunt the harmonics and prevent them from feeding back into the utility grid. An AF system could provide the same compensation capabilities as a much larger bank of tuned LC filters and potentially reduce overall system cost.

AFs can be classified based on converter type, topology, and number of phases. The converter type can be either Current Source Inverter (CSI) or Voltage Source Inverter (VSI). Neither of these configurations requires an active source to perform the filtering function, but instead uses a passive storage element on the DC side of the switching network. The CSI topology uses a switching network fed by a constant current source, so the storage element is an inductor placed in the DC side of the converter (Mika Salo et al 2003). The VSI uses a voltage fed switching network and the passive element is a capacitor across the DC bus. The use of the VSI is currently favored because of improved efficiency and reduced initial costs.

The topology can be shunt, series, or a combination of both called Hybrid Filter as given by Akagi (2006). AFs of many configurations have been introduced and improved. Shown in Figure 1.5, are the fundamental configurations.
Figure 1.5 Active Filter Fundamental System Configurations
(a) Shunt Active Filter (b) Series Active Filter

The AF can be connected in shunt with the three phase lines as shown in Figure 1.5 (a). The shunt filter is controlled to inject harmonic currents to compensate for the harmonic currents drawn by nonlinear loads. The AF can also be connected in series with the power lines as shown in Figure 1.5 (b). The series AF injects correcting voltages to the power lines through a matching transformer.

AFs can be operated as standalone units or they can be designed to operate in conjunction with passive filters, called a hybrid topology (Hirofumi Akagi et al 2003). Hybrid filters consist of combinations of shunt/series AFs and shunt passive filters. The main purpose of hybrid filters is to reduce the initial costs and to improve efficiency. The passive filters reduce the bulk harmonic content of the load current, whereas the AF handles the rest of the harmonic content not filtered by the passive filters. Therefore, the rating of the AF can be decreased compared to a stand-alone AF and thus reduce the initial cost (Akagi 2006). Figure 1.6 shows two examples of hybrid filter configurations.
The third classification is based on the number of phases, such as two-wire (Costa-Castello et al 2009) (single-phase) and three phase three-wire or three phase four-wire (Cheng-Che Chen et al 2000), (Antonio Dell' Aquila et al 2003) systems. However, single-phase AFs would attract much less attention than three-phase AFs because single-phase versions are limited to low-power applications except for electric traction or rolling stock (Akagi 2006). Three phase AFs are used for high-power nonlinear loads such as Adjustable Speed Drives (ASD) and AC/DC converters. The advantages of AFs when compared to passive filters are

- The rating of AF can be less than that of a conquerable passive filter for the same non-linear load.

- The AF will not introduce system resonances that can move a harmonic problem from one frequency to another.

Of all the various configurations, the parallel AF using the voltage source inverter topology accompanied by high performance current regulation
methods is the most frequently employed type for the reduction of harmonics due to non-linear loads.

1.9 PROBLEM STATEMENT

An unrelenting proliferation of nonlinear loads in industrial, commercial, and residential applications requires the supply of reactive power, harmonics power, and power losses pertaining to the former two. Over a period of three decades, various types of reactive power compensators have been researched and developed for power factor correction, harmonic compensation, and load balancing (Ambrish Chandra et al 2000). The custom power device such as SAF is found to be quite suitable to cater to the aforesaid problems (Avik Bhattacharya et al 2009).

It has been established by Gyugyi et al (1976) that a VSI can instantaneously supply reactive power and compensate harmonics of the nonlinear loads. This postulate led to the formulation of the famous – theory of reactive power (Akagi 1984). According to this theory, the instantaneous reactive power compensator comprising switching device which practically does not require any energy storage components can compensate fundamental reactive power in transient states along with harmonics currents, caused by instantaneous imaginary power of the loads. Apart from reactive power theory there have been numerous other theories used to improve the performance of the active and hybrid filters. Some of them are the Notch Filter (Jora Gonda et al 2009); Flux Based Controller (Sasaki et al 1971), (Bhattacharya et al 1995); Sliding Mode Control (Saetieo et al 1995), (Nassar Mendalek et al 2002); Synchronous Reference Frame Theory (Naimish Zaveri et al 2009), (Alberto Pigazo et al 2009); Phase Angle Balance Control (Souvik Chattopadhyay et al 2003), Instantaneous Active And Reactive Current Component Method (Vasco Soares et al 2000); Optimal and Flexible Control (Rafiei et al 2002) and direct and indirect current control techniques of the
AFs (AFs). Also, attempts have been made on a reduced switch AF system (Brij Singh et al 2007) and four-pole topology (Robert Griñó et al 2007) of the AF system.

Even though there are many types of active filters available, most of the studies in literature favor the shunt-connected topology for harmonic current compensation. The main issue related to the effective operation of SAF is its controllability to compensate reactive power, harmonics, and unbalanced loading. However, the major disadvantages of most of the AF controllers are (Ali Ajami et al 2006):

1. They need to low pass filters to separate the average and oscillating parts of instantaneous powers. This factor introduces time delays and therefore, the dynamic performance of AF is not guaranteed.

2. They demand more calculation, since they need the use of Clark transformation, and are not suitable for hardware implementation.

So the main objective of this research work is to propose a very simple control technique to generate the reference currents for the purpose of reducing the % THD, compensate the reactive power, improve the input power factor of the system and balance the load of a three phase six pulse uncontrolled rectifier with resistor.

1.10 SCOPE OF THE PRESENT RESEARCH

In this thesis, a SAF control technique is designed and it is the result of an analytical development which supplies a design Equation for switching signal generation and effective current tracking. The proposed control
technique takes care of all the problems encountered in the previous techniques. The proposed control technique is not based upon the PQ theory so there is no need for any transformation. In fact, it is very simple and effective.

Simulations on various loads were carried out in MATLAB/SIMULINK to show AF performance under highly polluting load operation and the results confirmed the effectiveness of the proposed technique. The various loads and conditions used for the simulation in the thesis are these:

1. Balanced Supply with Constant R load
2. Balanced Supply with Variable R load
3. Balanced Supply with unbalanced load
4. Unbalanced Supply with balanced load
5. Distorted Supply with balanced load

It is shown that as the load varies control methods adjust themselves to the new conditions and use the tradeoff between compensation and power dissipation for the best possible outcome. As well as in order to verify the effectiveness of the proposed control technique, it is compared with other techniques like Sinusoidal Multiplication method, PQ theory and Synchronous Detection method. The simplest control technique for current controlled PWM inverters, used as an APF, is hysteresis control. However, at critical points, where changes of reference waveform slope are unpredictable, hysteresis control causes a dangerous increase in switching frequency which cannot be justified, even if it has the advantage of not exceeding the designed error band (Antonio Dell’ Aquila et al 2003). So in this thesis an adaptive hysteresis current control is implemented and the comparison is made between HCC, SPWM, SVPWM and AHCC and the results are presented.
The proposed control technique of the AF system has been implemented using the analog components as well as on a (Field Programmable Gate Array) FPGA system for power-factor correction, harmonic elimination and reactive power compensation of nonlinear loads. Dynamic and steady state performances of the AF system have been observed under different operating conditions of the load. The proposed control technique of the AF has an inherent property to provide a self-supporting dc bus and requires less number of current sensors resulting in an overall cost reduction. However, this technique faces the problem of rigorous hit and trial analysis to evaluate the controller parameters of the system. So the soft computing techniques like NN, FLC, Neuro Fuzzy and GA are also used to perform the calculations to develop the reference currents.

1.11 ORGANIZATION OF THE THESIS

The thesis is organized into six chapters, including this first chapter which reviews the power quality issues and standards. It explains the types of power quality problems, sources of harmonics, symptoms of harmonics and problems due to harmonics on various equipment. It also discusses various solutions for harmonic problem and their short comings.

Chapter 2 reviews the various literatures related to the area of research.

Chapter 3 describes the preliminaries of the SAPF, modeling of the SAPF, various design parameters of the SAPF and the nonlinear load considered for the analysis. It explores the proposed technique for calculating the reference current based on the average power algorithm and the HCC. It also analyses the proposed technique under various conditions like balanced supply voltage, unbalanced supply voltage and unbalanced load. It also brings out the detailed comparison between the results obtained through the proposed
technique with other popular methods like PQ theory, Sinusoidal Multiplication and Synchronous Detection Method.

Chapter 4 details the technique for the practical implementation of the proposed technique in both analog and digital way. In analog implementation method the proposed technique is realized through the op amp based circuits. In digital implementation FPGA SPARTON 3A DSP is used for implementing the control algorithm. It compares the results of the hardware implementation with the simulation methods.

Chapter 5 addresses the use of soft computing technologies for the power quality improvement. It provides theoretical description regarding Artificial Neural Networks (ANN), FL, Neuro Fuzzy and GA. It explains the implementation of these computational intelligence techniques for the SAPF application. It brings out the comparison between the results of the original algorithm with the soft computing methods.

Chapter 6 concludes the thesis with some suggestion on the scope for future work. The appendices that follow consist of details of data used for NN training and AHCC bands.