Chapter 1
Overview

Industrial loads have thyristor control which generates harmonics. These harmonics affect the quality of power supply, generating over voltages due to harmonic resonance. higher losses and poor power factor. Electrical utilities are imposing strict norms on the levels of harmonic injection. Hence industries are forced to provide filters at the incoming buses, having frequency equal to that of harmonics to be filtered. The efficiency of these filters changes with the system configuration of the utility looking from the bus. Since the change in configuration is beyond the control of the consumer, it is necessary to find a method to make filter independent of the system impedance.

This can be done by the electronic controllers, which injects the equivalent voltage at the neutral end of the filter proportional and in phase opposition to the harmonic current injected into the system. Such systems are described in the literature but no commercial design is available. Theoretical aspects are well understood but the practical utility and cost analysis for a given load are to be investigated. It is mandatory for the industrial houses to provide filters at the incoming buses, to maintain quality of the power supply, so there are strict norms on level of injecting harmonics. At the same time it is desirable to have the filter to be independent of the system configuration.

Project envisages the development of an electronic controller to improve the performance of a passive filter. Ideas of the practical application of such a filter for industrial loads and cost benefit analysis have to be looked in to detail. The project provides sufficient insight into these aspects. The technical report discusses technical and economical competitiveness of the proto type. The technology can be commercialized

DSPs are group of processors suitable for the computation extensive applications. The project uses a 320C6711 DSP from Texas Instruments for implementation. It is possible to build up an active filter at the commercial scale for the loads up to 1 MW, which may require a filter rating of 100KW. Over the years there has been a continuous proliferation of nonlinear type of loads due to intensive use of power electronic control in all branches of industry as well as by the general consumers of electric energy. These equipments are designed to offer optimum performance at low running costs but affect the performance of other equipment connected in the system. These disturbances include harmonic distortion, voltage unbalance, voltage surges, increased reactive power demand and power system fluctuations etc.

Harmonic contamination has become a major concern of power system specialist due to its effects on sensitive loads and on power distribution system. Harmonic current component increase power system losses, causes excessive heating in rotating machinery, can create significant interference with the commutation circuits that shared common right of ways with ac power lines, can generate noise on regulating and control circuits causing erroneous operation of such equipments. The effect of voltage and current harmonics can be noted at far of places in equipment connected to the same circuit.

Large part of total electrical energy produced in the world supplies different type of non-linear loads. Static Converters (SC), in most of the cases generates line currents at multiples of the AC line frequency. In three-phase drives they generate a series of currents at harmonics 5, 7, 11, 13, 17, 19 and other higher odd multiples of the fundamental frequency [1], [2]. The amplitude of these harmonics depends on the type of SC circuit.

Thyristor drives (SCR), generally used in the higher power applications, the harmonic amplitudes are equal to the reciprocal of the harmonic order, thus 20% for the 5th, 14% for the 7th, 9% for the 11th and so on. The "diode front end" drives can present even higher 5th and 7th harmonic distortion, reaching levels of 60% and 30% of the fundamental respectively.

The non-linear loads to AC mains produce harmonic currents, which lead to low power factor, low energy efficiency and harmful disturbance to other consumers. Unity power factor rectifiers and active power filters can eliminate these harmonics and improve the overall power factor. Several hardware solutions and different control strategies based on Digital Signal Processors were presented.

The harmonic currents flow in the utility supply lines and produce extra losses and cause voltage distortion. Besides interfering to data communications, telephone circuits, digital controls, they can also overheat transformers and supply apparatus. Harmonics can flow also into power factor capacitors, power cables and be magnified by resonance, seldom with disastrous results. The modern technology processes are very vulnerable to power supply quality. The international standards (IEC 1000-3-2 and IEEE 519-1992) allow a certain level of harmonic current depending on the source short circuit ratio. At a ratio of 20 or less, the norms allows only 5% total current harmonic distortion. It is obvious that neither an SCR drive with 30% distortion nor a diode supplied PWM drives with 60% or greater, does not meet the imposed limits and contra-measures must be taken [3].

For those involved in the generation and distribution of electricity, reducing or even canceling the harmonics in the supply is essential in both economic and technological terms, this will help to achieve maximum utilization of plant and equipment is a significant overall economic factor. Passive filters can remove only one of the harmonics. Since the current cannot be controlled they produce reactive power. IGBTs made it possible to have a power switch with nearly ideal performance and reliability. Active Power Filter (APF) Fig 1.1 may be used.
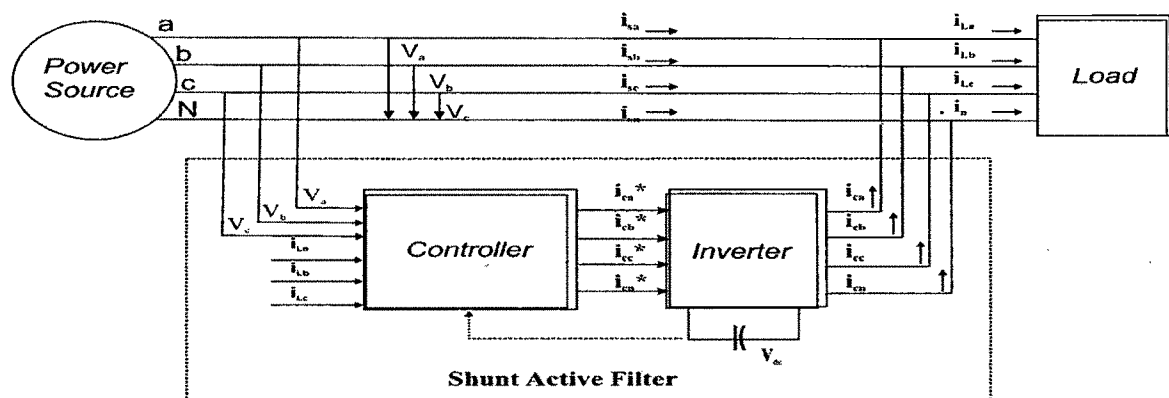

Fig 1.1: Shunt Active Filter in Three Phase Power System

The inverter for APF applications present a fourth IGBT leg or a centre tap on the main filtering capacitor battery which is connected to the neutral [4]. This type of inverter can operate as a current source, a PI current regulator being used on each phase. In the first case the control system calculates in real time the harmonics in the load current which are applied as references to the inverter in order to cancel them and to guarantee a sinusoidal form for the supply current, such a solution is called Shunt Active Filter [5].

The technique called "The Generalized Theory of the Instantaneous Reactive Power in Three-Phases Circuits" or p-q theory was developed by Akagi et al. [7] starting with the classical change of coordinates from ABC to α, β, 0 for the three phase voltages and currents. For sinusoidal voltage references only first harmonic currents are producing non zero average active and reactive power. Consequently, by some simple calculations one can determine the fundamental of the load currents and respectively their harmonics [8], [9]. APF developed in the project uses active compensation technique.

The active filtering system is based on a philosophy that addresses the load current distortion from a time domain rather than a frequency domain approach. The most effective way to improve the power factor in a non-sinusoidal situation is to use a nonlinear active device that directly compensates for the load current distortion. The performance of active filters is based on three basic design criteria.

    1. The design of the power inverter
    2. PWM control method
    3. Control strategy used to generate the reference template

The active power filter concept uses power electronics to produce harmonic current components that cancel the harmonic current components generated by non-linear loads. The active power filter configuration is based on a pulse-width modulated (PWM) voltage source inverter that interfaces the system through a system interface filter as shown in Fig 1.2.
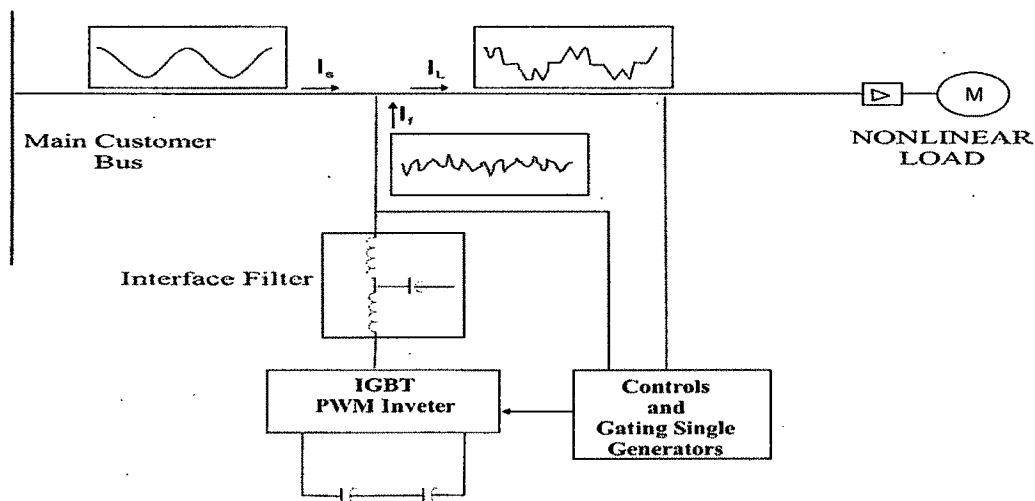

Fig 1.2 Shunt APF with waveforms

The filter is connected in parallel with the load. The voltage source inverter used in active power filter makes the harmonic control possible. Inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal which cancels the harmonics. The harmonic currents to be cancelled out show up as reactive power. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated according to the reactive power associated with the harmonics to be cancelled and on the actual current waveform (rms and peak current magnitude) that must be generated to achieve the cancellation.

The current waveform for canceling harmonics is achieved with the voltage source inverter in the current controlled mode and an interfacing filter. The filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors IGBTs in the inverter. Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance.

The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter. This is important because relatively high values of di/dt may be needed to cancel higher order harmonic components. Therefore, there is a trade-off involved in sizing the interface inductor.

A larger inductor is better for isolation from the power system and protection from transient disturbances. However, the larger inductor limits the ability of the active filter to cancel higher order harmonics. The control strategy of active filters has great impact not only on the compensation objective and required kVA rating of active filters, but also on the filtering characteristics in transient state as well as in steady state. There are two types of control strategies for extracting current or voltage harmonics from the corresponding distorted current or voltage: Fourier analysis and p-q theory. The p-q theory is applied for design of controller.

The active filter current imposes the peak value of the current which is bi-directional. An appropriate semiconductor device may be an IGBT with an anti- parallel diode and must be protected against over current. The capacitor provides DC voltage with acceptable ripples. In order to assure the filter current at any instant, the DC voltage V_{dc} must be at least equal to 3/2 of the peak value of the line AC mains voltage. The shunt three-phase four-wire active filter configuration is composed from a conventional three-leg with a dynamic hysterisis-band PWM current control and active filter controller that realizes an "instantaneous" control algorithm.

The inputs of this controller are the instantaneous phase voltages and load currents. Its outputs are the instantaneous three-phase current references $i_{ca}{}^*$, $i_{cb}{}^*$, $i_{cc}{}^*$ The voltage regulator supervises the dc capacitor voltages and provides two control signals, $\overline{p}_{loss}$ and ε as shown in Fig.1.3. The signal $\overline{p}_{loss}$ compensates for losses in PWM converter, which tends to discharge the capacitors C_1 and C_2. The signal ε is the dynamic offset level used to control the capacitor voltage difference.
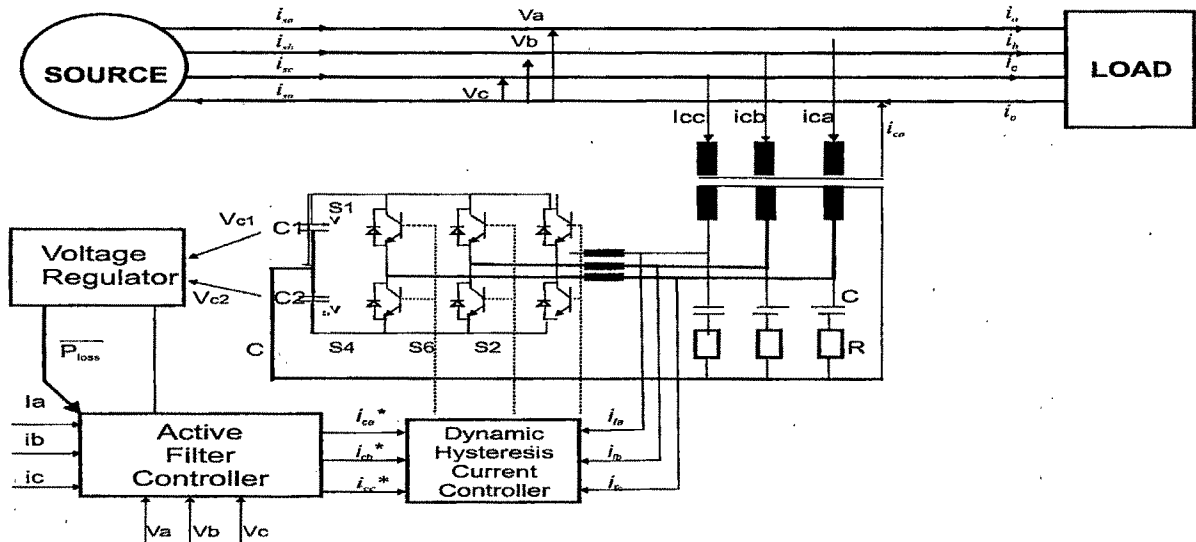
Fig 1.3 System Set up: 3- Φ four wire APF

There are mainly two configurations of voltage source inverters (VSI), which can be used in three-phase four wire systems. The fundamental difference between them is the number of power semiconductor devices.

In a conventional three leg converter the ac neutral wire is connected directly to the mid point of the dc bus, while in other configuration Fig 1.4, the fourth leg is used to provide the ac neutral is provided through a fourth leg. Since the configuration has PWM current control, it behaves as controlled current source. The ac current generated by the VSI has some high-order harmonics at the switching frequency, which can be easily filtered using a small passive filter (R and C). Ideally the currents track accurately their reference i_{ck}^* (k = a, b, c).

The four switch-Leg inverter topology Fig 1.4 is used to remove the problems related to the dc capacitor voltage control which is prominent in the three leg configuration.
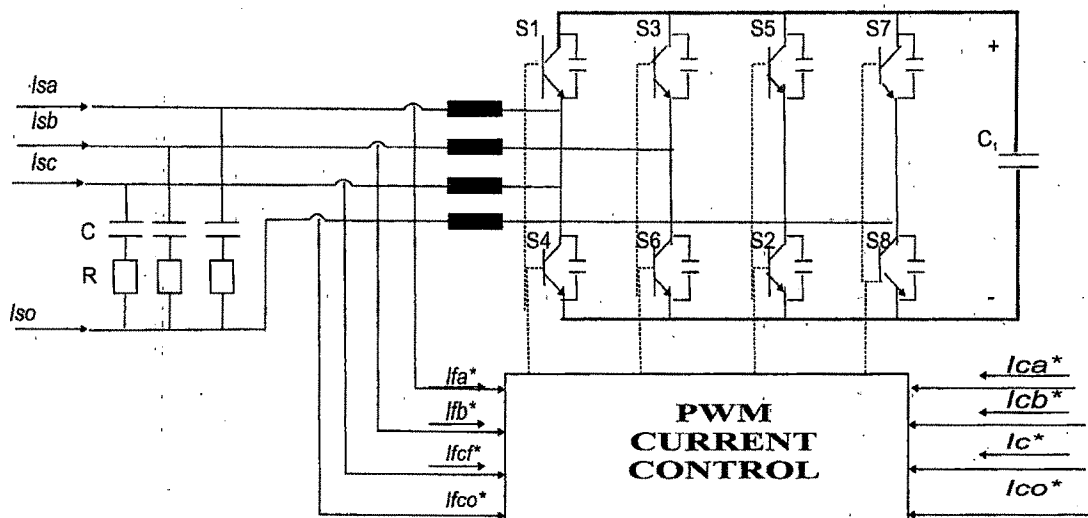

Fig 1.4 Four Leg Converter

Fig 1.4 depicts the system with a dynamic hysterisis-band PWM current control and an active filter controller that realizes an instantaneous control algorithm. The inputs of this active filter controller are the instantaneous phase voltages and line currents of the load. Its outputs are the instantaneous three-phase current references $i_{ca}*$, $i_{cb}*$ and $i_{cc}*$ should be same as previously defined Active power filter consists of: Power circuit and a control circuit. The power circuit consists of 3-phase PWM inverter. The controller generates the eight control signals of eight switches of PWM inverter. The controller needs to compute generated 3 $-\varphi$ compensating current and generate eight signals from these compensating currents using dynamic hysterisis current control.

Instantaneous reactive power theory (p-q theory) is used to implement the control signal generator unit of APF. The **p-q theory** compensates the current of a non-linear load such that the compensated current shall draw a constant active power from the network, even if the system voltage is already distorted. It provides constant real power to the source. The active filter compensating currents are obtained from the instantaneous active and reactive powers p and q of the non-linear load respectively.

The use of software development support tools such as MATLAB, SIMULINK and Tool Boxes [13-17] makes simulation study as well design of graphical user interface simpler.
The work described in the thesis includes:

- Design and implementation of control signal generator unit using TMS320C6711 DSP For Three Phase Four Wire Shunt Active Power Filter [18-20] which generates the firing Pulses, which can be given to the power circuit of Active Power Filter. Two alternatives Embedded configurations;
  - Hybrid or mixed embedded controller employing analog components and software [21-23] (High resolution Setup)
  - Software based Embedded Controller (Low Resolution Setup)[24] ... is proposed.

- Use of p-q theory, which is suitable for analysis of nonlinear three phase systems and for the control circuit of Active Power Filter. The implementation of active power filters based on p-q theory are cost effective solutions, allowing the uses of a large number of low-power active power filters in the same fashion. close to each problematic load (or group of loads), avoiding the circulation of current harmonics, reactive currents and neutral currents through power lines.

- Development of Control circuit for three phase four wire shunt active filter. With some small modification it can be developed for the series active filter.

- p-q theory is used for simulation and implementation However the d-q theory, FFT or Notch Filtering can also be used as control strategy.

- Software development using MATLAB®/SIMULINK® and Code composer Studiov2.1® from TI for TMS320C671X series of DSP processors. [13-15,18-19]

- DSP processor is used to generate corresponding compensation currents for particular harmonic current.

* Realization using analog control circuits.

* Voltage and current harmonics as well as the non symmetric component of the load current cancellation based on specialized DSP developed by TI 320C671X series providing an inexpensive solution [20-24]

The thesis is organized in the form of ten chapters as follows:

Chapter: 2   The general preview of the configuration and Control strategies of Active power filters for control circuit as well as power circuit.

Chapter:3   Describes the survey of current trends in design and applications of Active power filters for control circuit as well as power circuit

Chapter: 4   It provides a comprehensive study of the work done by the researchers for the analysis of active power filter.

Chapter: 5   Discusses Design, Analysis and Simulation of power circuit for the proposed APF filter. The chapter includes the implementation of Power circuit.

Chapter: 6   Describes the development of the control circuit for APF. Simulation study of control strategy using MATLAB/SIMULINK.

Chapter: 7   It contains the development and design of analog controller card for APF. Test results are also depicted and discussed.

Chapter: 8   Software development of control circuit for DSP Implementation. It also describes proposed alternatives, Mixed Setup and Software based Setup for embedded controller.

Chapter: 9   It contains discussion of the results obtained using Analog controller and the embedded controller employing DSP. The scope for future work is also discussed.

Chapter:10   It contains Bibliography.