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A Three Phase Shunt Active Power Filter Based on Instantaneous Reactive Power Theory

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ABSTRACT—Active power filters have become very popular inAC power networks for reducing harmonic pollution and for Reactive e power compensation. The network containing non-linearloads like power converters are provided with either shunttype or series type active power filter for improving THD. Italso improves voltage regulation and flicker unbalance. Theinstantaneous power theory also known as p-q theory is usedfor most of the active power filters. Shunt active power filter forthree phase three wire AC network is explained in this paper.Instantaneous reactive rower theory is used in proposed shuntactive power filter for extracting harmonic from source currents.The simulation results on MATLAB/simulink tool are presented.

Keywords - Active Power Filter (APF), Voltage SourceInverter (VSI), THD, p-q theory, PWM

I. INTRODUCTION

Harmonic is a word that not only threatens the utilitiesbut also the consumers. Both current and voltage harmonicsare said to be pollutants in sinusoidal AC networks. Theseharmonics will result in lot of undesirable phenomena.The main cause for the harmonics are non-linear loads.Non-linear loads are classified into two types, identified andunidentified [1]. High power converters, cycloconverters, highpower thyristor rectifiers are the identified type of non linear

load. Because harmonics produced by them and its effect ongrid can be easily observed by utilities. Harmonics injectedat point of common coupling (PCC) by these identifiedloads can be seen and can be eliminated individually. A lowpower diode rectifier, low power appliances having powerelectronic elements are the unidentified type of non-linear load.

Electrical machines, transformers, measuring instruments,consumer appliances are mostly affected by harmonics. Itdirectly attacks on performance of machine and reduces itslife span.

Initially passive filtering was popular solution for mitigatingharmonics [2]. They have some advantages such as simplicity,reliability, efficiency and cost. But due to their limitations likeresonance and frequency specific tuning they are becomingless popular. To overcome with these disadvantages, recentefforts have been concentrated in the development of activefiltering techniques. The active power filter uses powerelectronic switching to generate harmonic currents. Generatedharmonic currents are injected into the line which cancelthe original harmonics components. Shunt and series activefilter are the basic two types of active power filter, whichsuppress voltage and current harmonics respectively [3]. Theinstantaneous reactive power theory is very popular amongother control strategies available for active power filters.The aim of this work is to implement the p-q theory onthree phase shunt active filter connected directly to powersystem for suppressing current harmonics. The technique isimplemented by using MATLAB/Simulink development tool.

II. INSTANTANEOUS REACTIVE POWER THEORY.

In 1983, Akagi [4] proposed the generalized theory ofthe instantaneous reactive power in ac networks. It is alsoknown as instantaneous reactive power theory, or p-q theory.This theory is valid for three phase three wire, three phasefour wire as well as single phase networks. The first step inp-q theory is an algebraic transformation of the three-phasevoltages and currents from a-b-c coordinates to theα-β-0coordinates. Clarke's transformation is used to complete thistask. The a, b, and c axes are fixed on the same plane. Theyare placed 120^0 apart from each other. αand β axes areplaced 90^0 from each other. Three phase voltages andcurrents are represented as space vectors [5] and these spacevectors are transformed into α-βcoordinates as follows.

III. HARMONIC DISTORTION IN NON-LINEAR LOADS:

The specific object of power quality is the pureness of supply including voltage variations and waveform distortion. Harmonics arise whenever non-sinusoidal currents and/or voltages are generated in the power system, they are generally referred to as harmonic distortion.

Harmonics are one of the major power quality concerns. Harmonics cause distortions of the voltage and current waveforms, which have adverse effects on electrical equipment.

Some examples of nonlinear loads are:

• Computers, copy machines, and television sets
• Static var compensators (SVCs) , HVDC transmission
• Electric traction, Wind and solar power generation
• Battery charging and fuel cell, Slip recovery schemes of induction motors
• Fluorescent lighting and electronic ballasts

Simulation of non-linear load is necessary to analyse harmonics.

IV.P-Q THEORY:

Akagi proposed a theory based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms called as Instantaneous Power Theory or Active Reactive (p-q) theory which consists of an algebraic transformation (Clarke transformation) of the three-phase voltages in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & {}^{1}/_{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -{}^{1}/_{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix}$$

V.COMPENSATION STRATEGY :

The reactive and harmonic compensation is carried by injecting appropriate currents into the circuit through a compensator i.e., shunt active filter as shown in Fig 1.

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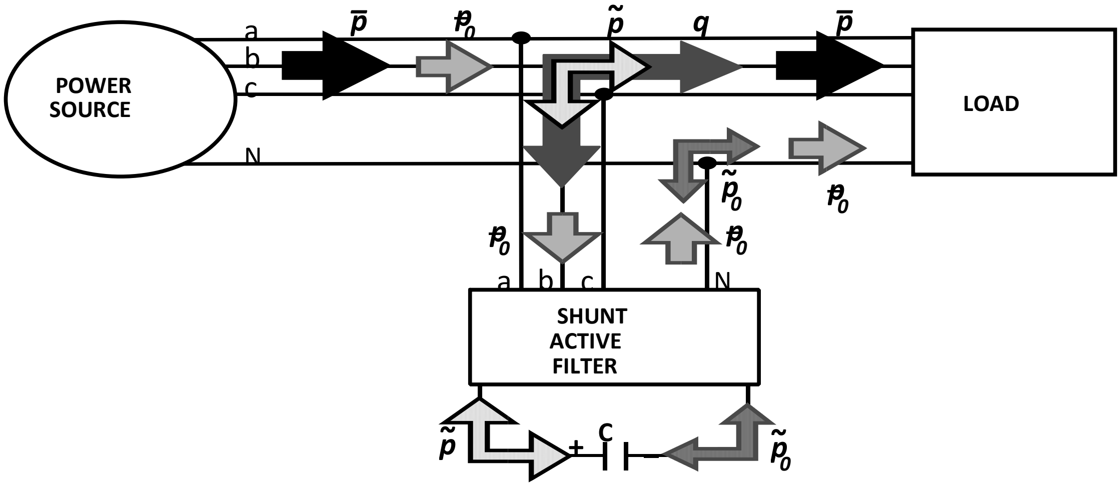

Fig:1 compensation strategie

It provides harmonic and reactivepower compensation simultaneously. Also it doesn't require any real power itself so losses are only switching losses whichare very less and can be neglected. This is the main reasonbehind the popularity of active power filtering technique. Fig.1. shows real and reactive power flows in AC networks
The calculations presented so far are synthesized and correspond to a shunt active filter control strategy for constant instantaneous supply power. This approach, when applied to a three-phase system with balanced sinusoidalvoltages, produces de following results (Fig. 2):- the phase supply currents become sinusoidal, balanced, and in phase with the voltages. (in other words, thepower supply "sees" the load as a purely resistive symmetrical load);
- the neutral current is made equal to zero (even 3rd order current harmonics are compensated);
- the total instantaneous power supplied,
p3s (t) = va·isa+ vb·isb+ vc·isc is made constant

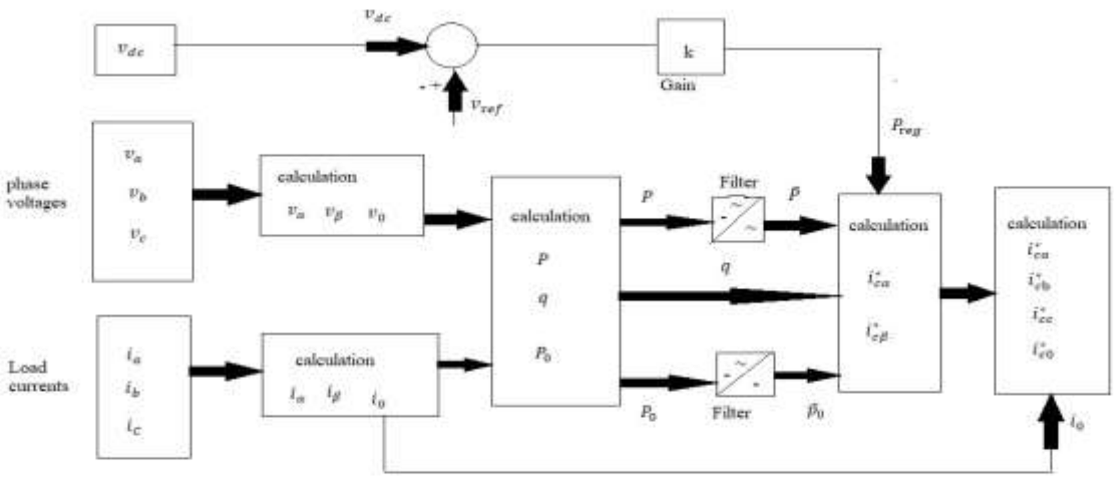

Fig. 2 – Calculations for the constant instantaneous supply power control strategy

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VI. SIMULATIONS AND RESULTS

Fig. 3 shows complete scheme implemented in MATLAB/Simulink. Pulse generator block contains reference currentcalculation and hysteresis band PWM blocks. Each blockis explained in following sections.

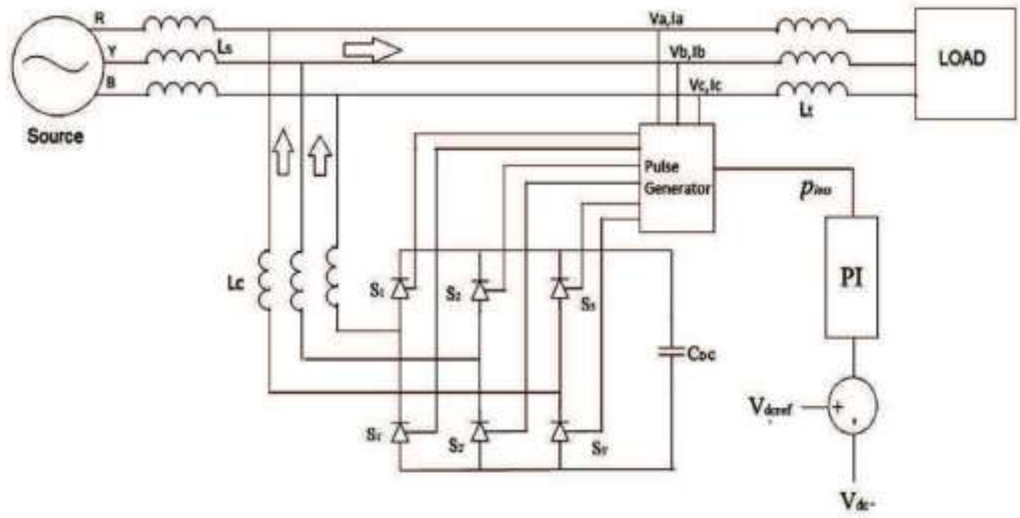

Fig:3Block diagram of representation scheme

A. Nonlinear load

`Three phase three wire 440 Volts (line to line), 50 Hzsystem is considered with source inductance of 0.3 mHand negligible source resistance. For generating harmonics,a three-phase diode rectifier with R-L load is simulated inMATLAB/simulink. First active power filter is not connectedso three phase rectifiers along with R-L load act as harmoniccurrent source. Due to this source side current contains harmonics.

Fig. 4. shows a phase source side current. As we cansee this current is highly distorted and contains harmonics.Total harmonic distortion is found to be 25.9%. Which is notacceptable as per the IEEE-519 standards.

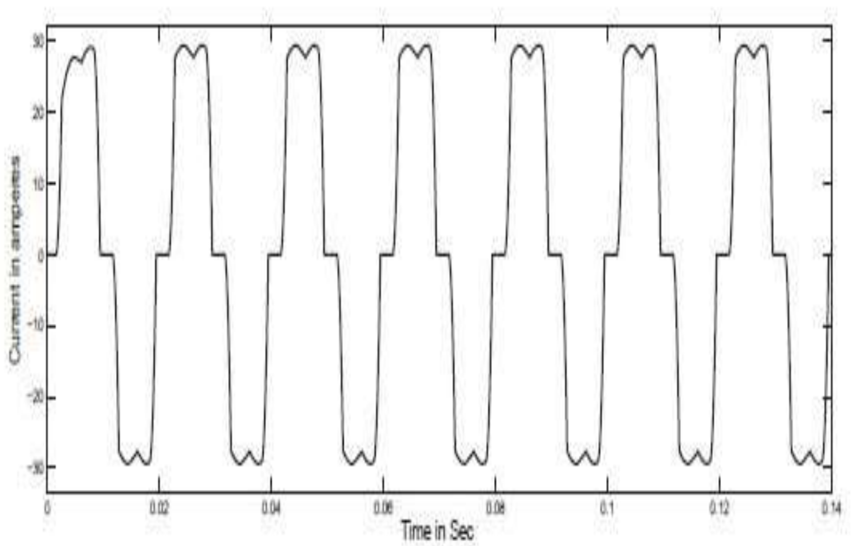

Fig:4. “a” phase current without APF

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B. Reference current calculations

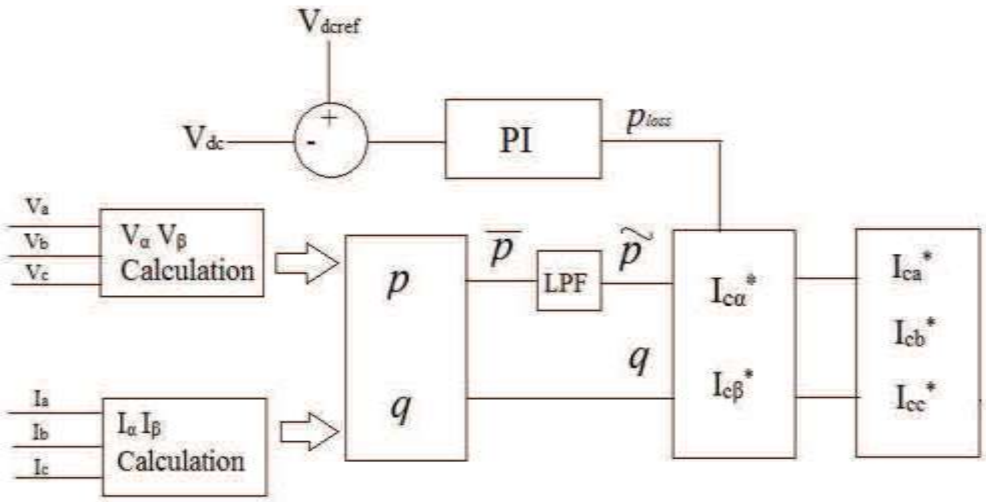

Fig.5 compensating current calculation

Fig5.shows steps involved in calculation of compensatingcurrents (ica,icb,icc). From this reference compensating currents are calculated as follows

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \frac{2}{\sqrt{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix}$$

To separate ep and p from p fifth order butterworth filter is designed

C. Voltage Source Inverter based on Hysteresis band PWM:

A three phase voltage source IGBT bridge connected inparallel with the load is acting as active power filter .Large energy storage capacitor is connected to dc side ofthe inverter. To maintain the DC side capacitor voltage PIcontroller is designed, which act as a DC voltage regulator. PIcontroller will provide ploss component to calculate referencecurrents.

D. Simulation Parameters:

TABLE I
PARAMETERS USED IN SIMULATION

parameters	values
v_s	440V,50HZ
R_L,L_L,L_S	20Ω,30mH,0.3mH
Cdf	1200µF
V_{DC}	700V
Lf	2.5mH

VII. SIMULATION RESULTS

Various waveforms without shunt active power filter andwith shunt active power filter are plotted below.

(A) Reference currents:

Fig. 6,7,8 shows compensating currents for a, b, crespectively. These currents contains all the undesirable currentcomponents. In other words these are the currents, which VSIshould draw from source.

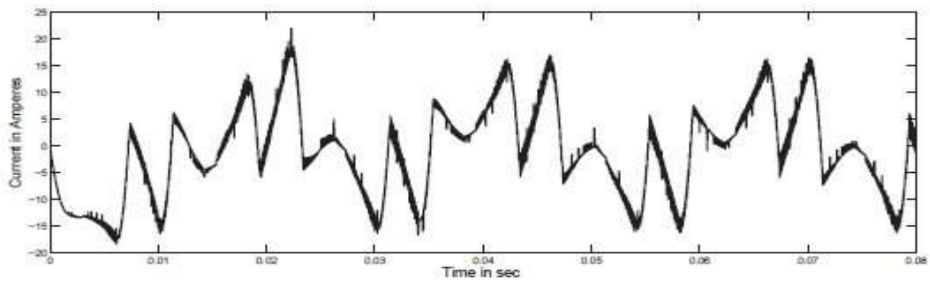

Fig 6 . a phase reference comensating current

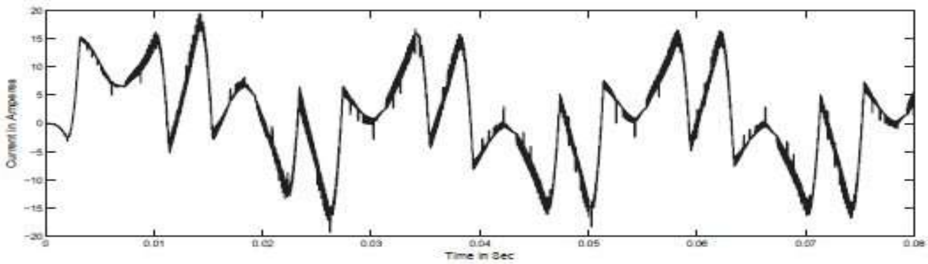

Fig 7.bphase reference compensating current

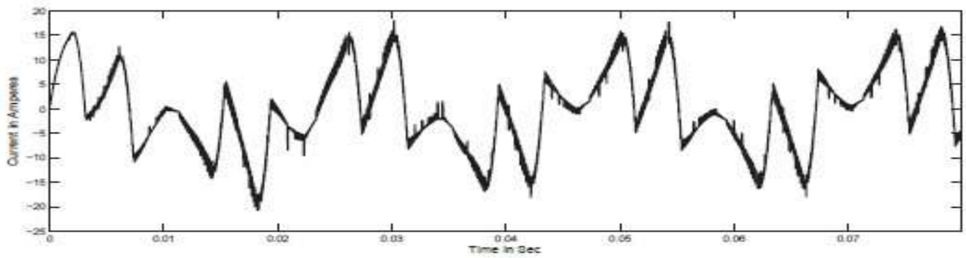

Fig:8 c phase reference compensating current

B. Source current with active power filter:

Fig.9,10, and 11 shows source currents of phase a, b, cwith APF . It is observed that nearly all dominant harmonicsare eliminated by APF, which result in nearly sinusoidal threephase current waveform. THD of these currents is found to bewithin IEEE-519 standards.

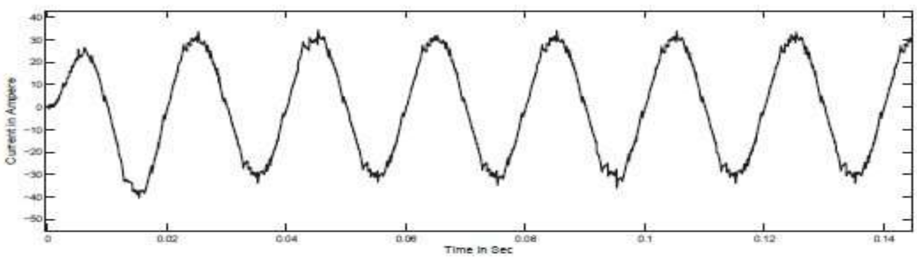

Fig 9.a phase source current with shunt APF

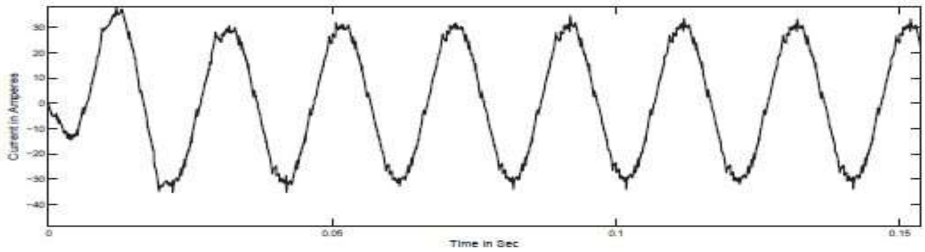

Fig 10. b phase source current with shunt APF

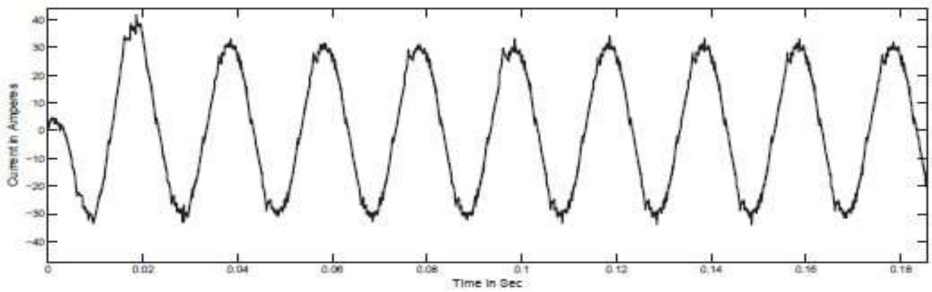

Fig11 .c phase source current with shunt APF

(C)DC side Capacitor voltage:

Large energy storage capacitor with automatic voltage regulatoris used instead of DC voltage source. PI controllermaintains capacitor voltage to desired value [8]. As seen fromFig. 12 after few seconds capacitor voltage settles to 700 volts.The advantage of active power filter is that it does not have anyactive source at DC side. So no active losses in active powerfilter. Only switching losses are present due to high switching frequency

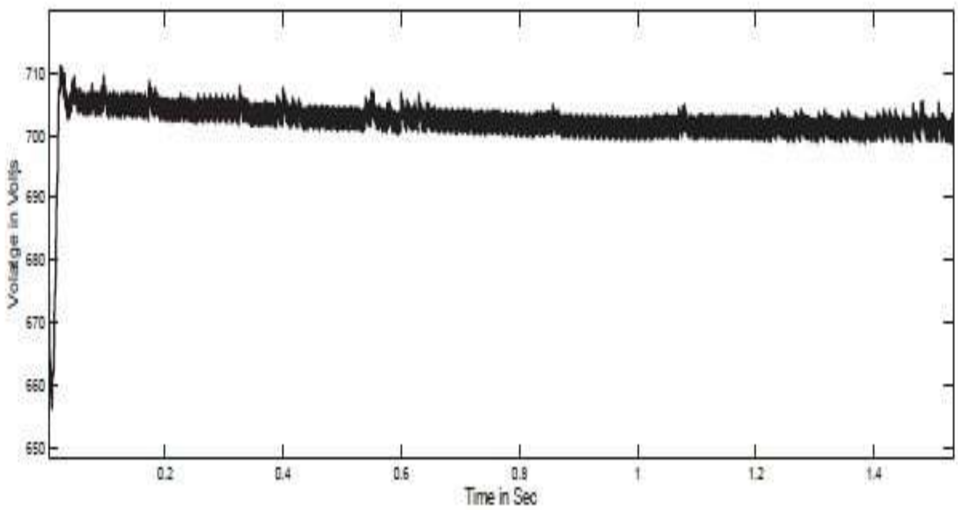

Fig. 12. DC Capacitor voltage

(D)HARMONICS REDUCTION

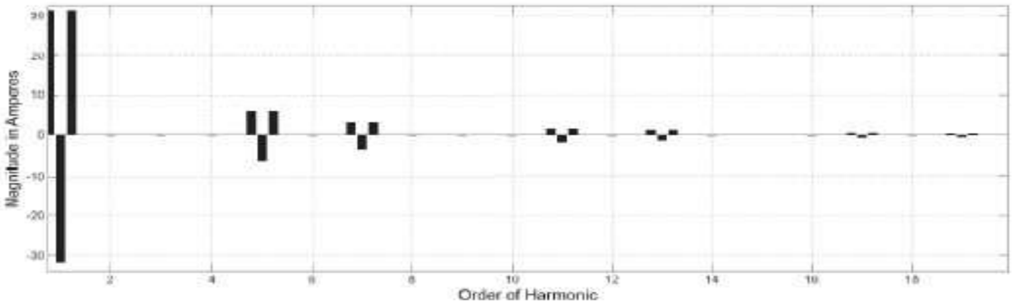

Fig 13. Harmonic spectrum of source current without APF

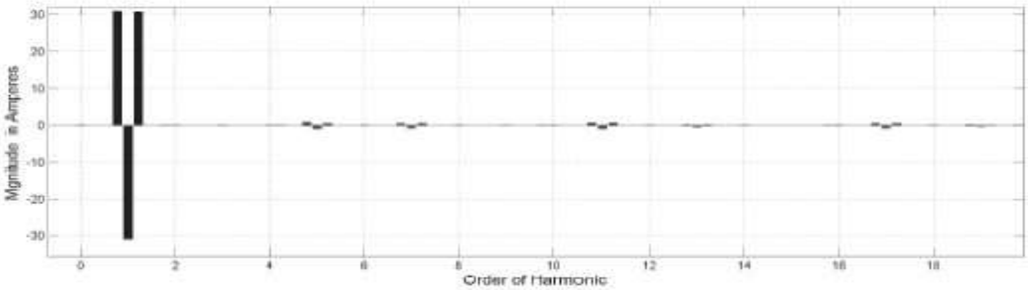

Fig.14. Harmonic spectrum of source current with APF

The comparison of harmonic spectrum in Fig.13 and14 clearly shows the reduction in the harmonics after applicationof active power filter.

% REDUCTION IN CURRENT HARMONICS:

TABLE II
Parameters Without APF With APF

parameters	Without APF	With APF
THD	25.9%	4.70%
5^{th} Harmonic	19.38%	2.46%
7^{th} Harmonic	10.81%	1.81%
11^{th} Harmonic	5.6%	2.09%
13^{th} Harmonic	3.84%	1.2%

VIII. CONCLUSION

This paper introduces a scheme for reducing current harmonicsin the three phase three wire AC network by using ashunt active power filter. Instantaneous reactive power theoryis used as a base for scheme. Result shows the accuracy oftheory for extracting harmonic currents as well as reactive current components. Hysteresis band PWM method used inthis paper is one of the easiest current control methodsfor reference current matching. Automatic voltage regulatordesigned in this paper for active power filter maintains DCside voltage constant.The proposed shunt active power filter is able to reduce supplycurrent THD below 5%, which meets IEEE-519 Standards.This control scheme also compensates for reactive powerrequirement of load.

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