Design of Shunt Active Filters based on Phase Locked Loop and PI Controller

R. Balaji, B.Mohamed Faizal

Abstract: This paper presents a active filter topology and its control technique. Active power filter topology is the most efficient way to compensate reactive power and lower order harmonics generated by non linear loads. The shunt active power filter was consider to be the most basic configuration for the APF. Different techniques have been applied to obtain a control signal for the active filters. One technique is Phase Locked Loop controller combined with PI controller, where the current waveform injected by the active filter is able to compensate the reactive power and load current harmonics. Here the simulation has been carried out through the MATLAB SimPowerSystems Toolbox and the results are tabulated. With the proposed control strategy the total harmonic distortion is reduced to a great level and hence the power factor is also improved there by towards power quality enhancement.

***Index Terms:** Active power filters, harmonics, Power quality, Phase Locked Loop.*

I. INTRODUCTION

The power electronic related facilities have been widely used in different areas. Due to the nonlinear input characteristic of the input current waveforms the power electronic related facilities might generate a large amount of harmonic problems. The harmonic current may pollute the power system causing problems such as transformer overheating, rotary machine vibration, voltage quality degradation, electric power components damage and malfunctioning of medical equipments. Hence, the harmonic suppression is very important in today's distribution power systems. Conventionally, a single tuned passive power filters have been used to solve the problem of harmonic pollution in industrial power systems due to its low cost and easy installation. Passive filter has several disadvantages such as resonance problems, overloads can happen in the passive filter due to the circulation of harmonics coming from non linear loads etc. So active filters have been developed to replace the role of passive filters. The active filters can be used for suppressing the harmonic current. Comparing with the passive power filters, the active power filters have the better performance and can avoid most of the problems in the passive filters. At the point of common coupling of the utility interface, active power filters can absorb harmonics and reactive power that are created by the nonlinear load and make the source current almost sinusoidal.

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The controller is the primary component of the active power filter. So in this paper shunt active filter and one of its control topology is discussed.

II. STRUCTURE OF ACTIVE FILTER TOPOLOGY

The structure of shunt active filter topology is shown in Fig. 1. A shunt active power filter is a device that is connected in parallel and cancels the reactive and harmonic currents from a group of nonlinear loads so that the resulting total current drawn from the ac main is sinusoidal. The purpose of the shunt active filter is mainly to compensate the current harmonics generated from the distribution lines. When the shunt active filter is connected to the line the input current is almost sinusoidal and the distortions are reduced. A non linear load may be diode rectifier.

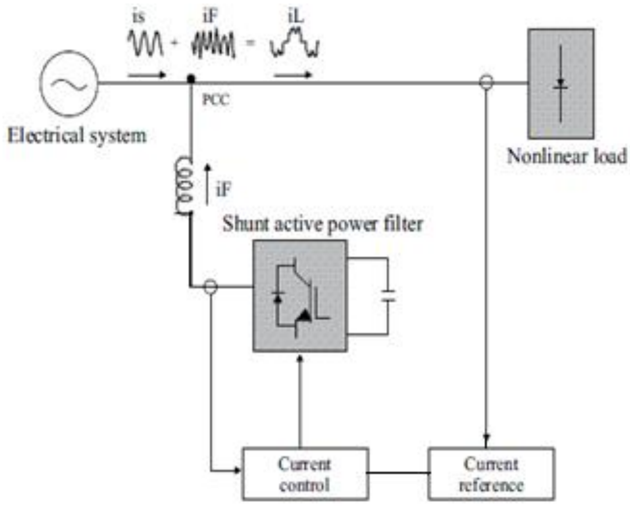

Fig.1 Shunt active filter topology.

A number of active filter configurations have been proposed in the last two decades to achieve the desired harmonic compensation level. The performance of an active filter depends mainly on the technique used to compute the reference current and the control method used to inject the desired compensation current into the line. There are several methods for reference current generation for the shunt active power filters. In 1984, H. Akagi introduced instantaneous active and reactive power theory control method that is quite efficient method for balanced three phase loads, being later worked by Watanabe and Aredes for three phase four wire systems, zero sequence currents was later proposed by F.Z.

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Peng. In 1995, Bhattacharya proposed the calculation of d-q components of the instantaneous three phase currents and this method creates synchronous reference frame concept. Synchronous reference frame(SRF) concept is simple algorithm and has good dynamic responses. The SRF has the ability to compensate for current harmonics and reactive power component from the distorted load currents. Control techniques are mainly classified into time domain approaches and frequency domain approaches. Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), and Recursive Discrete Fourier Transform (RDFT) are frequency domain based methods. Instantaneous reactive power theory, Synchronous reference frame theory Synchronous detection method etc come under time domain approaches. Other techniques are combination of Phase Locked Loop and PI controller. Here in this paper shunt active power filter is analyzed for harmonic mitigation and also for power quality improvement. This paper describes the design and analysis of shunt active filter using PLL along with PI controller In this a band pass controller generates switching signals for the active power filter to follow the reference current within a specified limits. The dc capacitor ripple voltage of the PWM voltage source inverter is reduced using the PI controller. The figure shows the general block diagram of a active power filter connected in a power system with the non linear load .

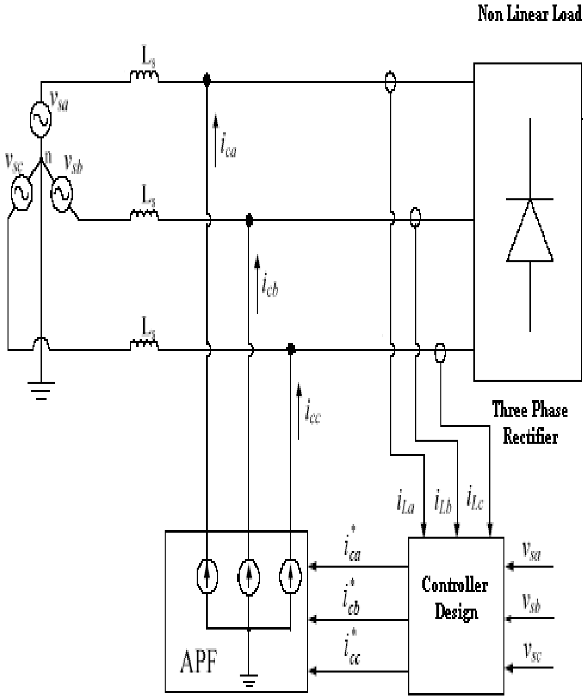

Fig. 3 Active Power filter connected in a power system

Here in the figure shown above the non linear load which has harmonics is connected to a three phase source. Due to the presence harmonics in the non linear load the sine wave of the source current get distorted. The main aim of the shunt active filter circuit is to inject filter current at the point of common coupling so as to maintain the source current sinusoidal.

III. CONTROLLER DESIGN

There are several methods for reference current generation for shunt active power filters. One such technique is using PLL and PI controller. The block diagram of this controller is shown in Fig. 3. The controller design consists of PI controller, PLL and hysteresis band pass controller and then the inverter circuit. The DC side consists of a capacitor and the capacitor voltage is sensed and compared with the reference voltage. The error voltage is given to the input of the PI controller.

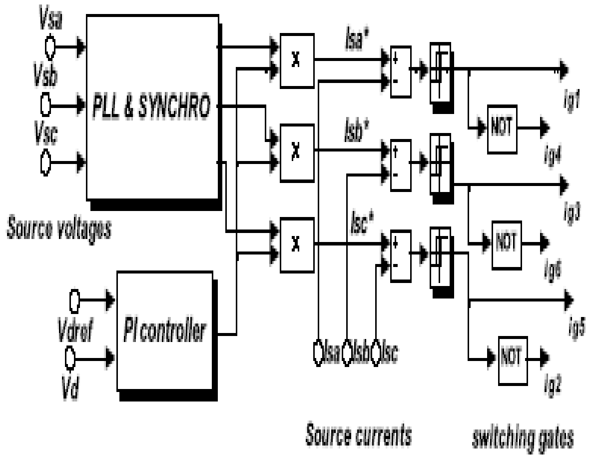

Fig. 2 Controller Design

The PWM is used to control the voltage across the DC capacitor. The PI controller is used to minimize the error. The transfer function can be represented as follows.

$$H(S) = K_p + \frac{K_i}{S}$$

Where K_i is the integration constant that determines the settling time and K_p is the proportional constant that determines the dynamic response of the DC bus voltage control. PI controller is used to eliminate the steady state error. The proportional gain and integral gain values are set such that the voltage across the DC capacitor is maintained constant. The Phase Locked Loop gets input as the system voltages (Vsa,Vsb,Vsc). The PLL design should allow proper operation under distorted and unbalanced voltage waveform. The output of PLL block is i_{a1}, i_{b1}, i_{c1} three phase currents. The PLL output currents are defined as follows.

$$i_{a1} = \sin(\omega t - \pi/2)$$
$$i_{b1} = \sin(\omega t - \pi/2 - 2\pi/3)$$
$$i_{c1} = \sin(\omega t - \pi/2 + 2\pi/3)$$

The PLL output current signals i_{a1}, i_{b1}, i_{c1} and the distorted source voltages Vsa,Vsb,Vsc are measured which are in phase with the fundamental component. The PLL output is multiplied with the PI controller and the output is the desired reference current. Next is the hysteresis band pass controller. The Hysteresis band pass controller is one of the easiest way for giving signal to the inverter. An error signal is used to control the switches in a PWM-VSI. This error is the difference between the desired current reference signal and the current being injected by the inverter. If the error exceeds the upper limit of the hysteresis band, the upper switch of the inverter is turned on and the lower switch is turned on. As a result the current starts to decay.

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If the error current crosses the lower limit of the hysteresis band pass controller, the lower switch of the inverter is switched off and the upper switch is turned on. As a result the current gets back into the hysteresis band. The minimum and maximum values of the error signals are $e_{\min}$ and $e_{\max}$ respectively. The range of the error signal directly controls the amount of ripple in the output current from the PWM Voltage source inverter. Current harmonic reduction is achieved by injecting equal but opposite current harmonic components at the point of common coupling thereby canceling the original distortion. The voltage source inverter is connected at the point of common coupling. The active filter is connected in parallel to the non linear load which has to be compensated. The current waveform for canceling harmonics is achieved by using VSI in the current controlled mode and the interface filter. The desired currents are obtained by adjusting the switching patterns of the inverter.

IV. SIMULATION RESULTS AND ANALYSIS

The performance of the controller is evaluated in Matlab simulink environment. The system parameters are shown below.

Parameters	Values
Source Voltage (V)	220 V
Fundamental Frequency (f)	50 Hz
Source Impedance (Ls)	2 mH
Filter Impedance(Lc)	2 mH
DC side capacitance	2000 µF
Reference Voltage (Vdc ref)	500V

The various simulation results are shown below. The source voltage and source current before waveform before compensation is shown below.

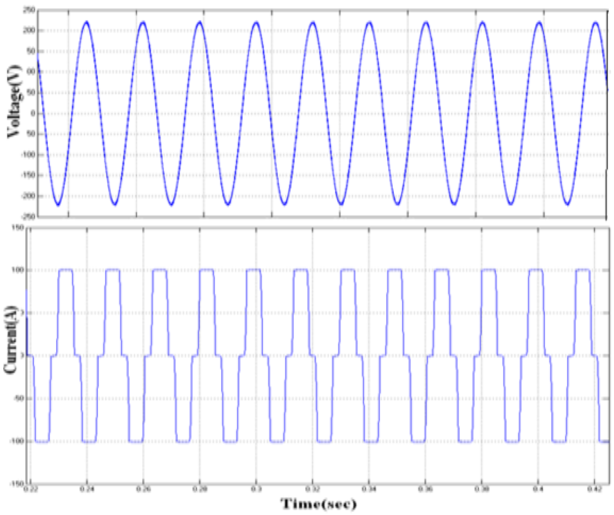

Fig.4 Source Voltage and Source Current before Compensation

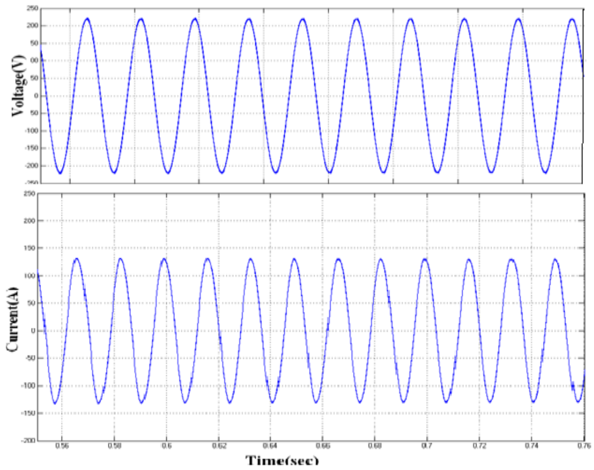

Fig.5 Source Voltage and Source Current after Compensation

The above shows the source voltage and source current after compensation. From the above waveforms it is clear that the shunt active filter circuit provides an compensation current so that when the shunt active filter circuit injected at the point of common coupling the source current becomes sinusoidal and the Total harmonic distortion is reduced. The figure below shows the compensation waveform by a shunt active filter circuit for compensation.

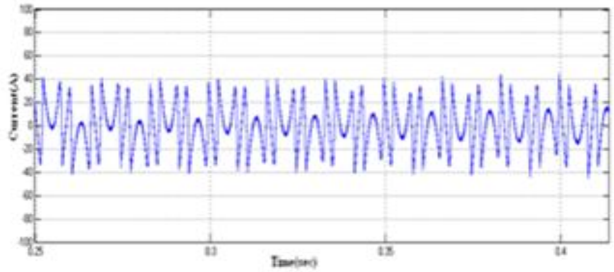

Fig.6 Compensation Current

The above waveform shows the output of a capacitor voltage that is connected across the inverter circuit. It has a constant output level.

Next we can see the voltage waveform across the non linear load which is shown in below figure

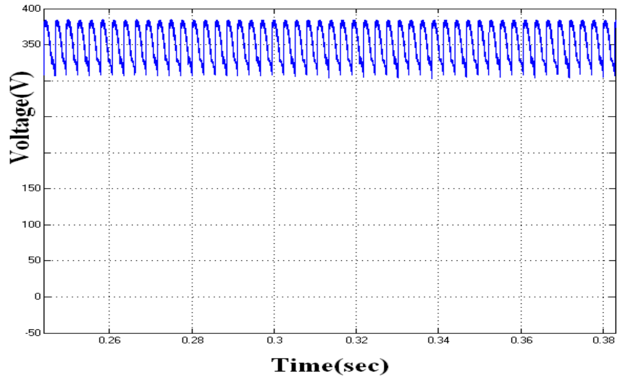

Fig.8 Voltage waveform across the non linear load

The main aim of the shunt active filter circuit connected across the power system is to reduce the Total Harmonic Distortion thereby enhancing power quality. The Total Harmonic Distortion(THD) before and after compensation is shown below.

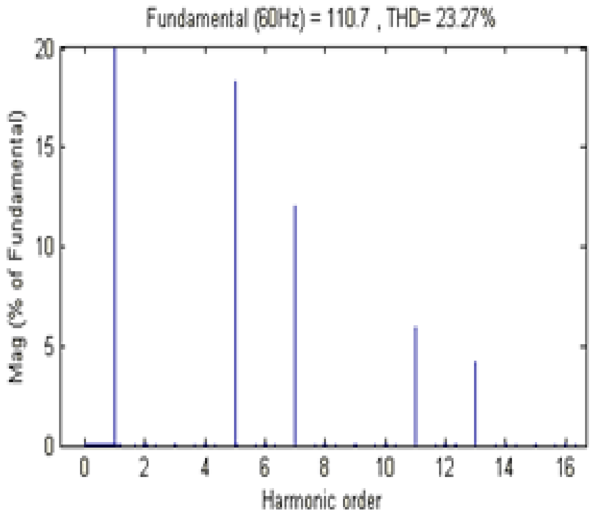

Fig.9 Total Harmonic Distortion (THD) before Compensation

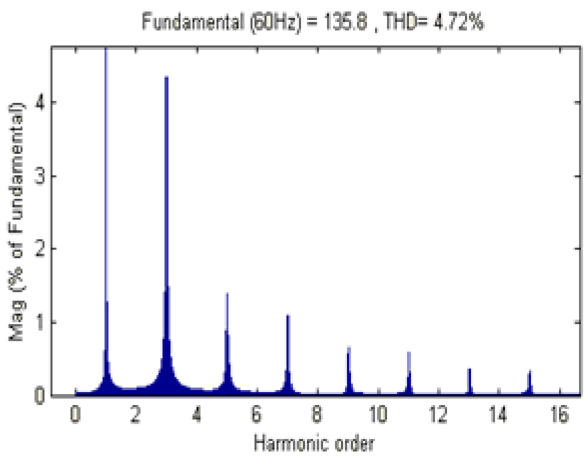

Fig.10 Total Harmonic Distortion (THD) before Compensation

From the below analysis it is seen that the Total Harmonic distortion which is 23.27% is reduced to 4.72% after compensation and thereby enhancing power quality improvement.

V. CONCLUSION

The above PI controller and PLL controller design extracts the harmonics produced by the non linear load. From the above simulation results it is observed that the performance of the shunt active filter is quite satisfactory as it reduces the harmonics of the load currents resulting in the sinusoidal source current after compensation. From the analysis of the shunt active filter circuit it is seen that the THD before compensation which is 23.27% is reduced to 4.72% after compensation which is between the IEEE standards thereby enhancing power quality improvement.

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