Shunt Active Power Filter for 3 Phase Rectifier Based on Instantaneous Power Theory

Mahadev R. Hadial
Department of Electrical Engineering, Vadoara Institute of Engineering

Abstract- **Power converters and non-linear load which distort current and voltage waveform of power system this case produces harmonics in transmission system. Three-phase six-pulse uncontrolled rectifier is the basic element in transmission system. This paper presents an analysis and reduction of source current harmonics in three phase uncontrolled rectifier using PQ (instantaneous power) theory based active power filter. This filter also improve power factor. Results are obtained by computer simulation.**

Index Terms- **Nonlinear load, Active power filter (APF), Uncontrolled rectifier, instantaneous power (p-q) theory, Power factor (PF), THD.**

I. INTRODUCTION

Increasing use of power converters and non-linear load which distort current and voltage waveform of power system this cases produce harmonics in transmission system. Harmonic is component of a sine wave with a periodic amount which the frequency of this is integer Multiple of the Fundamental wave. Harmonic In a power system Cause losses and drop in the transmission and distribution equipment and power consumption so study and their reduction are essential. Active power filter is the most efficient way to compensate reactive power and reduces low order harmonics generated by nonlinear load and it also provides power factor improvement as well as correction.

Three-phase six-pulse diode converters are the basic element in transmission system. These converters because of their nonlinear Properties generate harmonic currents cause serious problems in system.

The RMS value of the nth harmonic of input current

$$I_n = \frac{2\sqrt{2}I_a}{n\pi}\sin\frac{n\pi}{3} \quad (1)$$

The total RMS value of current is

$$I_{rms} = (I^2_{1(rms)} + I^2_{2(rms)} + I^2_{3(rms)} + \ldots + I^2_{n(rms)})^{1/2} \quad (2)$$

Input current in the system is

$$i_a = \frac{2\sqrt{3}}{\pi}I_d\begin{pmatrix}\sin(\omega t-\phi_1)+\frac{1}{5}\sin 5(\omega t-\phi_1) \\ -\frac{1}{7}\sin 7(\omega t-\phi_1)+\frac{1}{11}\sin 11(\omega t-\phi_1)-\ldots\end{pmatrix} \quad (3)$$

Where φ_1 is phase angle between source voltage and mean current.

Total harmonic distortion is defined as the ratio of the rms value of all harmonic components to the rms value of the fundamental frequency:

$$THD = \frac{\sqrt{\sum_{k=2}^{\infty} I^2_{k\,rms}}}{I_{1\,rms}} \quad (4)$$

For a k-pulse ideal rectifier, the harmonics being generated are of orders 5, 7, 11, 13, 17, 19 ..., i.e. those of orders 6k ± 1, where k is an integer

II. SHUNT ACTIVE POWER FILTER

Basic circuit configure of shunt active filter in a three phase, three wire system shown in figure. This is one of the most fundamental active filters intended for harmonic current compensation of a nonlinear load.

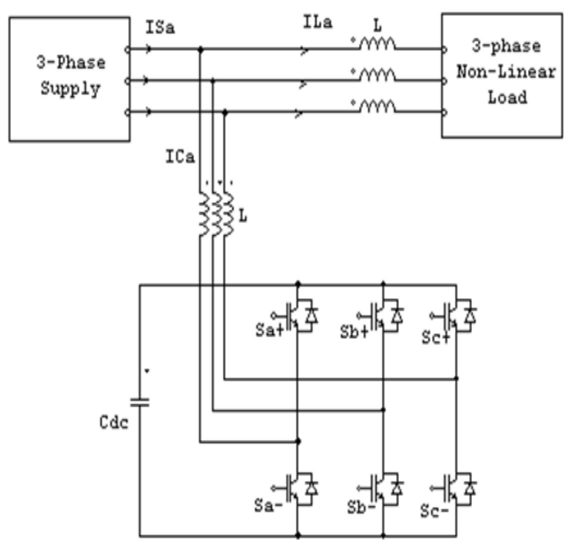

Fig.1 Principle of Current Harmonic Compensation

This shunt active filter equipped with a current minor loop is controlled to draw the Compensating current ic from the ac power source, so that it cancels the harmonic current contained in the load current iL [2].

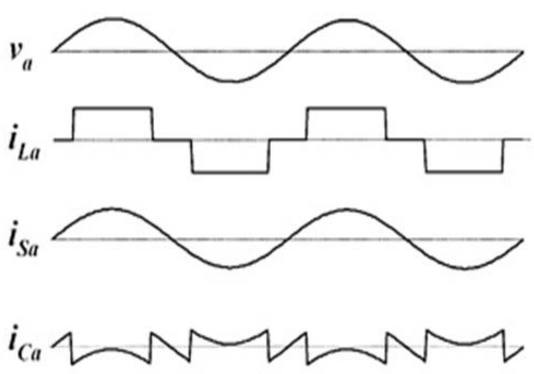

Fig.2 Waveform of Voltage and Current

Figure shows voltage and current waveform of the ac power source V_a, the source current i_{Sa}, and the compensating current i_{Ca} in the a phase, under the following assumption. The smoothing reactor L_{dc} in the dc side of the rectifier large enough to keep constant dc current, the active filter operates as an ideal controllable current source, and the inductor is equal to zero [2].

The shunt active filter should be useful to a nonlinear load that can be considered as a harmonic current source, such as a diode/thyristor rectifier with an inductive load, an arc furnace and so on. At present, a voltage source PWM converter is generally preferred as the power circuit of the active filter, instead of a current source PWM converter. A main reason insulated gate bipolar transistor (IGBT), which is one of the most popular power switching devices, is integrated with a freewheeling diode, so that such an IGBT is much more cost effective in constructing the voltage source PWM converter than the current source PWM converter. Another reason is that the dc capacitor indispensable for the voltage source PWM converter more compact and less heavy than the dc inductor for current source PWM inverter [2].

The main function of active filter is draw reactive and distortion power to nonlinear load. This can be also illustrated by the form of currents. On the base of Kirchhoff's law for each phase is filter current given as [3]:

$$i_F(t) = i_L(t) - i_S(t) \quad (5)$$

According to Fourier's analysis distorted periodic function (non-harmonic current of load) can be given by sum of sinusoidal functions (sum of harmonics), after load current is:

$$i_L(t) = I_0 + \sum_{i=1}^{n} I_{mi} \sin(i \cdot \omega t - \varphi_i) \quad (6)$$

Where, I_0 = DC component of current (we will not consider it), I_{mi} = amplitude of i^{th} harmonic, i = harmonic order and φ_i = phase angle of i^{th} harmonic.

So, we can consider for line current

$$i_S(t) = I_{m1A} \sin(\omega t) \quad (7)$$

Where, I_{m1A} = the amplitude of active part of current fundamental component.

Current defined is in phase with voltage providing sinusoidal line voltage. That means no phase shift between voltage and current.

After that compensating current of filter is

$$i_F(t) = -\mathrm{I}_{m1R} \sin\left(\omega t - \frac{\pi}{2}\right) + \sum_{i=2}^{n} I_{mi} \sin(i \cdot \omega t - \varphi_i) \quad (9)$$

Where, I_{m1R} = the amplitude of reactive part of current fundamental component.

This current representation has physical background. From the power representation, first component of present's reactive power of fundamental component and second distortion power.

III. PQ THEORY

The theory of the Instantaneous Reactive Power in Three-Phase Circuits known as instantaneous power theory or p-q theory. It is 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. The p-q theory consists of an algebraic transformation or clarke transformation of the three-phase voltages and currents in the a-b-c coordinates to the a-ß-0 coordinates, followed by the calculation of the p-q theory instantaneous power components [4].

Using this transformation we obtain for a voltage system:

$$\begin{bmatrix} v_\alpha(t) \\ v_\beta(t) \\ v_0(t) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \quad (10)$$

For current

$$\begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \\ i_0(t) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \quad (11)$$

On the base of instantaneous α-β components we can define "instantaneous active and reactive power" by following equations:

$$\begin{bmatrix} p(t) \\ q(t) \end{bmatrix} = \begin{bmatrix} v_\alpha(t) & v_\beta(t) \\ -v_\beta(t) & v_\alpha(t) \end{bmatrix} \begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \end{bmatrix} \quad (12)$$

So that,

$$p(t) = v_\alpha(t) \cdot i_\alpha(t) + v_\beta(t) \cdot i_\beta(t) \quad (13)$$

And

$$q(t) = v_\beta(t) \cdot i_\alpha(t) - v_\alpha(t) \cdot i_\beta(t) \quad (14)$$

IV. COTROL STRATEGY

Reference is the main part of APF control. In fig is shown APF reference current calculation. The calculation is based on p-q theory. Inputs of the calculation are phase voltages (va, vb, vc) and phase load currents (iLa, iLb, iLc). After transformation (abc to αβ), the αβ components of voltage and load current are the inputs of the block of instantaneous active and reactive power calculation defined by pq theory. Shunt APF should inject to the nonlinear load current which consists of every harmonics beyond active part of fundamental current component. The easier method to obtain reference current is based on calculation of active part of fundamental current component which will be after subtracted from load current To obtaining only DC part of instantaneous active power p(t) is desirable to use low pass filter. We can use multiplication by zero for instantaneous imaginary power q(t) filtering. Back transformation for αβ current components is given by the following equation [3].

$$\begin{bmatrix} i_{\alpha ref}{}^* \\ i_{\beta ref}{}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p_{DC} \\ 0 \end{bmatrix} \quad (15)$$

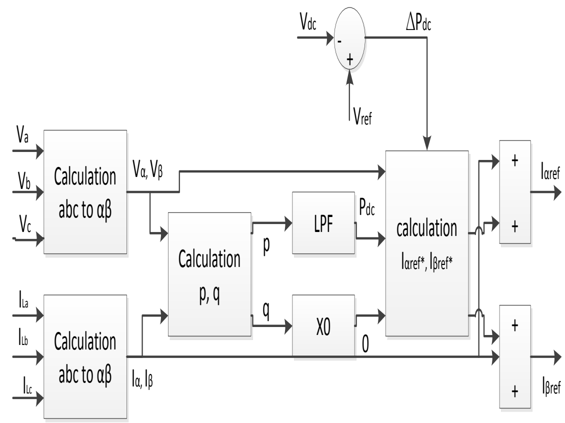

Fig.3 Reference Current Calculation

The inputs of back transformation will be only the DC part of instantaneous active power and αβ components of voltage. By the back transformation we will obtain αβ components of active part of current fundamental component. Complete reference current components can be obtained by addition αβ current fundamental components and αβ load current components. For completeness' sake of reference current calculation is necessary to consider the DC bus voltage control keeping constant voltage on capacitor. Charging and discharging of capacitor is ensured by active power flow, in this case represented by active part of current fundamental component. For DC bus control is used PI controller. Value from the output of PI controller ΔPdc is added to value of DC component PDC of instantaneous active power [3].

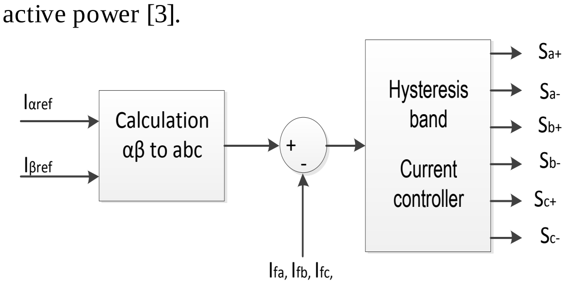

Fig.4 Control Strategy after Reference Current Calculation

Reference current in αβ coordinates is transferred by inverse transformation (αβ to abc) to abc reference frame. The hysteresis-band controller is used for the current control. The reference current wave is compared with the actual phase filter current wave. As the error exceeds a prescribed hysteresis band, the upper switch is turned off and the lower switch is turned on. As a results, the output voltage transitions from 0.5 to -0.5 V and the current starts decay. As the error crosses the lower band limit, the lower switch is turned off and the upper switch is turned on [3].

$$\begin{bmatrix} i_{\alpha ref}^{*} \\ i_{\beta ref}^{*} \end{bmatrix} = \frac{1}{v_{\alpha}^{2}+v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} p_{DC} \\ 0 \end{bmatrix} \qquad (16)$$

V. SIMULATION RESULTS

Simulation result is done using MATLAB/Simulink. Figure shows the Simulink diagram of shunt active filer with a three phase diode based uncontrolled rectifier load. The diagram consists power circuit having IGBT switches based VSI inverter with dc link capacitor, three phase controlled rectifier as a load and control block which include pq theory reference current calculation and switching pulse generation.

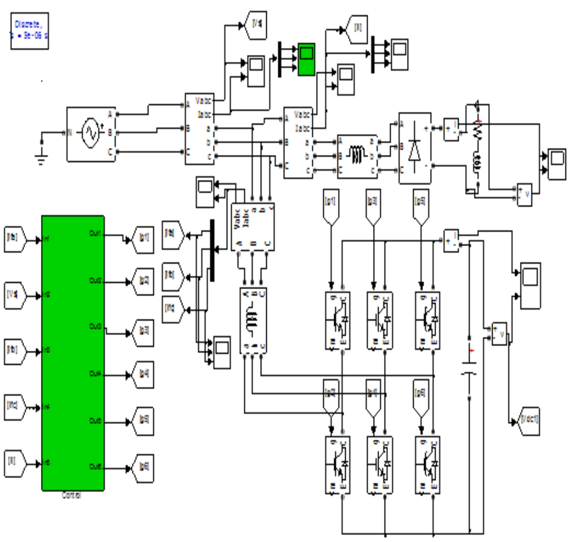

Fig.5 Simulink Diagram of Shunt Active Filter with Controlled Rectifier

Waveform and FFT analysis of Load, Source and Filter Current at load Idc = 5.934A

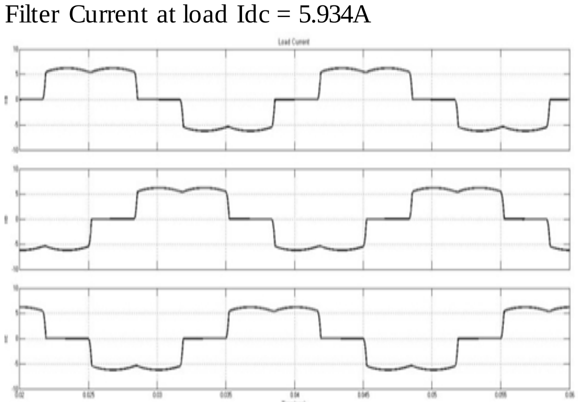

Fig.6 (a) Waveform of Load Current

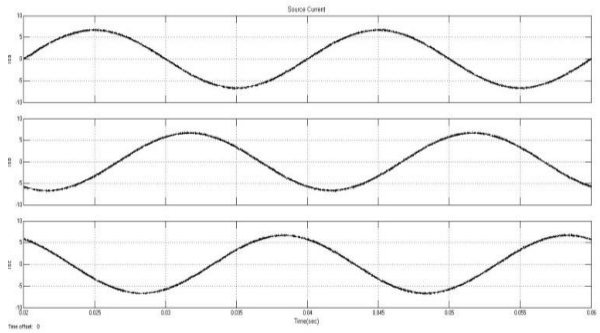

Fig.6 (b) Waveform of Source Current

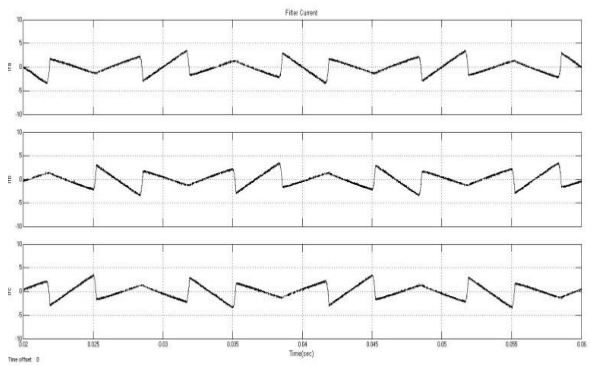

Fig.6 (c) Waveform of Filter Current

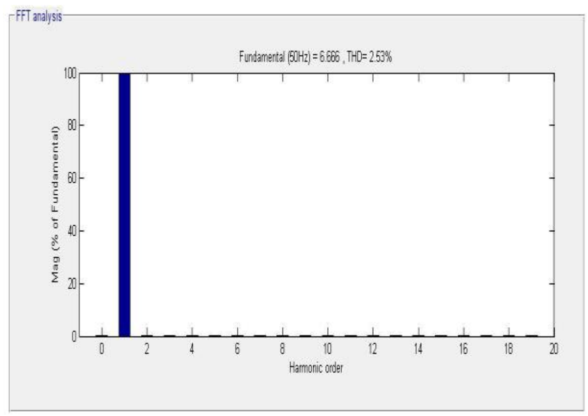

Fig.6 (d) FFT analysis of Source current THD= 2.53%

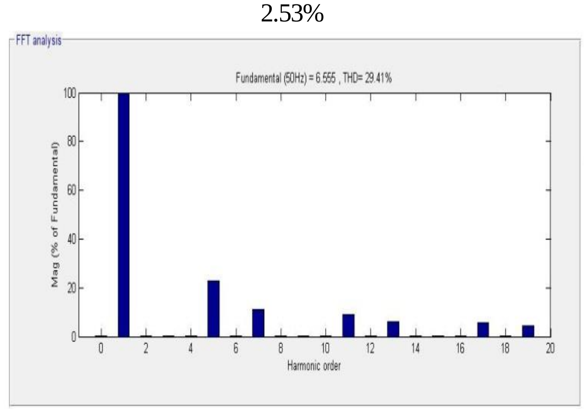

Fig.6 (e) FFT analysis of Load current THD = 29.41%

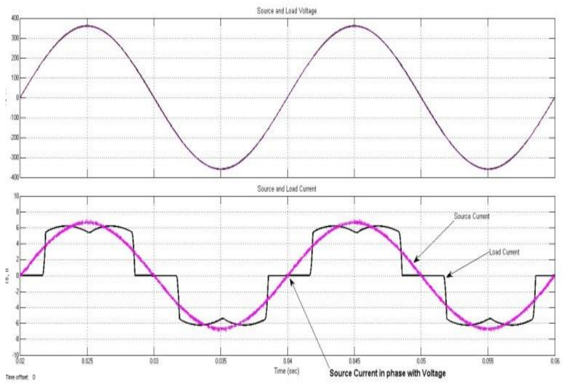

Fig.6 (f) Source and Load Voltage and Current

TABLE I Source THD and Load with o/p DC current variation.

Load(DC side)		Idc (avg)	source THD%	Load THD%
R (ohm)	L (mH)			
10000	-	0.05942	93.2	30.14
1000	-	0.5941	21.99	30.29
500	-	1.188	11.82	30.14
200	-	2.969	5	29.82
100	50	5.933	2.52	29.32
100	-	5.934	2.56	29.45
100	5	5.934	2.49	29.43
100	10	5.934	2.53	29.41
50	-	11.85	1.56	28.29
50	50	11.85	1.65	28.65

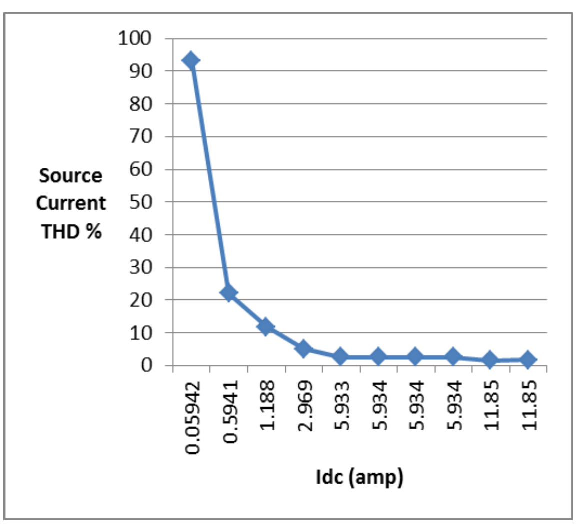

Fig. 7 Source THD with o/p DC current

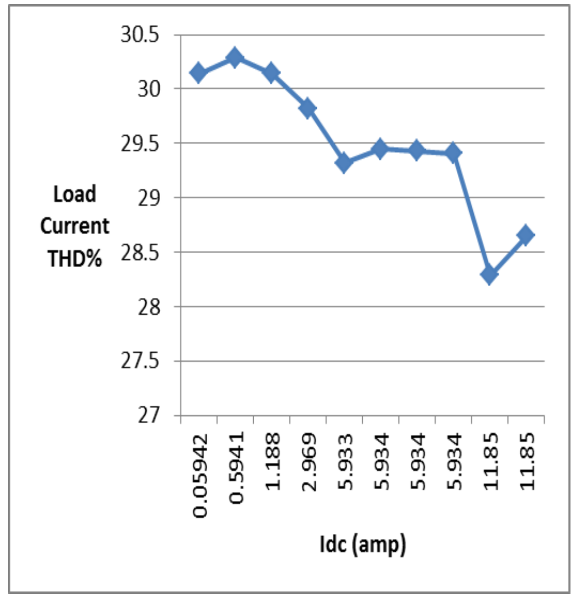

Fig. 8 Load THD with o/p DC current

VI. CONCLUSION

This paper presents an analysis and reduction of source current harmonics in three phase uncontrolled rectifier using PQ (instantaneous power) theory based active power filter. Results are obtained by computer simulation.

REFERENCE

[1] Ali akbar Motie birjandi, Zahra ameli, "Three phase controlled rectifier study in terms of firing angle variations", aceee int. J. On electrical and power engineering, vol. 03, no. 02, may 2012.

[2] Hirofumi Akagi, Edson Hirokazu atanabe, Mauricio Aredes "Instantaneous Power Theory And Applications To Power Conditioning", IEEE Press John Wiley & Sons, Inc., Publication.

[3] R. Pavlanin, M. Marinelli, B. Zigmund, "Different view on pq theory used in the control algorithm of active power filters", advances in electrical and electronic engineering.

[4] João Afonso, Carlos Couto, Julio Martins. "Active Filters with Control Based on the p-q Theory", IEEE Industrial Electronics Society Newsletter vol. 47, no. 3, Sept. 2000, ISSN: 0746-1240, pp. 5-10

[5] W. Mack Grady, "Harmonics And How They Relate To Power Factor", Proc. of the EPRI Power Quality Issues & Opportunities

Conference (PQA'93), San Diego, CA, November 1993.

[6] G.Mohan Babu, "Simulation Study of Indirect Current Control Technique for Shunt Active Filter", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 Vol. 3, Issue 4, Jul-Aug 2013, pp.831-851.