International Journal of Electrical, Electronics and Computer Engineering **3**(1): 111-115(2014)

ISSN No. (Online): 2277-2626

Hybrid active Power Filter for Power line Conditioning

Sangeeta Chouhan*, Amol Barve** and Sumit Tiwari***

**M.Tech, Scholar, Department of Electrical Engineering, Laxmi Narayan College of Technology, Bhopal, (MP)*

***Associate Professor, Department of Electrical Engineering, Laxmi Narayan College of Technology, Bhopal, (MP)*

****Assistant Professor, Department of Electrical Engineering, Laxmi Narayan College of Technology, Bhopal, (MP)*

(Corresponding author Harsha Nigam)

(Received 05 April, 2014 Accepted 23 May, 2014)

ABSTRACT: This paper investigates mitigation of current harmonics using five level cascaded multilevel inverter based shunt hybrid active power filter (SHAPF) and to improve power quality of the system. The main objective of this paper is to develop and analyze the compensation characteristics of cascaded multilevel inverter based shunt hybrid active power filter by employing indirect current control algorithm. This work explores design and analysis of Hybrid Active Power Filter (HAPF) based in p-q instantaneous theory and using trianguler sampling current controller to obtain the gating signals for five-level diode clamped multilevel inverter (DCMLI). The technique used is capable of reducing the Total harmonic distortion drawn by the non-linear load, compensate the reactive power and correct the power factor, therefore, the power quality problem of a distribution system is reduced especially harmonic problems. The simulation results of the systems have been carried out with MATLAB. Also, the PI controller is employed to reduce the ripple voltage of the dc capacitor of the diode clamped inverter. The designed system have been tested the effect of the control approaches for real time current compensation harmonics for steady state condition.

Keywords: Hybrid Active power filter (HAPF), Diode Clamped Multilevel Inverter (DCMLI), Trianguler Sampling current controller, Harmonic compensation, Total Harmonic Distortion (THD).

I. INTRODUCTION

Power quality management is the main problem that the industry is facing today. This is mainly affected by the generation of harmonics. The growing use of electronic equipment produces a large amount of harmonics in distribution systems because of non-sinusoidal currents consumed by non-linear loads. As we know for the better quality of power, the voltage and current waveforms should be sinusoidal, but in actual practice it is somewhat disturbed and this phenomenon is called "Harmonic Distortion" [1]. The unbalanced source voltage may generate low-order harmonic current components in the power system and also cause a negative sequence current and torque reduction in case of electric machine drive systems [2]. Therefore, much of research has been performed on active power filters and their practical applications. In 1984 introduce a new concept of p-q instantaneous reactive power theory with the three phase voltages and currents. Thyristors converters and diode rectifiers with smoothing dc capacitors are a common source of harmonic currents. The distortion of the current results from the switching operation of thyristors and its harmonic amplitude is greatly affected by the impedance of the ac side. This type of harmonic source behaves like a current source. Therefore, they are called harmonic current source [3]. The Active Power Filter (APF) controlled on the bases of instantaneous p-q theory has a good dynamic compensation characteristic for load current. It improves the utility supply system power-factor as the ac source provide only the fundamental frequency of current, in addition to that reactive power compensation and harmonic mitigation. At the same time it have some draw-backs such as it is difficult to realize high power PWM inverters with a rapid current response, some resonance at specific frequency occurs between the source impedance and the APF initial cost is high when compared with passive filter [4]. A hybrid active power filter is presented to achieve harmonic currents elimination and reactive power compensation. Active power filters are operated as an ideal current source to provide a dynamic and adjustable solution for eliminating the harmonic currents and compensating the reactive power. In this technique cost of power quality improvement can be reduce [5]. This paper describes the design and analysis of a novel work that uses instantaneous power theory along with PI controller for APF. The sensed voltages and currents of the load have been used for instantaneous power calculation to generate reference currents. A hysteresis band current controller generates switching signals for APF to follow the reference current within specified band limits. The THD and the PF of the load have been investigates for the non-linear load system before and after using the proposed filter at different load conditions. Fig. 1 summarizes the simulation procedure of hybrid active power filter controlled by trianguler sampling current controller.

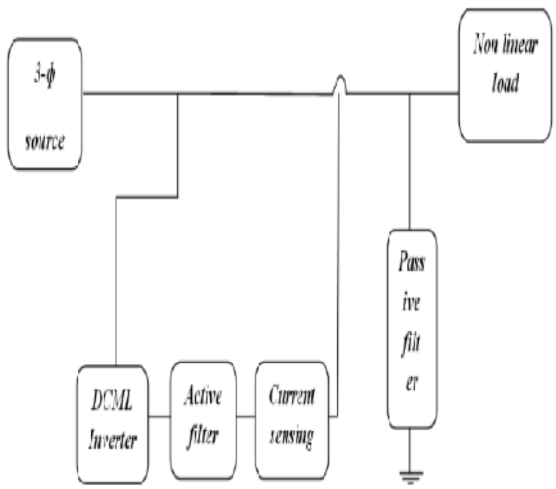


Fig. 1: Hybrid active power filter with current controller connected to the system.

The purpose of using this combined system is to reduce the harmonics effectively. The power factor also improved by using this combined System. In electrical power supply there are many non-linear loads drawing non-sinusoidal current. This current will pass through the different kind of impedance in power system and produce voltage harmonics. This will affect the sinsitive equipment connected to the power system [8]. Traditionally passive filters (LC filters) used for harmonic reduction, but it may result in parallel resonances with the network impedance. For this disadvantage of the passive filters, the active power filters have been introduced. The shunt active power filter is designed to improve the power quality with less disadvanteges of passive filters. In the following the main components of the APF is enlightened as follow:

A. Diode clamped multilevel inverter

The shunt active power filter is operated as a controlled current source connected in parallel with the non-linear loads deriven by Pulse Width Modulation (PWM) to inject current harmonics into the ac source. The diode-clamped multilevel inverter uses capacitors in series to divide up the dc bus voltage into a set of voltage levels. To produce (m) levels of the phase voltage, an (m) level diode-clamp inverter needs (m-1) capacitors on the dc bus. A three-phase five-level diode-clamped inverter is shown in Figure 2. The dc bus consists of four capacitors, C1, C2, C3, and C4. For a dc bus voltage *Vdc*, the voltage across each capacitor is *Vdc*/4, and each device voltage stress will be limited to one capacitor voltage level, *Vdc*/4, through clamping diodes.

DCMLI output voltage synthesis is relatively straightforward. To explain how the staircase voltage is synthesized, point O is considered as the output phase voltage reference point. Using the five-level inverter shown in Fig. 2, there are five switch combinations to generate five level voltages across A and O. (O point is the neutral point of the load not shown in Fig. 2. In each phase leg, a set of four adjacent switches is on at any given time. There exist four complimentary switch pairs in each phase, Sa1-Sa1’, Sa2-Sa2’… and Sa4-Sa4’ [9].

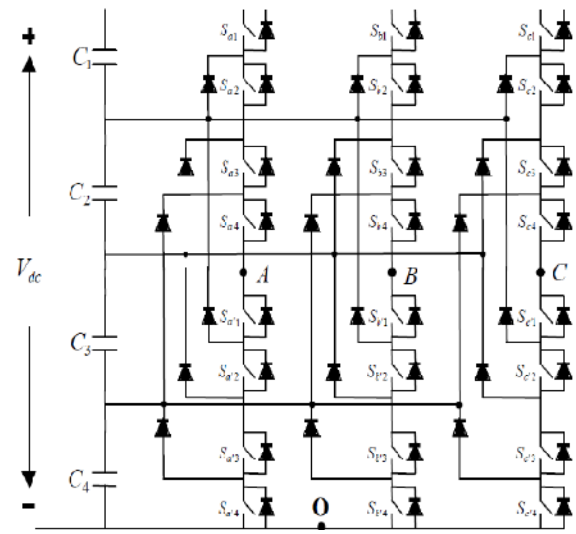


Fig.2: Three Phase Five Levels DCMLI

B. P-Q instantaneous theory and reference current generation

The instantaneous reactive power theory was initially published in English in the Proceedings of the International Power Electronics Conference in 1983 [10]. The P-Q instantaneous theory concept is very popular and useful for this type of application, and basically consists of a variable transformation from the a, b and c, reference frame of the instantaneous power, voltage, and current signals to the α, β reference frame. The transformation equations from the a, b, c, reference frame to the α, β coordinates can be derived from the phasor diagram shown in Figure 3 [11]. This theory is used to calculate the instantaneous active current (Ip) and instantaneous reactive current (Iq) of three phase system based on instantaneous reactive power theory, based on the Clark transformation. The transformation is applied to the voltage and current vectors the instantaneous values of voltages and currents in the α, β coordinates can be obtained from the following equations.

$$\begin{bmatrix} \boldsymbol{V_\alpha} \\ \boldsymbol{V_\beta} \end{bmatrix} = [A] . \begin{bmatrix} \boldsymbol{V_a} \\ \boldsymbol{V_b} \\ \boldsymbol{V_c} \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} \boldsymbol{I_\alpha} \\ \boldsymbol{I_\beta} \end{bmatrix} = [A] . \begin{bmatrix} \boldsymbol{I_a} \\ \boldsymbol{I_b} \\ \boldsymbol{I_c} \end{bmatrix} \qquad (2)$$

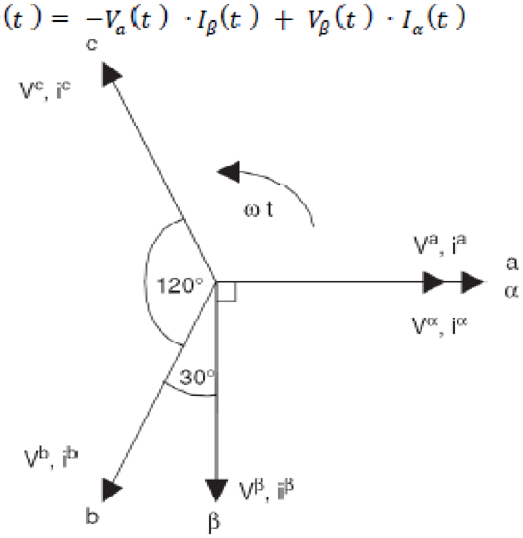
Where A is the transformation matrix, and A is equal to:

$$A = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \qquad (3)$$

This transformation is valid if and only if $V_a(t) + V_b(t) + V_c(t)$ is equal to zero, and also if the voltages are balanced and sinusoidal. The instantaneous active and reactive power in α, β coordinates are calculated with the following expressions: [11], [12].

$$p(t) = V_\alpha(t) \cdot I_\alpha(t) + V_\beta(t) \cdot I_\beta(t) \qquad (4)$$

$$q(t) = -V_\alpha(t) \cdot I_\beta(t) + V_\beta(t) \cdot I_\alpha(t) \qquad (5)$$



The expression of the currents in the α–β plane, as a function of the instantaneous power is given by the following equation:

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{V_\alpha{}^2 + V_\beta{}^2} \cdot \left(\begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} . \begin{bmatrix} p \\ 0 \end{bmatrix} + \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} . \begin{bmatrix} 0 \\ q \end{bmatrix} \right) = \begin{bmatrix} I_{\alpha p} \\ I_{\beta p} \end{bmatrix} + \begin{bmatrix} I_{\alpha q} \\ I_{\beta q} \end{bmatrix} \qquad (6)$$

This yields that:

$$I_{\alpha p} = \frac{V_\alpha \, p}{V_\alpha{}^2 + V_\beta{}^2} \qquad (7)$$

$$I_{\alpha q} = \frac{V_\beta \, q}{V_\alpha{}^2 + V_\beta{}^2} \qquad (8)$$

$$I_{\beta p} = \frac{V_\beta \, p}{V_\alpha{}^2 + V_\beta{}^2} \qquad (9)$$

$$I_{\beta q} = \frac{-V_\alpha \, p}{V_\alpha{}^2 + V_\beta{}^2} \qquad (10)$$

From Equations 4 and 5, the values of p and q can be expressed in terms of the dc components plus the ac components, that is:

$$p = \bar{p} + \tilde{p} \qquad (11)$$

$$q - \bar{q} + \tilde{q} \qquad (12)$$

In order to compensate reactive power (displacement power factor) and current harmonics generated by non-linear loads, the reference signal of the active power filter must include the values of p , q and q . In this case the reference currents required by the active power filters are calculated with the following expression:

$$\begin{bmatrix} I_{c\alpha}{}^* \\ I_{c\beta}{}^* \end{bmatrix} = \frac{1}{V_\alpha{}^2 + V_\beta{}^2} \cdot \left(\begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} . \begin{bmatrix} \tilde{p} \\ \bar{q} + \tilde{q} \end{bmatrix} \right) \qquad (13)$$

The final compensating currents including the zero sequence components in a, b, c reference frame are the followin

$$\begin{bmatrix} I_{ca}{}^* \\ I_{cb}{}^* \\ I_{cc}{}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} -I_0 \\ I_{c\alpha}{}^* \\ I_{c\beta}{}^* \end{bmatrix} \qquad (14)$$

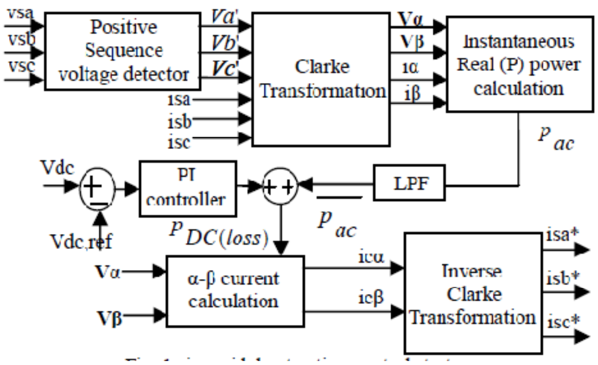


Fig. 3. Sinusoidal extraction control strategy.

C. Trianguier- Sampling current controller:
The triangule-sampling current control for active power filter line currents can be carried out to generate the switching pattern of the inverter. There are various current control methods proposed for such active power filter configurations; but the trianguler current control method has the highest usage among other current control methods, because of quick current controllability, easy implementation and unconditioned stability. The trianguler-sampling current control is robust, provides excellent dynamics and fastest control with minimum hardware [13]. The switching logic is formulated as follows:

III. CIRCUIT AND SIMULATION PARAMETERS

.

System Parameter	Values
Sending end voltage (Line to Line) V	415 V (RMS)
Supply frequency F	50Hz
Line impedance L_s	1.2mH
Line impedance R_L,L_L	20Ω,8mH
Active filter parameter R_{dc},L_{dc},C_{dc}	0.5mH,0.1Ω,2400μF
Carrier Frequency for PWM circuit	10KHz
Passive filter parameter L_p,C_p	7mH,10 μF

IV. SIMULATION RESULTS AND ANALYSIS

In this section, simulation results of three-phase shunt hybrid active power filter based on five level cascaded multilevel and its comparative analysis are presented. The goal of the simulation is to examine harmonic and reactive power compensation under balanced system. The system consist of a three-phase network feeds a three-phase diode bridge rectifier with a resistor R and inductor L in series at its dc output. Simulation investigation was carried on using MATLAB/SIMULINK simulation software in power system block set toolbox.

Fig. 5. demonstrates the steady state response of source voltage, source current, compensation current, load current and output Vdc voltage under balanced source and balanced load is clearly depicted.

The harmonic spectrum of source current before and after compensation is shown in Fig.4. and Fig. 6. From the obtained results, the total harmonic distortion (THD) of source current is observed to be reduced from 21.03% before compensation to 4.56% after compensation.

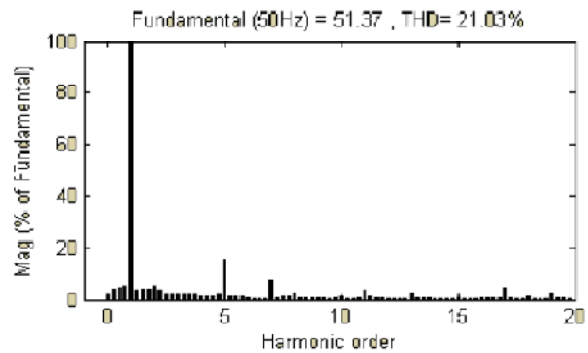


Fig. 4. Harmonic Spectrum of Source current before compensation.

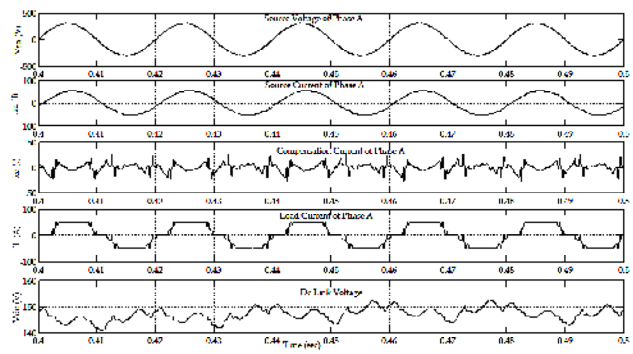


Fig. 5. Steady State Response of 5-level Cascaded MLI based SHAPF.

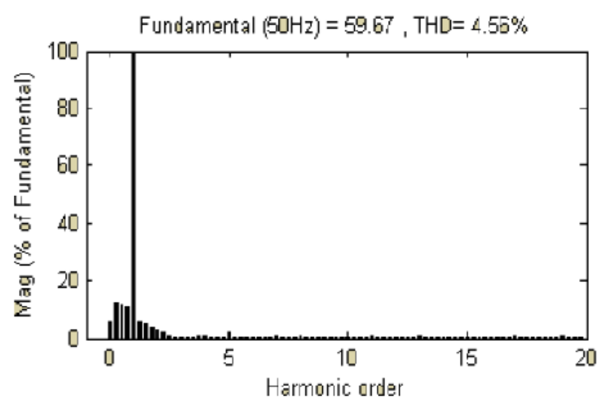


Fig. 6. Harmonic Spectrum of Source current after compensation.

V. CONCLUSIONS

This paper describes the design and analysis of Hybrid Shunt Active Power Filter based on p-q instantaneous theory and using hysteresis current band to obtain the gating signals for five-level Diode Clamped Multilevel Inverter (5-DCMLI). The simulation results show an effective solution for power quality problems. The hybrid shunt Active Power Filter proposed reduces harmonics and reactive power components of load currents. The results show the ability of the HAPF system to present fast response for real time current compensation harmonics for steady state**.** A sinusoidal source curre nt and closed to unity power factor is achieved. The THD of the source current after compensation is 4.56% which is less than the harmonic limit imposed by the IEEE-519 standard.

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