INTERNATIONAL JOURNAL OF ENHANCED RESEARCH IN SCIENCE TECHNOLOGY & ENGINEERING
VOL. 2 ISSUE 3, MARCH.-2013 ISSN NO: 2319-7463

An introduction of Shunt Active Power Filter (SAPF) to improve power quality

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Abstract: Due to large amount of non-linear power electronic equipment's impact and fluctuating loads , problems of power quality have become more and more serious with each passing day. Active power filtering has gained much more importance in the power quality arena as it gives the best solution for all power quality issues. Shunt active filtering is effective and the performance of such units largely depends upon the control strategies used for reference current generation. This paper presents the brief introduction of the two control techniques to determine the reference current for the three phase three wire SAPF in order to improve the power quality using PI controller. The first one is based on the Instantaneous real and reactive power (p-q) method and second one is the Instantaneous active and reactive current (I_d-I_q) method.

Keywords: Shunt power, filter, quality, Switch Mode Power Supply (SMPS).

I. Introduction

An increase in power quality problems in the electric power networks are due to the increased use of non-linear loads , such as switch mode power supply (SMPS) in computers, rectifier devices in TV's, telecommunication power supplies and commercial lighting systems, etc. Harmonic pollution is an important power quality problem. In this increasing global competition, modern industries have to make their production process more efficient in order to compete. To do this, advanced technologies have to be used. With the proliferation of static power converters or non-linear loads in industrial application and distribution systems, the compensation of harmonics is becoming a significant concern. Static power converters have a current source, injecting harmonics into the supply network. This causes the problem of power system harmonics, leads to the voltage distortion in the power system, at point of common coupling (PCC). When power converters inject a distorted current in the supply network, a harmonic voltage is developed across the source impedance. The voltage at PCC, being the difference of the source voltage and voltage across the source impedance, will distort [1]. Several power quality standards are defined in order to keep the harmonic distortion within the limits like IEEE-519-1992/IEC 61000 [2]. Traditionally, passive LC filters have been used to eliminate the current harmonics and to improve the power factor. However, these passive second order filters presents many disadvantages such as aging and tuning problems, series and parallel resonance, and the requirement to implement one filter per frequency harmonics that need to be eliminated. In order to overcome these problems, different kinds of active power filters, based on forced commutated devices, have been researched and developed. In recent years, shunt active power filters based on current controlled PWM converters have been widely investigated and organised as viable solutions [3-5]. Though several control strategies have been developed but still two control theories, Instantaneous real and reactive power (p-q) method and Instantaneous active and reactive current (I_d-I_q) method [6,7] are always dominant. Present paper mainly focuses on these two control strategies using PI controller.

II. SAPF Control Techniques

A. SYSTEM DESCRIPTION

The control techniques are implemented for a common system that is represented in figure (1). Here a three phase supply is used to feed a non- linear load consisting of a diode bridge rectifier feeding RL load at its DC side. At PCC, a current controlled voltage source inverter (CCVSI)is acting as SAPF.

The DC side capacitor and AC side inductance of this VSI acts as filter components. The gate pulses to the inverter are generated by an hysteresis type pulse generator. The heart of APF is the reference current generator block. This unit takes voltage and/or current from the supply and/or load to generate the reference current depending upon the type of control strategy used [2].

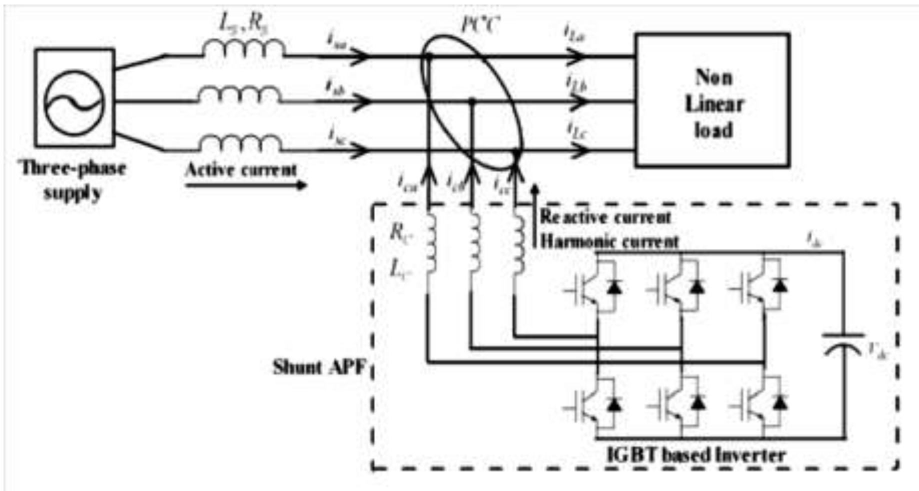

Figure 1. Basic scheme of SAPF compensation

B. Instantaneous real and reactive power (p-q) method:

This concept based on the theory of instantaneous reactive power in the α-β reference frame; this theory stimulates the realization of three phase, three-wire APFs. In this theory, the instantaneous source voltage and current signals in a-b-c coordinates are transformed into two-phases i.e. α-β orthogonal coordinates as follows.

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (2)$$

For simplicity, the zero-phase sequence component voltage and current signals are eliminated in (1) and (2). The instantaneous active power (p) and the instantaneous imaginary power (q) in a three-phase circuit are defined in (3).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (3)$$

Using (3) load current in α-β frame can be calculated as:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

The block diagram of this method is as shown in figure (2). The reference compensating current can be calculated in such a way that it supplies the instantaneous reactive power (q) and the harmonic component of the instantaneous active power (p~). The reference compensating current (i_c*) can be obtained as:

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{5}$$

The compensating current signals in α-β frame can be transferred to a-b-c frame using inverse Clark's transformation as:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{6}$$

This method does not take into account the zero sequence components, and hence, the effect of unbalanced voltages and currents. The instantaneous reactive power (p-q) theory is widely used for three-phase balanced non-linear loads, such as rectifiers.

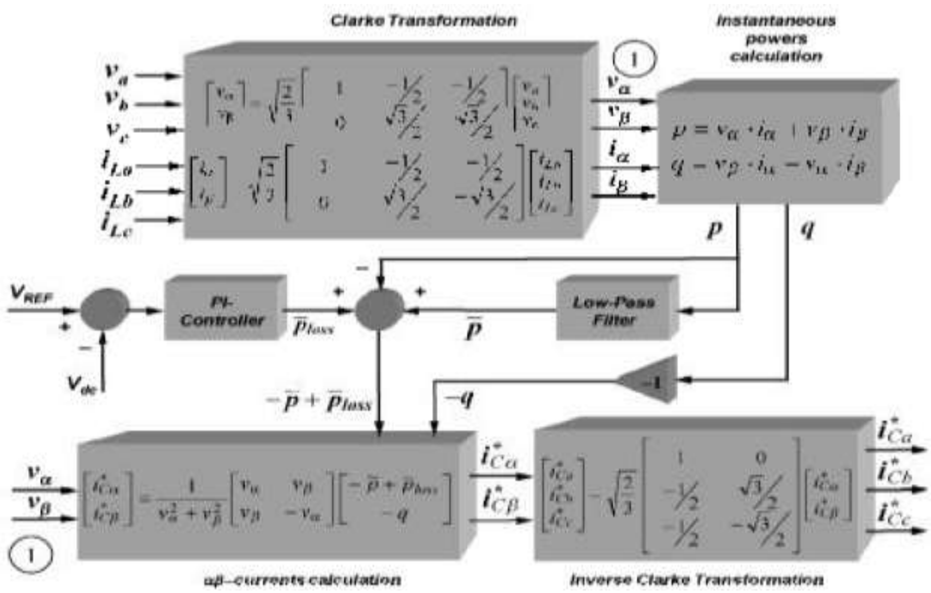

Figure 2. Block diagram of the instantaneous reactive power theory.

C. Instantaneous active and reactive current control strategy(I_d-I_q):

The active power filter control algorithm, based on Instantaneous active and reactive current control strategy(I_d-I_q), as shown in figure(3). In this method, the load current signals are first **transformed** into synchronous reference (dq0) frame. The fundamental component of the load current after transformation is a DC value and the harmonics appear like a ripple over this DC offset. A low pass filter is used to separate harmonic components from the load current. The active power loss component is subtracted from this current to get the reference d and q component of filter currents. Then reference current in abc frame is obtained using inverse transformation. The reference current is compared with actual filter current and the error current is used by the hysteresis controller to generate the pulses. In general the rotating frame dq0 is obtained from abc quantities by the following transformation.

$$\begin{bmatrix} x_o \\ x_d \\ x_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

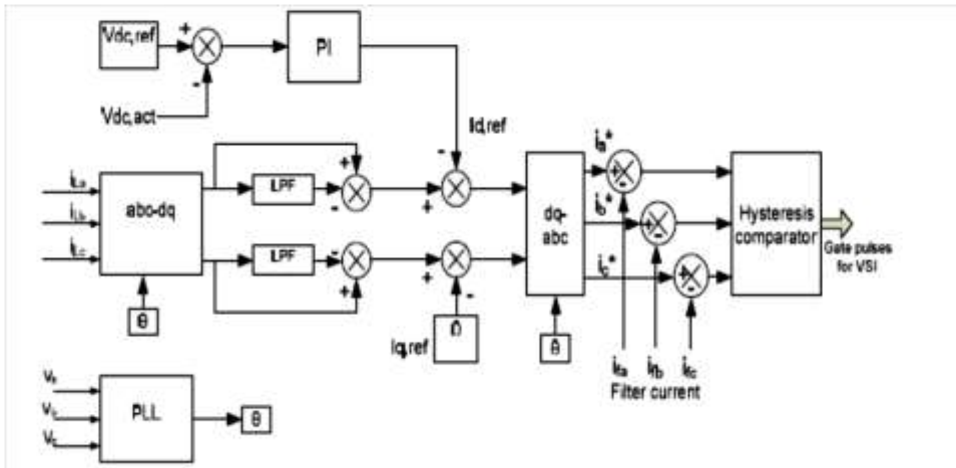

Figure 3. block diagram of Instantaneous active and reactive current control strategy, (I_d-I_q) method.

For synchronization a PLL is used which derives phase angle θ the AC supply voltage. The whole description given in[8] for these two control strategies.

D. Design of PI Controller

The control scheme consists of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a PI controller, which contributes to zero steady error in tracking the reference current signal. The output of the PI controller is considered as peak value of the supply current (I_{max}), which is composed of two components: (a) fundamental active power component of load current, and (b) loss component of APF; to maintain the average capacitor voltage to a constant value. Peak value of the current (I_{max}) so obtained, is multiplied by the unit sine vectors in phase with the respective source voltages to obtain the reference compensating currents. These estimated reference currents (I_{sa}*, I_{sb}*, I_{sc}*) and sensed actual currents (Isa, Isb, Isc) are compared at a hysteresis band, which gives the error signal for the modulation technique. This error signal decides the operation of the converter switches. In this current control circuit configuration the source/supply currents I_{sabc} are made to follow the sinusoidal reference current I_{abc}, within a fixed hysteretic band. The width of hysteresis window determines the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is kept constant throughout the operating range of the converter. In this scheme, each phase of the converter is controlled independently. To increase the current of a particular phase, the lower switch of the converter associated with that particular phase is turned on while to decrease the current the upper switch of the respective converter phase is turned on. With this one can realize, potential and feasibility of PI controller.

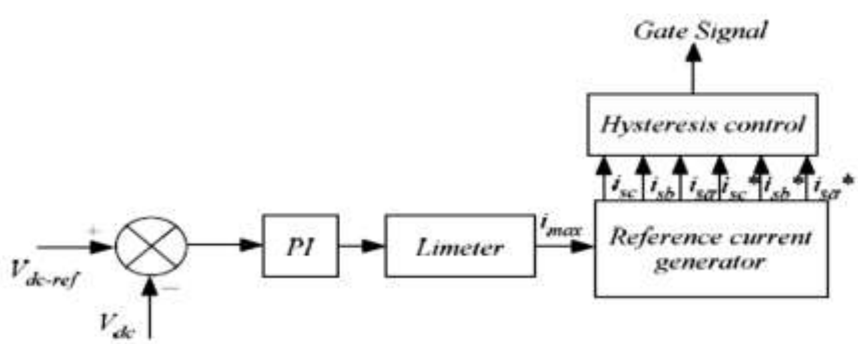

Figure 4. Conventional PI Controller

E. Hysteresis Controller

In fixed band hysteresis current control, a varying modulation frequency of the power converter produces, which in turn, results in increasing the switching losses. To avoid this situation, adaptive hysteresis current controller methods with the variable hysteresis band have been recommended in literature [9-10]. Hence, a variable hysteresis band is defined for each phase so that the switching frequency remains almost constant.

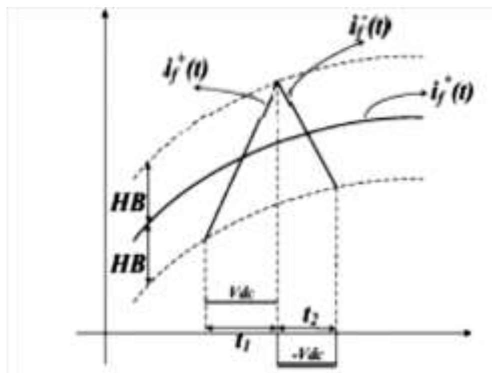

Figure 5. The upper and lower bands of the reference compensation current.

From Fig. 5, the below relations can be obtained,

$$\frac{di_{fa}^{+}}{dt} = \frac{1}{L_f}(V_f - v_s(t))$$
$$\frac{di_{fa}^{-}(t)}{dt} = \frac{1}{L_f}(V_f + v_s(t))$$

Where $i_f^+(t)$ and $i_f^-(t)$ are the rising current and the falling current, respectively. Furthermore, the following relations can be form:

$$\frac{di_{fa}^{+}(t)}{dt} * t_1 - \frac{di_{fa}^{*}(t)}{dt} * t_1 = 2HB$$
$$\frac{di_{fa}^{-}(t)}{dt} * t_2 - \frac{di_{fa}^{*}(t)}{dt} * t_2 = -2HB$$
$$f = \frac{1}{t_1 + t_2}$$

Where t1 and t2 are switching intervals and 1 is the switching frequency.

By substituting (8), (9) and (11) in (10), the hysteresis band (HB) can be achieved as follow:

$$HB = \frac{V_{dc}}{4fL_f} - \frac{L_f}{4fV_{dc}}\left(\frac{v_{s(t)}}{L_f} + \frac{di_f^{*}(t)}{dt}\right)^2$$

The adaptive HB should be derived instantaneously during each sample time to keep the switching frequency constant.

Conclusion

In this paper we have given the brief introduction necessary for implementing Shunt Active Power Filter to the network in order to compensate the harmonics. And also the two most popular control strategies used for extracting the reference currents are discussed here, using PI controller. Also the design of PI controller is discussed here. An adaptive hysteresis current controller which is a PWM controller, is discussed. Several papers have published regarding the comparative study of different control strategies used in the SAPF.

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