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Comparative Analysis for Extracting Compensation Current for Shunt Active Filter

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***Abstract* – The increase of non-linear loads in industrial, commercial and domestic facilities causes harmonic problems. Harmonics cause malfunctions in sensitive equipment, increase heat in the conductors, overvoltage by resonance and affects other customer loads connected at the Point of Common Coupling (PCC). Shunt Active Power Filter (APF) is designed and implemented for power quality improvements in terms of current harmonics and reactive-power compensation. . The performance of the Shunt Active Power Filter depends on the design and characteristics of the controller adopted for APLC. This paper is to find a suitable control strategy for reference current are utilized for extracting reference current. Furthermore, Hysteresis Current Controller (HCC) is applied to generate switching pulses of the PWM-inverter. This paper presents a comparative study of two control strategies to eliminated harmonics present in the source current. The system is simulated in MATLAB-Simulink for effectiveness study.**

***Index Terms*- p-q theory, Id-Qi method, reference current extraction, and harmonics**

I. INTRODUCTION

Now days, the power quality in the distribution system is polluted due to unbalanced load currents. It gives distorted current at the point of common coupling. In modern power system the most important power quality issues are harmonic mitigation and reactive power compensation. Nonlinear loads represent a large percentage of the total loads. Under these conditions, total harmonic distortion (THD) may become very high and dangerous for the system. The Power quality indices are governed by various standard regulations and recommendations such as IEEE-519.

Passive filters are achieved to mitigate harmonics for the past two decades .They have the disadvantage of potentially interacting adversely with the power system and it is important to check all possible system interactions when they are designed. They cannot operate successfully because of parallel resonance problem at a selected frequency. SAF is an active filter which is connected to shunt with the load and can work independently with of the system impedance characteristics. Active filters can be efficiently used to correct the power factor, harmonics mitigation and reactive compensation, etc.

The basic principle of a shunt active filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the PCC. The shunt active filter with the system configuration is taken as three phase bridge rectifier feeds RL load as non-linear load as shown in Fig.1.

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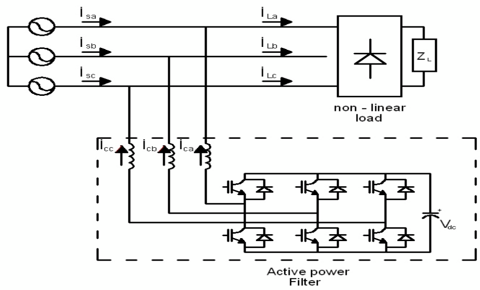

Fig.1.System configuration with SAF.

The efficiency of harmonic compensation depends on the type of control algorithm and to calculate the harmonics load current. The different control algorithms have been published for obtaining the APF reference current. These control algorithms can operate in time domain or frequency domain. In time domain these are based on instantaneous reactive power algorithm (PQ), Synchronous detection method, Symmetrical component theory (SC), Instantaneous reactive and reactive power current component theory (dq), constant power factor Compensation theory, Perfect harmonics cancellation theory, etc.

This paper compares the effective method of extracting reference current under balanced sinusoidal voltage conditions. The performance of pq theory, dq theory, are compared.

II. INSTANTANEOUS PQ THEORY

H.Akagi developed an instantaneous p-q method [1].In this theory active filter currents are obtained from the instantaneous active and reactive powers of the nonlinear load. The three phase voltages and currents in a-b-c coordinates are transformed into α-β-0 co-ordinates using Clarke's transformation as shown in equation (1) and (2)

$$\begin{bmatrix} vo \\ v\alpha \\ v\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \quad \textbf{(1)}$$

$$\begin{bmatrix} io \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad \textbf{(2)}$$

$$\begin{bmatrix} po \\ p \\ q \end{bmatrix} = \begin{bmatrix} vo & 0 & 0 \\ 0 & v\alpha & v\beta \\ 0 & v\beta & -v\alpha \end{bmatrix} \begin{bmatrix} io \\ i\alpha \\ i\beta \end{bmatrix} \quad \textbf{(3)}$$

$$\mathbf{p} = \bar{p} + \tilde{p} \quad \textbf{(4)}$$

$$\mathbf{q} = \bar{q} + \tilde{q}$$

The instantaneous active power (p), reactive power (q) and zero sequence power (p0) as shown in equation (3).The ac component of active power and reactive power are utilized as the reference power. The reference currents in α-β are calculated by using equation (5)

$$\begin{bmatrix} ic\alpha * \\ ic\beta * \end{bmatrix} = \frac{1}{v\alpha^2 + v\beta^2} \begin{bmatrix} v\alpha & v\beta \\ v\beta & -v\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \Delta\bar{p} \\ -q \end{bmatrix} \quad (5)$$

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$$\begin{bmatrix} ica* \\ icb* \\ icc* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} -io \\ ic\alpha* \\ ic\beta* \end{bmatrix} \quad (6)$$

The losses in VSI due to switching of semiconductor devices so that additional average power required to compensate for the losses. The actual DC link capacitor voltage (Vdc) is compared with reference value and error is processed by PI controller .These instantaneous current references to the hysteresis PWM current control are determined.

III. ID-IQ METHOD

In this method the compensation currents are obtained from instantaneous active and reactive current components ild and ilq of the nonlinear load [3]. The mains voltages and load currents are to be transformed into αβ coordinates as given by equations below.

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_u \\ e_v \\ e_w \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} p_L \\ q_L \end{bmatrix} \quad (9)$$

However, the dq load current components are derived from a synchronous reference frame Park’s transformation, where ‘θ’ represents the instantaneous voltage vector angle, given in eq. (10)

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix},$$

$$\theta = \tan^{-1}\left(\frac{e_\beta}{e_\alpha}\right) \quad (10)$$

Under balanced and sinusoidal conditions angle ‘θ’ is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance, therefore dθ/dt may not be constant over a mains period.

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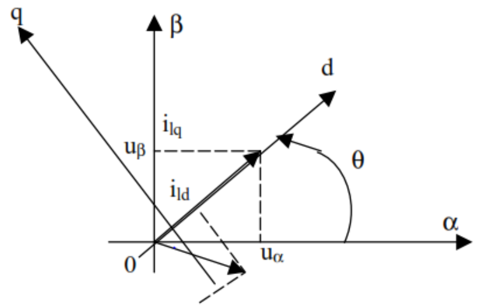

Fig. 2 Angular Representation

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{e_\alpha^2 + e_\beta^2}} \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \quad e_d = \left|\overline{e_{dq}}\right| = \left|\overline{e_{\alpha\beta}}\right| = \sqrt{e_\alpha^2 + e_\beta^2} \qquad (11)$$

The quadrature voltage component is always null, eq =0, from equation (10) becomes instantaneous active and reactive load currents ild and ilq decomposed into oscillatory and average terms.

$$i_{ld} = -\tilde{i}_{ld} + I_{Ld} \;, \; i_{lq} = -\tilde{i}_{lq} + I_{Lq} \qquad (12)$$

The first harmonic current of positive sequence is transformed to dc quantities. All higher order current harmonics including the first harmonic current of negative sequence, il+-dqnh+il-dq1h , are transformed to non-dc quantities and undergo a frequency shift in the spectra, and so, constitute the oscillatory current components. These assumptions are valid under balanced and sinusoidal mains voltage conditions. Eliminating the average current components by HPF's the currents that should be compensated are obtained, icd = -i~ld and icq = -i~lq .Finally, the compensating currents can be calculated by the following equations

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{e_\alpha^2 + e_\beta^2}} \begin{bmatrix} e_\alpha & -e_\beta \\ e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} \qquad (13)$$

$$\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}^T \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \qquad (14)$$

A Butterworth filter is chosen for the filtering of harmonics. Proportional-integral (PI) controller performs the voltage regulation on the VSC dc side.

IV. SIMULATION RESULTS

All the simulations are carried out under MATLAB/Simulink and simpower toolbox for the development of SAF and its control algorithm. The reference current extraction in the time domain for three phase SAF under nonlinear loads. The performance of the algorithm is

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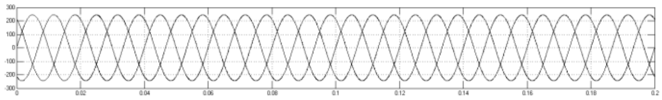
observed under nonlinear loads.

TABLE I: CORRESPONDING PARAMETERS AND ITS VALUES

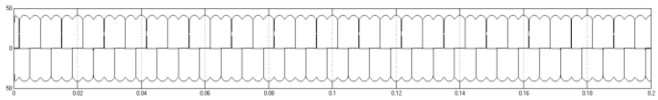
System Source voltage	400V
System frequency	50Hz
DC link capacitor	35µF
Source Resistance	0.1Ω
Source Inductance	0.1mH
Resistive Load(three phase diode bridge rectifier)	10Ω
Series Inductor Load	1 mH

a) Performance of Instantaneous PQ Algorithm

Line voltage



Load current



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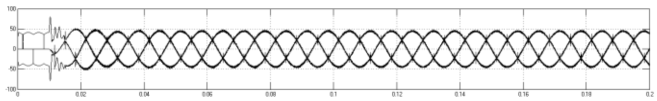
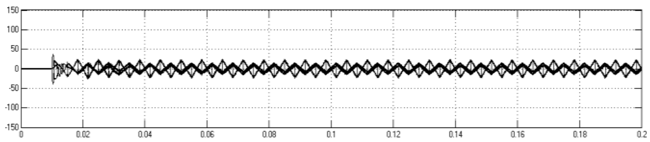
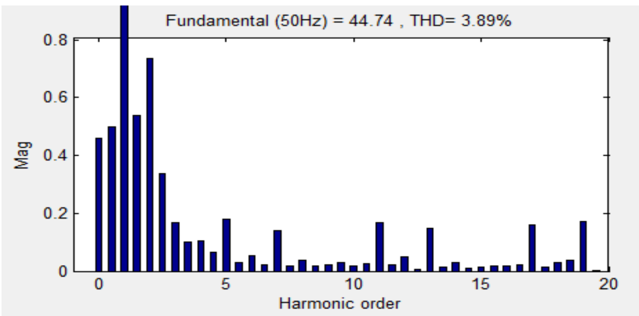


Filter current



FFT Analysis



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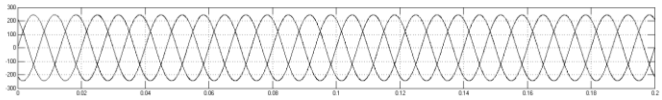
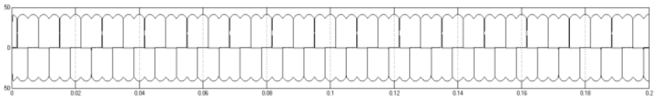
b) Performance of Id-I_q Method

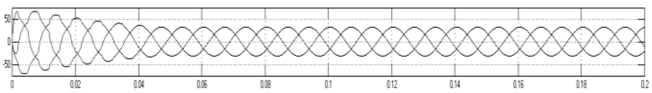
Line voltage



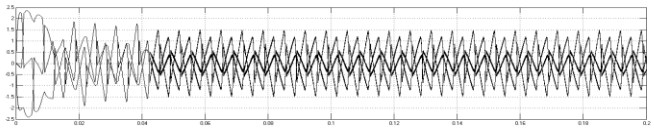
Load current



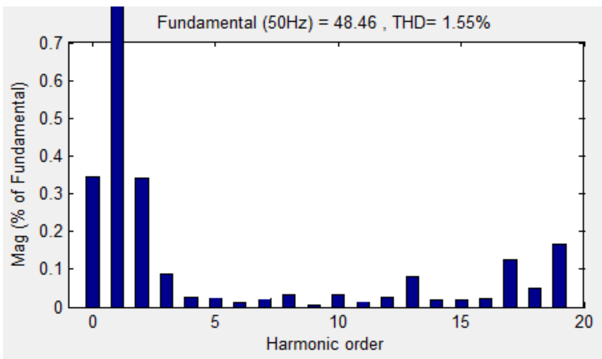
Line current



Filter current



FFT Analysis



V. CONCLUSION

In the present paper two control algorithms are developed and verified with three phase three wire systems. Both the methods are compensate the current harmonics in 3 phase 3wire system. The compensation performance of the two techniques is almost similar under ideal balanced conditions and they satisfy IEEE-519 standard it is observed that Id-Iq method is more sensitive than Instantaneous PQ algorithm under balanced sinusoidal main voltage conditions.

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