Comparative Study on Control Strategy for Harmonic Reduction in Three Phase Four Wire System

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***Abstract*— This paper deals with improvement of power quality in three phase four wire system and to make source current as sinusoidal using four leg Shunt Active Power Filter (SAPF) was used. The control of SAPF is based on reference current generation and current control methods. The comparative study on reference current computed by using instantaneous active and reactive power theory (p-q theory) and instantaneous current component theory (Modified d-q theory) with PI controller. The hysteresis controller is used to generate gate pluses and applied to four leg SAPF. The simulation of the work carried using MATLAB Simulink.**

Keywords*— *Hysteresis Controller, Modified d-q Theory, p-q Theory, PI Controller, SAPF

I. Introduction

In the power system there is an increase in harmonic instability which caused by the power electronic equipment. The ac mains are connected with the nonlinear load so that harmonics is generated to affect power quality. The nonlinear loads are adjustable speed drives, static power supplies and uninterrupted power supplies (UPS) which causes harmonics instability [1]. The passive filter is simplest method to reduce harmonic distortion but it have some disadvantages are large size and increase resonance problem. The SAPF is compared to other technique has been better for solving the harmonic related issues and reduce the harmonics [6].

The three phase four wire system uses split capacitor and four leg shunt active filter for VSI topologies. The split capacitor use six IGBT for compensate three phase current and the neutral point is connected in the mid of DC link capacitor. The SAPF based split capacitor VSI topology has some drawback are two capacitor at voltage deviation problem and overheating of components. The four leg SAPF is commonly used, it has 8 IGBT, the three leg are connected to three phase current and fourth leg is connected to neutral point for compensating neutral current and DC link at capacitor.

This work presents three phase four wire system with four leg shunt active filter in VSI topology, SAPF under instantaneous active and reactive power theory and instantaneous current component theory with PI controller for calculating reference current and the hysteresis current controller is used to generate gate pulses [4]. The work is organized as follows, chapter II described the proposed method, chapter III described the proposed control strategies in that a. instantaneous real and reactive power theory and b. instantaneous current component theory, chapter IV described the hysteresis controller and chapter V described the simulation result.

II. Proposed Method

The three phase four wire system is connected to nonlinear load in that three phase and single phase uncontrolled rectifier is used. The filter design is based on the topology of four leg SAF. The PI controller is used to regulate the DC link voltage. The four leg shunt active filter at three leg compensate source current and fourth leg compensate neutral current or zero sequence current shown in Fig.1.

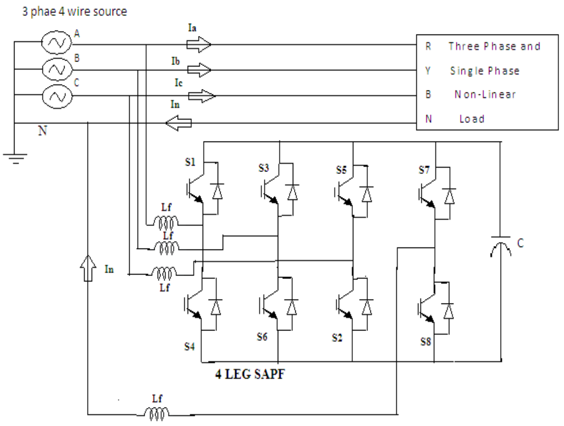

Fig.1 Four leg shunt active power filter with nonlinear

III. Proposed Control Strategies

A. Instantaneous Real and Reactive Power Theory

The p-q theory is based on set of instantaneous real and reactive power defined in time domain method. It is valid for both steady state and transient state [15]. This theory is efficient for designing shunt active filter. The three phase voltage and current (abc) are converted into αβ0 stationary reference frames. The Clarke and inverse Clarke transform of three phase voltage are given by,

$$\begin{bmatrix} V0 \\ V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V\alpha \\ V\beta \\ Vo \end{bmatrix} \quad (2)$$

Similarly three instantaneous line current ia,ib,ic can be converted into αβ0 coordinate,

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ 0 & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} \quad (4)$$

The three phase instantaneous real, reactive and zero sequence power calculated by,

$$\begin{bmatrix} p0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} V0 & 0 & 0 \\ 0 & V\alpha & V\beta \\ 0 & V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} \quad (5)$$

The stationary reference frame used for calculating compensating reference current given by,

$$ic\alpha\ ref = \frac{1}{V\alpha^2 + V\beta^2}[V\alpha(Po - P) + V\beta q] \quad (6)$$

$$ic\beta\ ref = \frac{1}{V\alpha^2 + V\beta^2}[V\beta(Po - P) + V\alpha q] \quad (7)$$

The inverse clarke transform of three phase instantaneous compensated reference current given by,

$$ica\ ref = \sqrt{\frac{2}{3}}[\left(\frac{-io}{\sqrt{2}}\right) + ic\alpha\ ref] \quad (8)$$

$$icb\ ref = \sqrt{\frac{2}{3}}[\left(\frac{-io}{\sqrt{2}}\right) - \frac{1}{2}ic\alpha\ ref + \frac{\sqrt{3}}{2}ic\beta\ ref] \quad (9)$$

$$icc\ ref = \sqrt{\frac{2}{3}}[\left(\frac{-io}{\sqrt{2}}\right) - \frac{1}{2}ic\alpha\ ref - \frac{\sqrt{3}}{2}ic\beta\ ref] \quad (10)$$

The instantaneous real and reactive power theory having some drawbacks, they are unable to compensation of harmonics current under non sinusoidal voltage conditions [14].

The block diagram of reference current calculation, in that Clarke transform to calculate real, reactive and zero sequence power and stationary frame at compensated reference current generate by using PI controller shown in Fig.2. The SAPF at using DC link capacitor and DC link reference voltage and actual voltage compared to voltage to be regulated. Then inverse Clarke transform to calculate three phase compensated reference current [2]. The real and reactive power is calculated to pass low pass butterworth filter, in that cutoff frequency is 50Hz. The hysteresis current control is used to compare actual and reference current to trigger gate pulses and given to shunt active power filter.

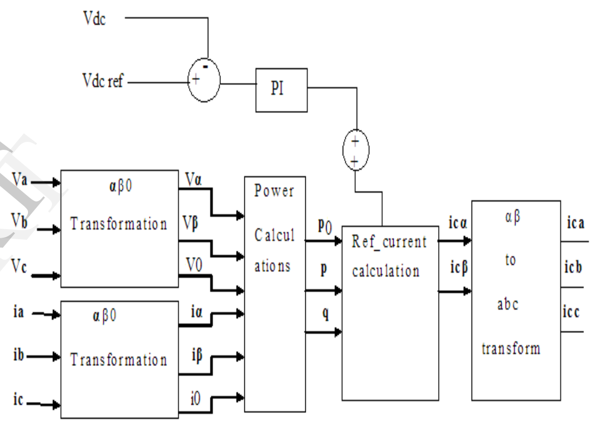

Fig.2 Block diagram of Reference Current Calculation Using p-q Theory

B. Instantaneous Current Component Theory

The Modified d-q theory is based on set of rotating direct and quadrant power defined in time domain method. It is valid for both steady state and transient state. This theory is very efficient and flexible for designing shunt active filter in non sinusoidal voltage condition. The three phase voltage and current (abc) are converted into dq0 synchronous rotating reference frames [12]. The park and inverse park transform of three phase current are given by,

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (11)$$

$$\theta = tan^{-1}\frac{V\beta}{V\alpha} \quad (12)$$

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos(\Theta) & \sin(\Theta) \\ -\sin(\Theta) & \cos(\Theta) \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (13)$$

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The three phase compensated reference current calculated by inverse park transform is given by,

$$ica\ ref = id\sin(wt) + iq\cos(wt) \qquad (14)$$

$$icb\ ref = id\sin\left(wt - \frac{2\pi}{3}\right) + iq\cos(wt - \frac{2\pi}{3}) \qquad (15)$$

$$icb\ ref = id\sin\left(wt + \frac{2\pi}{3}\right) + iq\cos(wt + \frac{2\pi}{3}) \qquad (16)$$

$$icn\ ref = ica\ ref + icb\ ref + icc\ ref \qquad (17)$$

The block diagram of shunt active power filter based Modified d-q theory shown in Fig.3. The three phase current is converted into rotating reference frame and passed to high pass filter (HPF), it attenuate higher order harmonics and through compute the compensated reference current using inverse Clarke transformation.

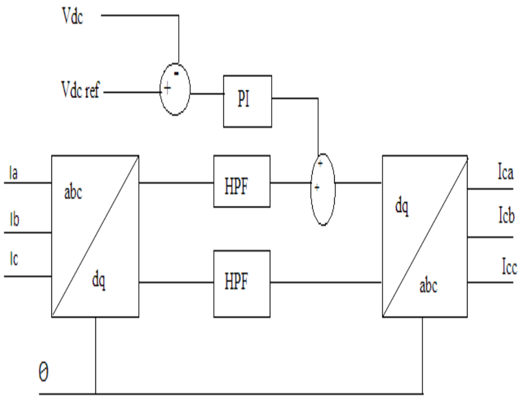

Fig.3 Block diagram of Reference Current Calculation using Modified d-q Theory

C. DC Link Voltage Regulator

The PI controller is generally used to regulate the DC Link voltage of shunt active power filter. The PI controller is used to compare actual dc link voltage and reference voltage in that error value is sampled. Its transfer function H(s) is represented as given by,

$$H(s) = Kp + \frac{Ki}{s} \qquad (18)$$

Where Kp is proportional constant and Ki is integral constant. The Kp and Ki are used to determine dynamic response of dc link voltage control and settling time. The PI control is used to improve the loop gain and eliminate steady state error values. The PI controller is to compare actual and reference DC link voltage to be regulated shown in Fig.3. The rotating frame coordinates dq0 converted into three phase compensated reference current Ica, Icb, Icc.

D. Hysteresis Current Control

The hysteresis current control is used to compare actual source current (ia,ib,ic) and compensated reference current (ica,icb,icc) to generate the triggering of gate pulses and applied to VSI based four leg shunt active power filter [7].

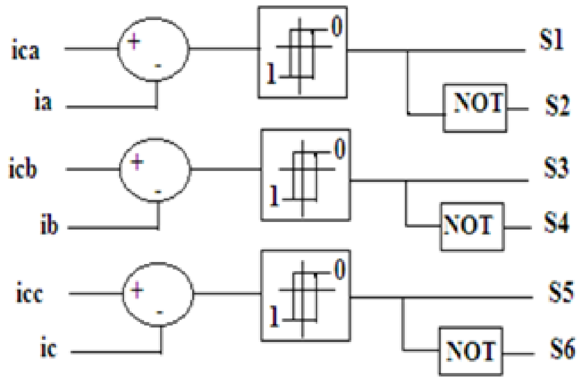

Fig.4 Hysteresis current control method

The hysteresis control method involves selection of two levels of current; one slightly greater than the reference compensated current and other slightly lower the reference current shown in Fig.4. The actual current is taken by feedback signal. When the actual current is less than lower value, the IGBT are switched on, and when the current crosses the higher value, the IGBT are switched off [13]. As a result, the actual current remains within the upper and lower bands of the current reference.

IV. Simulation Result and Discussion

The Matlab/Simulink simulation tool was used to develop a three phase four wire system with 4leg SAPF model that allowed the simulation and testing of controllers. The open loop simulation of three phase four wire system is connected to nonlinear load in that three phase and single phase uncontrolled rectifier with RL load is used. The simulated output waveform for source voltage, source current, Load voltage, Load current and neutral current before filter circuit shown in Fig.5.

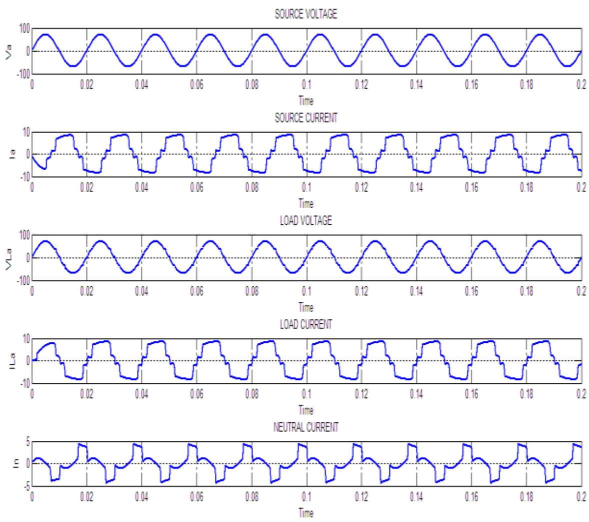

Fig.5 Simulation Waveforms for before SAPF Filter

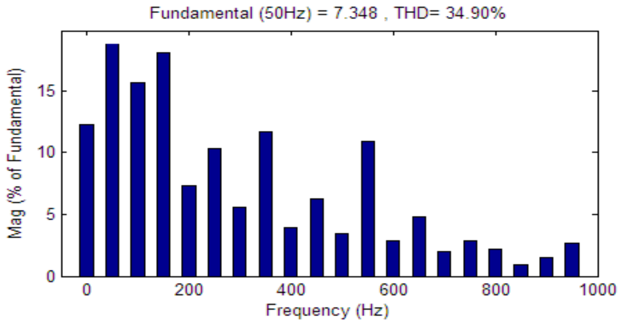

Fig.6 THD Value of source current before Filter

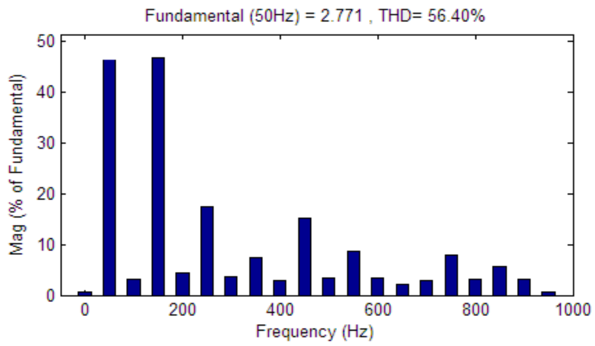

Fig.7 THD Value of Neutral current before Filter

The Fast Fourier transforms (FFT) analysis of open loop source current THD value is 34.90% shown in fig.6 and neutral current THD value is 56.40% shown in fig.7. The source current is sinusoidal by using four leg shunt active power filter.

The closed loop system for three phase four wire system is connected to nonlinear load. The source current is controlled by using four leg shunt active power filter with instantaneous active and reactive power theory with PI controller. The four leg SAPF with dc link capacitor to compensate the current harmonics. In fig.8 the point of common coupling (PCC) at using four leg shunt active power filter with dc link capacitor.

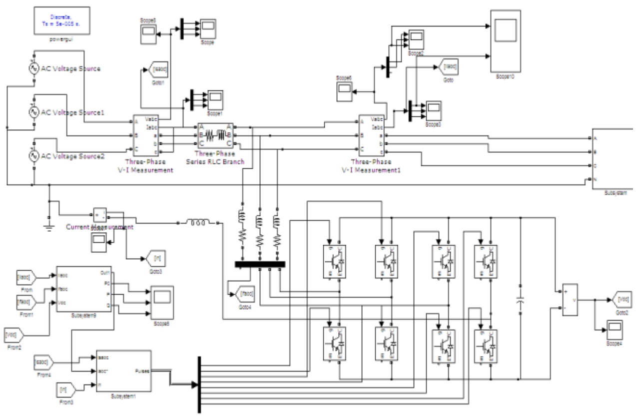

Fig.8 Simulation model of four leg SAPF with instantaneous active and reactive theory (p-q)

The three leg are compensating three phase current and fourth leg compensates neutral current in four leg SAPF method. The SAPF based reference current generated by using instantaneous active and reactive power theory with PI control. The PI control is comparing the actual and reference dc link voltage to eliminate error value and regulate of that voltage.

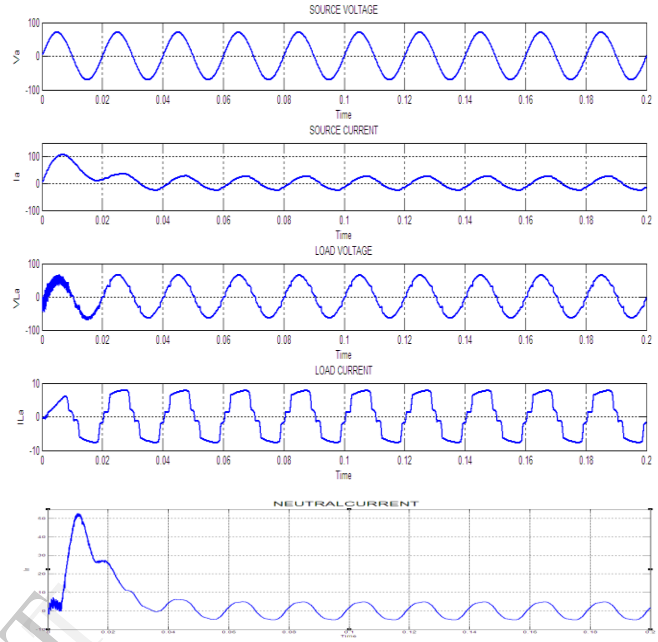

Fig.9 Simulation Waveforms for p-q theory based on four leg SAPF

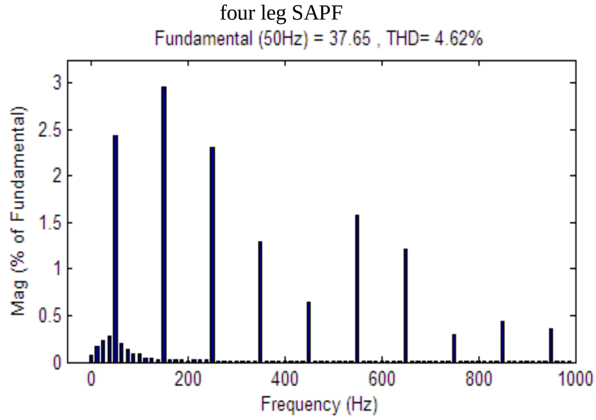

Fig.10 FFT analysis of Source current in SAPF based p-q theory

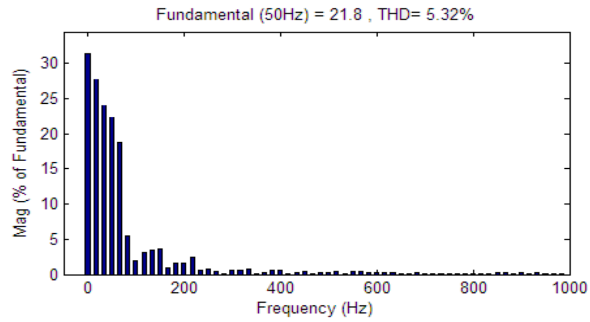

Fig.11 FFT analysis of Neutral current in SAPF based p-q theory

The simulated output waveform for p-q theory based four leg SAPF method shown in Fig.9. The Fast Fourier transforms (FFT) analysis of open loop source current THD value is 4.62% shown in Fig.10 and neutral current THD value is 5.32% shown in Fig.11.

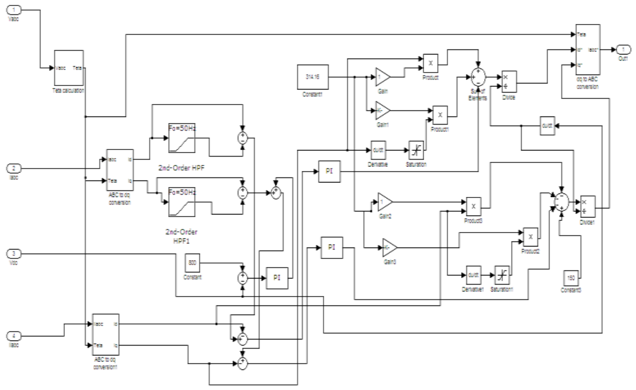

Fig.12 Simulation model of instantaneous current component theory (Modified d-q Theory)

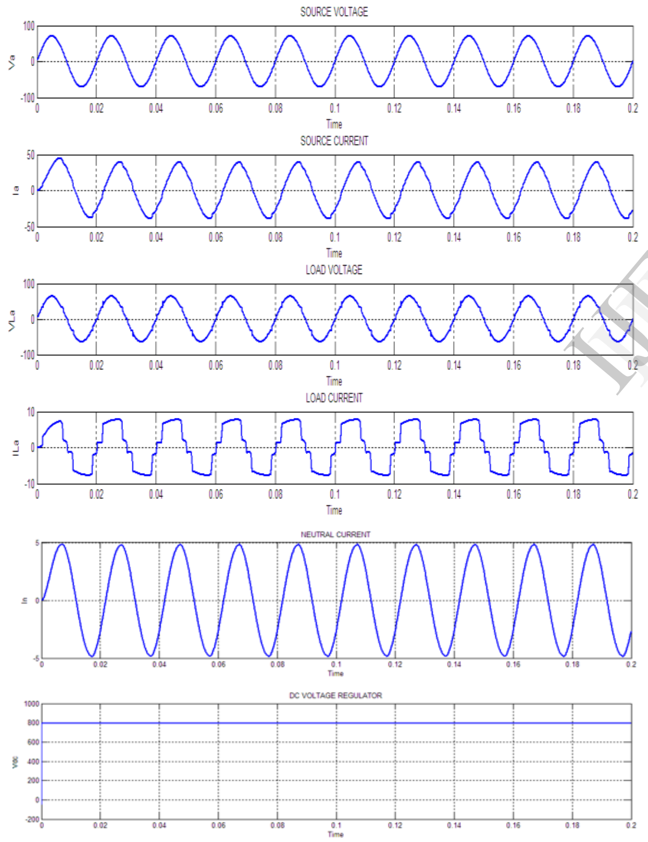

Fig.13 Simulation Waveform for SAPF based instantaneous current component theory (Modified d-q theory)

The closed loop simulation model of four leg SAPF with instantaneous current component theory (Modified d-q Theory) shown in Fig. 12. In that three phase four wire system and non linear load at four leg SAPF is connected in VSI. The SAPF at reference current calculated by using Modified d-q theory and dc link voltage is regulated using PI controller. The park transformation and inverse park transformation simulated in this diagram.

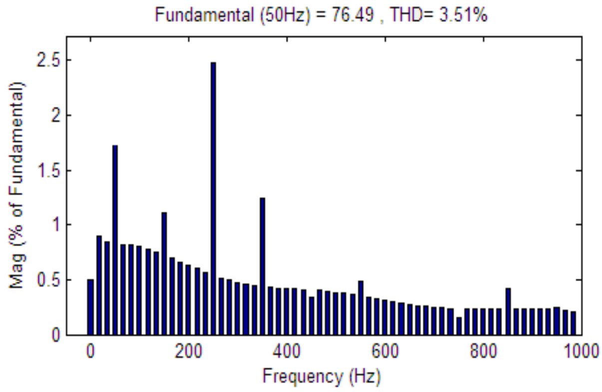

Fig.14 FFT analysis of Source current in SAPF based instantaneous current component theory

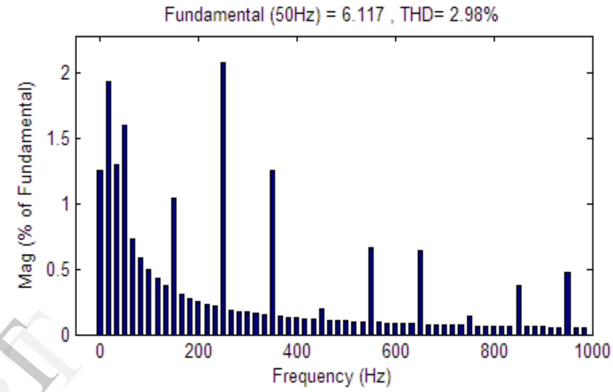

Fig.15 FFT analysis of Source current in SAPF based instantaneous current component theory

The Simulation output waveform for SAPF based Modified d-q theory with PI controller shown in Fig.13. In that three phase Source Voltage and current, three phase load voltage and current, neutral voltage to be presented. The FFT of source current is 3.50% shown in fig.14 and neutral current should be 2.98% shown in Fig.15. The four leg SAPF based Modified d-q theory is compared to p-q theory harmonics to be less in source current and neutral current. The PI controller is used to regulate the dc link voltage and improve the power factor.

A. Tables:

Table 1: Comparison of THD Values

THD Value	Before Filter	SAPF based p-q theory	SAPF based Modified d-q theory
Source current (Ampere)	34.90 %	4.62%	3.51%
Neutral current (Ampere)	56.40 %	5.32%	2.98 %

Table 2: Parameter Values

Parameter	Value
Supply Voltage	Vs = 70.7
Source resistance	Rs = 0.1Ω
Source inductance	Ls = 0.5mH
DC link capacitance	Cdc = 3000μf
DC link Voltage	Vdc = 800 v
PI	Kp = 10 Ki = 0.4
Load resistance	Rl = 20Ω
Load inductance	Ll = 60mH

V. CONCLUSION

In this paper four leg SAPF based two control strategies compared instantaneous real and reactive power theory and instantaneous current component theory (modified d-q theory), current control method at using hysteresis current controllers in three phase four wire system and their result are tabulated. In this method source current and neutral current harmonics has been compensated, THD value in IEEE 519 standard and reactive power to be compensated.

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