Compensating Current Generation using p-q Theory required for elimination of harmonics using Shunt Active Filter

Dhirendrakumar R Rana
Department of Electrical Engineering,Vadodara Institute of Enginnering, Kotambi

Abstract- **This paper describes a shunt active power filter with a controller based on the p-q theory, and studies its performance through simulation results obtained with different types of loads. It is explained, in a brief form, the p-q theory and its application in the control of a shunt active power filter. Matlab/Simulink is the simulation tool, used in the study, development, and performance evaluation of the shunt active power filter controller. The simulations are carried out for different loads, of linear and non-linear types. The shunt active power filter allows compensating harmonic currents, reactive power, unbalanced loads, and zero-sequence currents, presenting a good dynamic and steady-state performance, as it can be observed in the simulation results.**

Index Terms- **Active Filters, THD, Instantaneous Power Theory, Power quality, Harmonics Compensation.**

I. INTRODUCTION

In a modern power system, due to broader applications of nonlinear loads such as power electronic equipment or arc furnaces, the degree of waveform distorted is increasingly serious now. These loads may cause poor power factors, lead to voltage notch, or result in a high degree of harmonics. Such cases have brought the power quality as an increasing concern. Moreover, from economical viewpoints, a utility‘s revenue may get affected at a higher cost. Therefore, efficient solutions for solving these pollution problems have become highly critical for both utilities and customers.

Due to these problems, the quality of the electrical energy delivered to the end consumers is, more than ever, an object of great concern, being obligatory to solve the problem of the harmonics caused by polluting equipments (examples are: adjustable speed drivers, static converters, UPS‘s, PC‘s, and electronic equipments in general). The passive filters have been used as a conventional solution to solve harmonic currents problems, but they present some disadvantages: they only filter the frequencies they were previously tuned for; its operation cannot be limited to a certain load or group of loads; resonance can occur due to the interaction between the passive filters and others loads, with unexpected results.

To overcome these disadvantages, recent efforts have been concentrated on the development of active power filters. In this paper the development of a shunt active filter is proposed, with a control system based on the p-q theory. With this filter it is possible to effectively compensate the harmonic currents and the reactive power (correcting power factor to the unity), and also to balance the power supply currents (distributing the loads for the three-phases in equal form, and compensating zero sequence current).

II. P-Q THEORY

Akagi et al proposed a theory 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 called as Instantaneous Power Theory or Active-Reactive (p-q) theory which consists of an algebraic transformation (Clarke transformation) of the three-phase voltages in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix}$$

$p0 = v0 \cdot i0$ instantaneous zero-sequence power

$p = v\alpha \cdot i\alpha + v\beta \cdot i\beta$ instantaneous real power

$q = v\alpha \cdot i\beta - v\beta \cdot i\alpha$ instantaneous imaginary power

The power components p and q are related to the same α-β voltages and currents.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

The p-q Theory is defined in 3- systems with or without a neutral conductor. Three instantaneous powers: the instantaneous zero-sequence power-po, The instantaneous real power-p and the instantaneous imaginary power-q are defined from the instantaneous phase voltages and line currents on the αβ0 axes.

This theory is based on time-domain, which makes it valid for operation in steady-state or transitory regime, as well as for generic voltage and current power system waveforms, allowing to control the active power filters in real-time. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation (exception done to the need of separating the mean and alternated values of the calculated power components). The p-q theory performs a transformation (known as Clarke Transformation) of a stationary reference system of coordinates a - b - c to a reference system of coordinates α - β - 0, also stationary

III.SHUNT ACTIVE FILTER

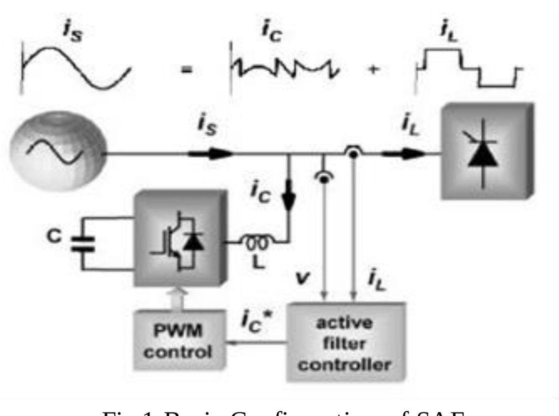


Fig.1 Basic Configuration of SAF

There are basically two types of active filters: the shunt type and the series type. It is possible to find active filters combined with passive filters as well as active filters of both types acting together.

Shunt active filters generally consist of two distinct main blocks the PWM converter and the active filter controller. The PWM converter is responsible for power processing in synthesizing the compensating current that should be drawn from the power system. The active filter controller is responsible for signal processing in determining in real time the instantaneous compensating current references, which are continuously passed to the PWM converter. Fig shows the basic configuration of a voltage-fed converter with a PWM current controller and an active filter controller. The shunt active filter controller works in a closed-loop manner, continuously sensing the load current and calculating the instantaneous values of the compensating current reference for the PWM converter.

IV.THREE-PHASE, THREE- WIRE SHUNT FILTER

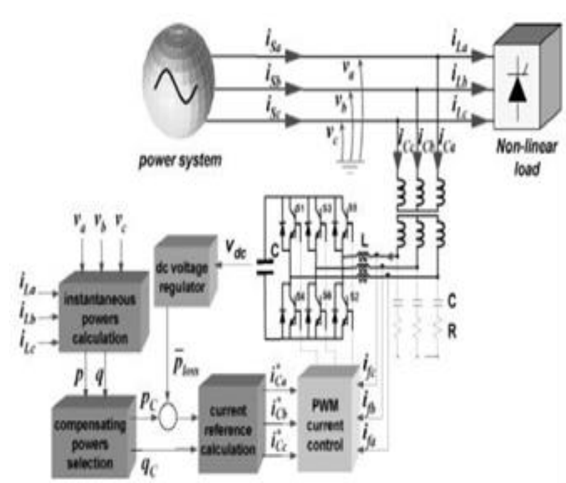


Fig.2 Block Diagram of SAF

A particular characteristic of three-phase, three-wire systemis the absence of the neutral conductor and the absence of zero-sequence current components. The zero-sequence power is always zero in these systems. Fig shows the most important parts of a three-phase, three-wire shunt active for current compensation. The control block calculates the instantaneous power takes as inputs the phase-voltages at the point of common coupling (PCC) and the line current of the nonlinear load that should be compensated. Shun active filter has a selective compensation characteristic.

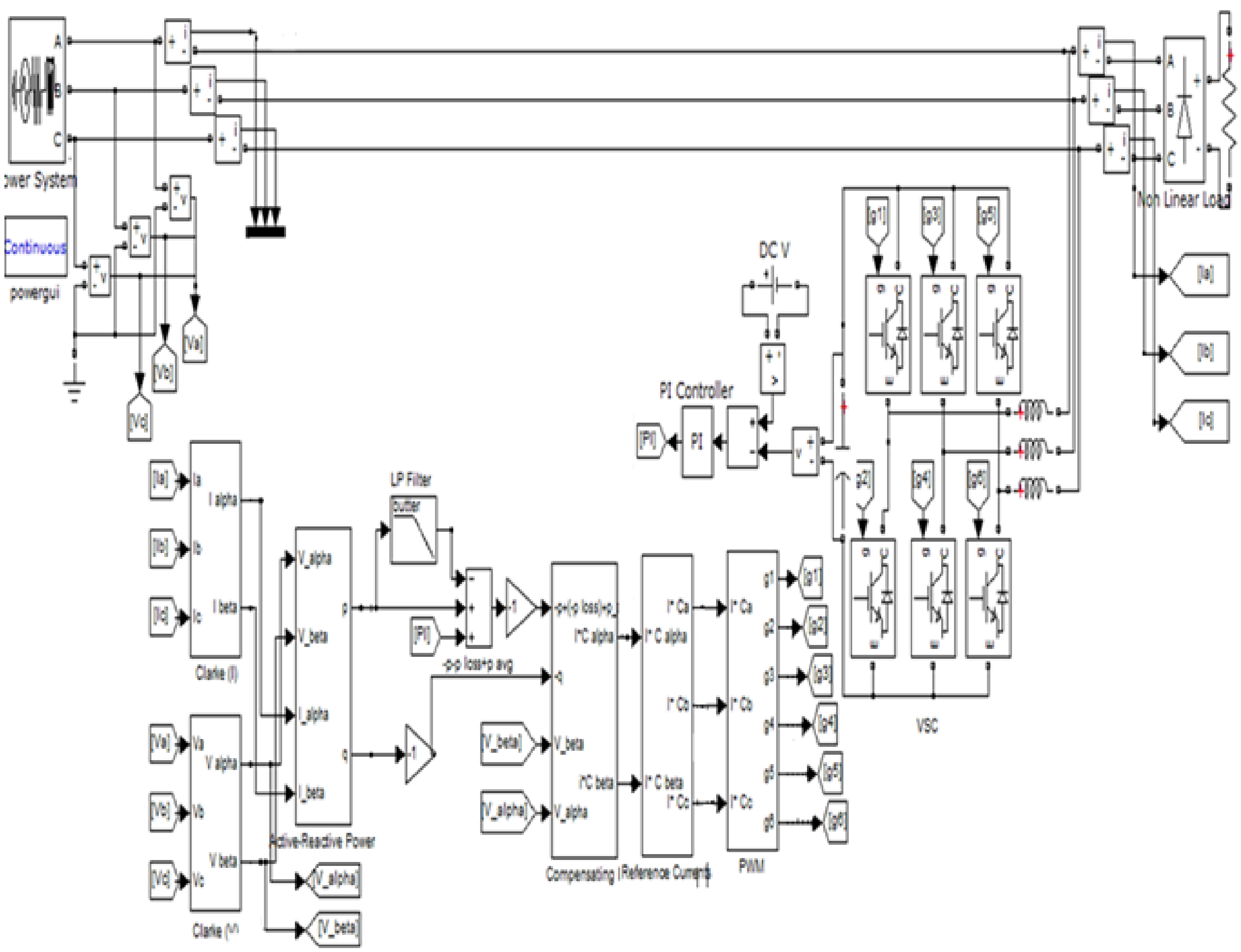
The shunt active filter for load-current compensation is one of the most common active filters. It can also provide harmonic damping throughout the power line to avoid ―harmonic propagation‖ resulting from harmonic resonance between the series inductance of the power system and shunt capacitors for power-factor correction. The active filter controller consists of four functional control blocks:

1. Instantaneous-power calculation
2. Power-compensating selection
3. dc-voltage regulator
4. Current reference calculation

The first block calculates the instantaneous powers of the nonlinear load. The second block determines the behavior of the shunt active filter. It selects the parts of the real and imaginary powers of the nonlinear load. The dc voltage regulator determines an extra amount of real power that causes an additional flow of energy to the dc capacitor in order to keep its voltage around a fixed reference value. This real power is added to the compensating real power pc which, together with the compensating imaginary qc, are passed to the current-reference calculation block. It determines the instantaneous compensating current references from the compensating powers and voltages.

Here, the inputs of the simulation are the three phase line currents and phase to ground voltages. And the outputs are three phase compensating reference currents

These reference currents are injected in the power system through voltage source inverter by proper applying gate pulses from the PWM converter. Now, inputs of the PWM converter are these compensating reference currents. These reference currents are opposite in nature with respect to harmonic current. Now by addition of harmonic and compensating current we can get supply current nearly sinusoidal.[1]



The power circuit of the shunt active filter consists of a three-phase voltage source converter made up of IGBTs and antiparallel diodes. The PWM current control forces the VSC to behave as a controlled current source. In order to avoid high di/dt , the coupling of a VSC to the power system must be made through a series inductor, commonly known as a commutation inductor or a coupling inductor.

IV.SIMULATION

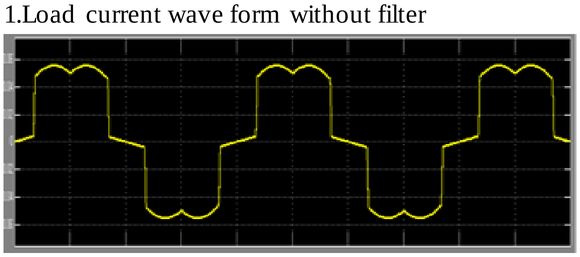
The block diagram of shunt active filter can be simulated using MATLAB SIMULINK as shown in the above Fig.

First of all the three phase line currents and phase voltages are converted to two phase orthogonal axes α-β using Clarke transformation. These two phase quantities are converted to instantaneous active and reactive power. We can also use the terms real and imaginary in place of active and reactive. Here both active and reactive components are bifurcated in average and oscillating components. Now our aim is to pass only average component of the active power. All other components: oscillating active power and total reactive power should be compensated. Using low pass filter having cutoff frequency from 20 to 100 Hz and by proper tuning we can discriminate the average power from the total power.

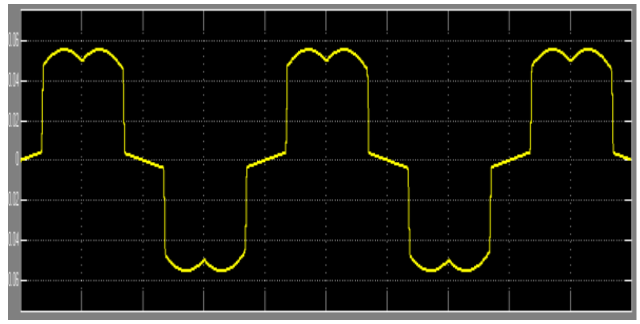
In the above simulation each square block indicates subsystem for calculation. The calculation is not shown in the above simulation. By using proper calculation we can get two phase compensating current reference and by using inverse Clarke transformation we can get three phase reference current. Here we can make the Simulink model in closed loop manner in which the controller can continuously sense the current and voltages and provide the reference currents with minimum THD. The standard IEEE limit for THD is 5%.

VI. SIMULATION RESULTS

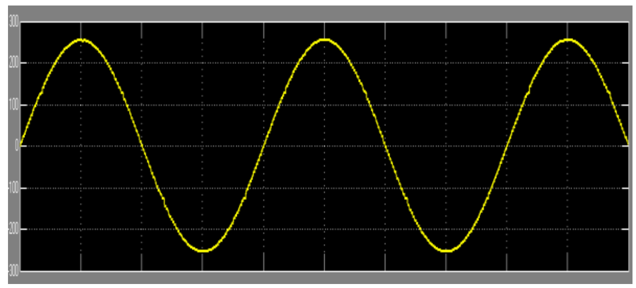
1.Load current wave form without filter



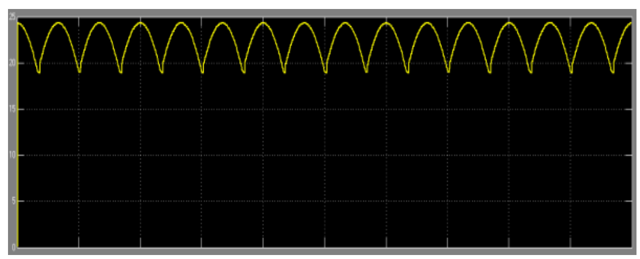
2.Source current wave form without filter



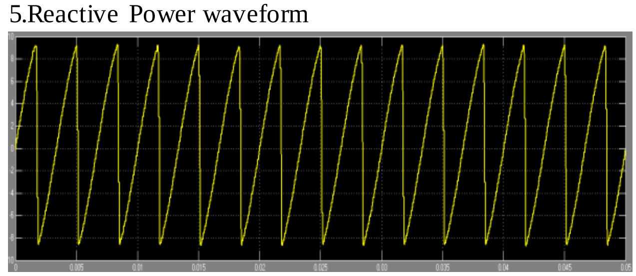
3 Source current wave form with filter



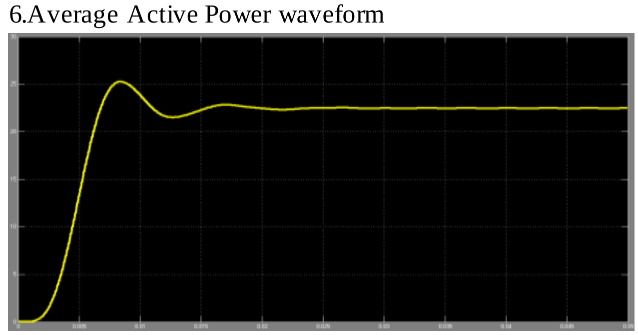
4. Active Power waveform



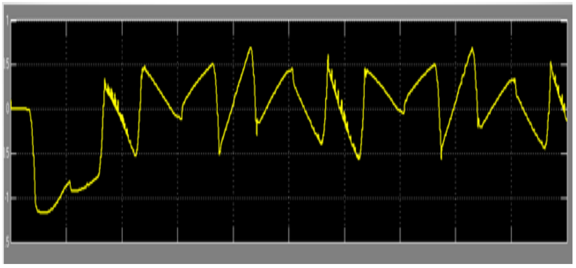
5.Reactive Power waveform



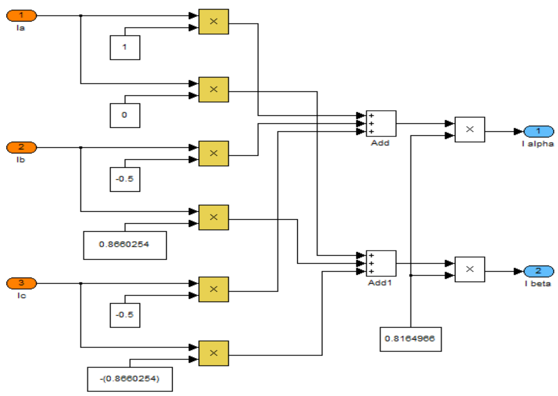
6.Average Active Power waveform



7.Compensating Reference Current waveform



8. Simulation of p-q Theory



VII. RESULT TABLE

	Phase	% THD in Current	% THD in Voltage
WITH FILTER	a	2.50	5.07
	b	1.04	6.45
	c	1.50	5.76
WITHOUT FILTER	a	25.66	8.28
	b	25.88	8.25
	c	25.68	8.36

VIII. CONCLUSION

p-q theory gives a piecemeal approach in analysis and control of the active and reactive components of the harmonic load and introduces the active power filter for appropriate corrective measure for the total harmonic distortion for improvement of the power quality as per the scheduled standards.

The percentage THD in current waveforms can be limited to 5%. Which is the prescribed IEEE limit according to 591:1992 standard.

The three phase reference currents are successfully obtained for harmonics mitigation. The THD level can be reduced to specified IEEE limits for different kind of nonlinear loads.

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