# Mitigation of Current Harmonics Using Single Phase Shunt Active Filter With P-Q Technique

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***Abstract*-This paper presents a single phase shunt active filter designed to minimize power quality in electrical system. Control system is based on instantaneous power theory in α-β-0 reference frame (p-q theory), derived to be applied in single phase system. The power stage of active filter is based on a two leg full bridge inverter with a single capacitor in a dc side and a filter inductor in ac side. In essence the shunt active filter is designed to drain from the electric grid, harmonic and reactive components of the load currents , such that the system will become basically,a sinusoidal waveform with low harmonic distortion, and in phase with system voltage.The simulation results are on MATLAB/Simulink environment tools presented in order todemonstrate the performance of the current load on single phase shunt active power filter.**

***Keywords– InstantaneousPower Theory, Shunt Active Power Filter, Source and Load Harmonics , Total Harmonic Distortion, Matlab simulation.***

## I. INTRODUCTION

In modem power systems the requirement for reactive power compensation is becoming more and more rigorous. During the last decades, voltage source inverters **(VSIs)** due to advancements in power electronics and control methods have attracted a greatdeal of attention for fast dynamic reactive power compensation. It is possible cancelling out the reactive power of load using injection of specified current waveform to the utility by VSI. Obviously, the most important subject in the operation of these inverters is the strategy of generation of reference current waveforms, which the inverter should inject in each of the phases. Between the various methods in this field, the instantaneous p-q theory has gained considerable attention

After the presentation of original p-q theory [1,2] some Instantaneous power based theories presented [3-1]. The main objectives of these articles were extension of p-q theory to three-phase three-wire and/or three-phase fourwire systems considering different utility voltage and/or load current conditions. These conditions include subjects such as imbalance and/or harmonic polluted utility voltage, imbalance and/or harmonic polluted load current and neutral current compensation.

Considering this fact that the p-q theory is a threephasesystem based theory, it is obvious that all of the researches which are based on this theory, are usableonly in three-phase systems. This subject results independency of reference compensation current in one phase to the current and voltage waveform of other two phases.

The main objective of this paper is presentation of single phase p-q theory and using it for instantaneous reactive power compensation of each of the phases of a three-phase system, independently. Single-phase p-q theory has two main advantages over existing original p-q theory as follows:

(a) Single-phase p-q theory compensates for Instantaneousreactive power of single-phase as well as three-phase systems. It can be used in single phase loaded three-phase systems, too. But, original p-q theory generates incorrect compensating currents in remaining phases of a three-phase system, which is loaded by a single-phase load on one of its phases.

(b) Single-phase p-q theory generates sinusoidalreference currents in the utility side when utilityvoltages and/or load currents are imbalance butoriginal p-q theory cannot generate sinusoidal current waveform in above-mentioned conditions.

There are some advantages of implementing shunt active filter on grid power system since it can be installed at housing estate or others system that using single phase grid power system. The aim of this paper is to implementthe p-q theory in single phase shunt active filter connected directly to gird power system. The technique is simulated by using MATLAB/Simulink.

### *Single Phase Shunt Active Filter*

The shunt-connected active power filter, with a self-controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensatingcurrent. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.Schematic of single phase shunt active filter is shown in Fig.1.

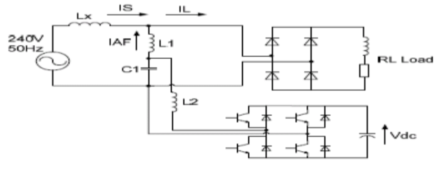


Fig.1 schematic ofsingle phase shunt active filter

The function of single phase active power filters compensation principle, which is controlled in a closed loop manner to actively shape the source current into sinusoidal. Single phase active filter concept uses power electronics to produce harmonic current components with $180^\circ$ phase shift to the harmonic current components generated from non-linear loads. The shunt connected single phase active power filter is based on the principle of injection of harmonic currents into the ac system of the same amplitude but opposite in phase to that of the load harmonic currents.

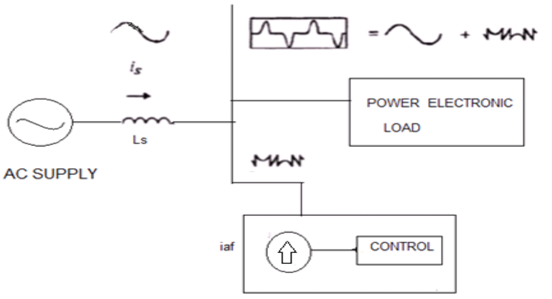


Fig2- principle of shunt connected SPAPF

The operation of the SPAPF, shown in Fig. 2, is investigated for the general case. It is assumed that the supply feeds single phase non-linear load, connected between the line and neutral. Also the current drawn by the load is non-sinusoidal and have all odd harmonics.
The load current is expressed as:

$$i = i_1 + i_h \qquad (1)$$

Where, $i_1$ is the fundamental component of the load current and $i_h$ is the harmonic current.
Now active filter current is given by:

$$i_{af} = i_h \qquad (2)$$

Supply current is given by applying KCL at PCC:

$$i_s = i + i_{af} \qquad (3)$$

Combining equations (1), (2) and (3):

$$i_s = i_1 \qquad (4)$$

Equation (4)theoretically shows that with SPAPF the supply current harmonics can be compensated completely.

*Control Strategy*

As shown in Fig, the sensed dc voltage of the APF is compared with its set reference value in the error detector. The voltage error is processed in the P-I voltage controller. Its output is limited to the maximum permitted value. This output of the voltage controller is taken as peak value of supply current.

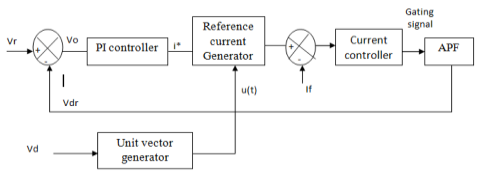


Fig3. Control loop

The unit vector in phase with supply voltage is achieved using sensed source ac voltage. The output of the P-I controller is multiplied to unit vector to generate reference sinusoidal supply current in phase with supply voltage for the unit power factor of the ac source. This reference supply current is compared with sensed source current. A PWM is used over this current error to generate gating signal for the devices of the APF. The APF, in response to these gating pulses, generates a PWM voltage at the ac side of the APF. The impressed PWM voltage causes a current to flow through the inductor for the compensation of harmonics and reactive power of the load resulting in a unity PF.

*Instantaneous Active and Reactive Power (PQ) Theory*

In modern power systems the requirement for reactive power compensation is becoming more and more rigorous. During the last decades, voltage source inverters (VSIs**)** due to advancements in power electronics and control methods have attracted a great deal of attention for fast dynamic reactive power compensation. It is possible canceling out the reactive power of load using injection of specified current waveform to the utility by VSI.

The p-q theory also known as instantaneous power theory is widely used for three wires three phase power system and also extended to four wires three phase power system. Although this theory using three current and three voltage signals, it also can be used for single phase active filter by duplicating two more current and voltage signal with 120º angel shifting. This theory based on separation power component separation in mean and oscillating values. Consider load current of single phase load as phase "*a"* and others phase (phase "*b"* and phase "*c"*) are generated by duplicating technique. The load current can be assumed as phase "*a"* current and with be expressed mathematically as shows in eq. (1). By assuming that eq.(1) as phase "*a"* load current, load current for phase "*b"* and *c* can be represented as eq. (2) and eq. (3).

$$i_a = \sum_{i=0}^{n} \sqrt{2} I_i \sin(w_i + \theta_i) \qquad (1)$$

$$i_b = \sum_{i=0}^{n} \sqrt{2} I_i \sin(w_i + \theta_i - 120°) \quad (2)$$

$$i_c = \sum_{i=0}^{n} \sqrt{2}\, I_i \sin(w_i + \theta_i + 120°) \quad (3)$$

Equation(1), (2) and (3) can be transformed in matrix form as shown in (4) and (5) for load current and load voltage respectively:

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} 1` \\ 1 < 120° \\ 1 < 240° \end{pmatrix} (i_a) \qquad (4)$$

$$\begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} = \begin{pmatrix} 1` \\ 1 < 120° \\ 1 < 240° \end{pmatrix} (v_a) \qquad (5)$$

**Akagi**proposed a theory based on instantaneous values in three phase power system with or without neutral wire, and is valid for steady-state or transient 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. The theory is based on a transformation from the phase reference system x-y-z to the 0-α-β system as shown in figure 4

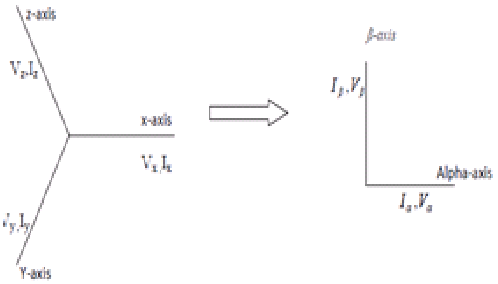


Fig4. X-Y-Z to0-α-β

The instantaneous space vectors, $v_x$ and $i_x$ are set on the x-axis, $v_y$ and $i_y$ are on the y axis, and $v_z$ and $i_z$ are on the z-axis. These space vectors are easily transformed into α-β coordinates as follows:

$$\begin{pmatrix} v_\alpha \\ v_\beta \\ v_0 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (6)$$

$$\begin{pmatrix} i_\alpha \\ i_\beta \\ i_0 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \quad (7)$$

The active and reactive power is written as

$p = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0$ *(8)* $q = v_\alpha i_\alpha - v_\beta i_\beta$

*(9)*

$$\begin{pmatrix} p \\ q \end{pmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \quad (10)$$

Active power and reactive power consist of two part which are mean part and oscillating part also known as DC part and AC part. The equations of active power and reactive power can be given as:

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

$q = \bar{q} + \tilde{q}$ (12)

Instantaneous zero- sequence power ($p_0$)

$$p_0 = v_0 i_0 = \bar{p}_0 + \tilde{p}_0$$

$p_0$ = mean value of the instantaneous zero-sequence power,

$\tilde{p}_0$= alternated value of the instantaneous zero-sequence power

$p$ = mean value of the instantaneous real power,

$\tilde{p}$ = alternated value of the instantaneous real power

$\bar{q}$=mean value of instantaneous imaginary power,

$\tilde{q}$= instantaneous imaginary power

The DC part can be calculated by using low-pass filter, which is can remove the high frequency and give the fundamental component or the DC part. From DC part active power and reactive power, the α-β reference current can be represented in (13).

$$i_{\alpha\beta} = \frac{1}{\Delta} \begin{pmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix} \quad (13)$$

Where $\Delta = v_\alpha^2 + v_\beta^2$

The three phase current reference of active power filter is given in (14) before the signal will subtracted to load current. The subtracted three phase current will be used to generated PWM signal using hysteresis band. Hysteresis band will produce six PWM signals and for single phase active filter it is only two are used as input of hysteresis band.

$$i^*_{abc} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{pmatrix} i^*_{\alpha\beta} \quad (14)$$

*Simulation and Results*

A simulation of single phase shunt active filter issimulated using MATLAB/Simulink. The simulation use single phase system 240Vand 50Hz as shows in Fig. 5. The non-linear load with 3KVA for compensation is connected before single phase diode rectifier.

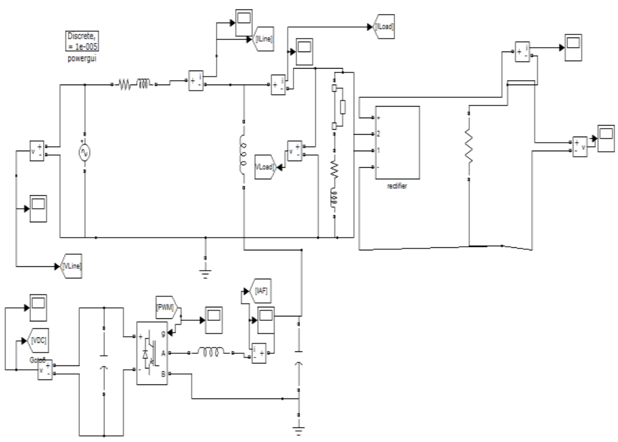


Fig 5. Simulink Diagram of Single Phase Shunt Active Filter

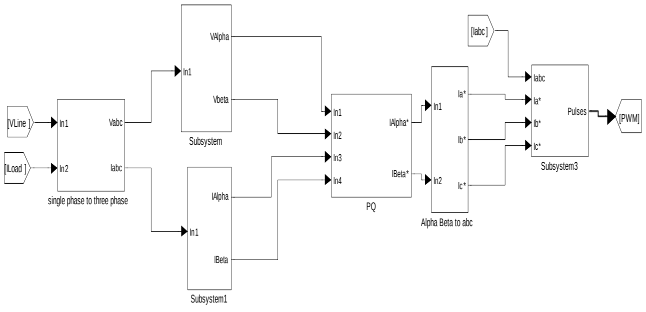


Fig 6. Modelling of P-Q Theory

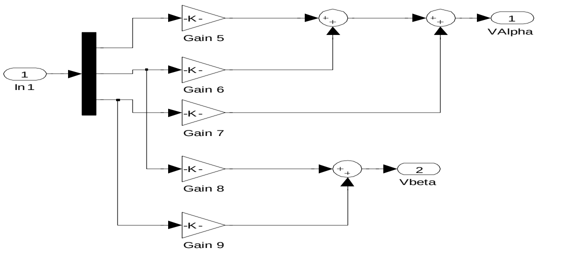


Fig 7.Vabc to Valpha and Vbeta

Fig. 6 shows the modelling of p-q theory. Fig q7 shows Vabc to Valpha andVbeta conversion model.

The load current in Fig. 9 will be compensated by injecting active filter currentas shown in Fig. 10 , so that the line current will be kept maintain in purely sinusoidal form as shown in Fig. 11. Fig 2 shows pulses and load current

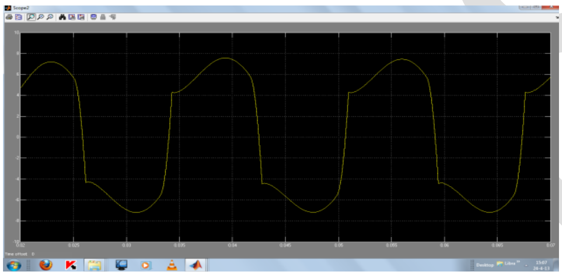

Fig 9.load current

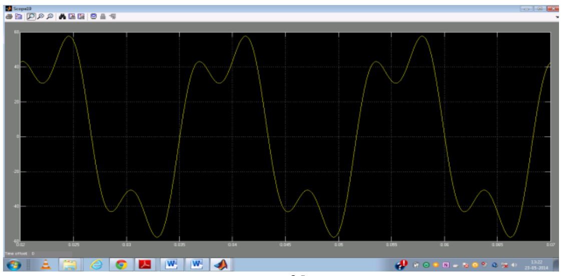

Fig 10.Active filter current

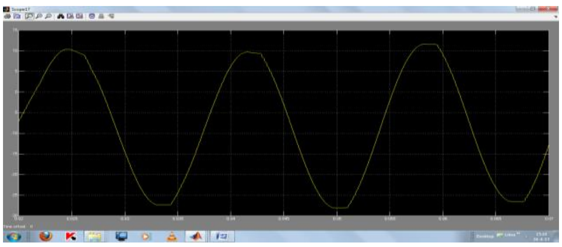

Fig11. Line Current

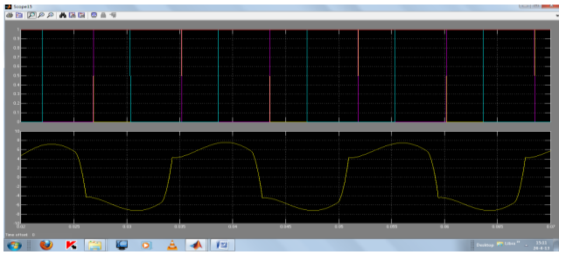

Fig12. Pulses and Load Current

## II CONCLUSION

In recent years the increasing usages of non-linear loadfacing of harmonic and power factor problem in powersystem. Many technique or topologies can be used to eliminate harmonics from power system; one of the techniques is active power filter. This paper proves that PQ-theory can be implemented to control single phase active filter, which the theory widely used to control three phase active power filter.

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