

Modeling of Shunt Active Filter Using P-Q Theory

Kirti Vibhute

Assistant Professor, Shri Dadaji Institute of Technology & Science, Khandwa (M.P.), India

Abstract: APF's are known to cancel the reactive and harmonic currents drawn by the load so as to make supply current sinusoidal and have been explored for executing different power conditioning functions simultaneously, along with harmonic elimination due to increase in Non-linear & unbalanced loads at the point of common coupling. The paper presents a study of different control strategies for APF's with an emphasis on instantaneous real power theory based Shunt APF, which is predominantly used in present scenario. The filter topologies are investigated through Matlab®/ Simulink© and the design issues of APF for Non-linear load conditions are also discussed.

Keywords: Active Power Filter (APF), Harmonics, Non-linear load, P-Q Theory, Reactive Power.

1. Introduction

The intensive use of power converters and other nonlinear loads in industry, domestic consumers in general has increased the deterioration of voltages and currents waveforms of power networks. The harmonics present in the power lines results in varied problems, like: greater power losses in distribution, problems of electromagnetic interference in communication systems, operation failures of protection devices, electronic equipments and industrial processes [3-4]. These problems result in high costs for industry and commercial activities, since they can lead to a decreasing in productivity and to a reduction of quality in the products or services duly delivered to consumers end more than ever. An object of great concern, being obligatory to solve the problem of the harmonics caused by "polluting" equipments such as adjustable speed drivers, static converters, UPS's, PC's, and electronic equipments in general.

Passive filters have been used as a conventional solution to solve harmonic currents problems, but they present some challenges such as they only filter the frequencies they are pre-tuned for, their 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 cope with these disadvantages continuous efforts have been concentrated on the development of active power filters [10-13]. In this paper the development of a shunt & series active filter is proposed, with a control system based on the p-q theory. The filter described effectively compensates the harmonic currents and the reactive power and also balances the power supply currents.

2. Proposed Instantaneous Power Theory (P-Q Theory)

In 1983, Akagi et al. [6] proposed "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous power theory or p-q theory. Based on instantaneous values in three-phase power systems with or without neutral wire, the theory is valid for steady-state or transitory operations and for generic voltage

and current waveforms as well. It involves an algebraic transformation of the three-phase voltages and currents in the a-b-c coordinates to the $\alpha\text{-}\beta\text{-}0$ coordinates, followed by the calculation of the p-q theory instantaneous power components. A summary of these transformations is given under

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{.....(1)}$$

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

$$P_0 = V_0 \cdot i_0 \quad (3)$$

$$p = V_\alpha \cdot i_\alpha + V_\beta \cdot i_\beta \quad (4)$$

$$q = V_\alpha \cdot i_\beta - V_\beta \cdot i_\alpha \quad (5)$$

Where:-

P_0 =instantaneous zero sequence power p =instantaneous real power

q =instantaneous imaginary power

The power components p and q are related to the same $\alpha\text{-}\beta$ voltages and currents, and can be written together:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} * \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad \text{.....(6)}$$

These quantities are illustrated in Fig.1 for an electrical system represented in a-b-c coordinates and have the following physical meaning:

p_0 = mean value of the instantaneous zero-sequence power corresponds to the energy per unit time transferred from the power supply to the load through the zero-sequence components of voltage and current.

$p_0 \sim$ =alternated value of the instantaneous zero-sequence power, which is energy per unit time that is exchanged between the power supply and the load through the zero-sequence components. Furthermore, the systems must have unbalanced voltages and currents in both voltage and current of at least one phase.

p = mean value of instantaneous real power, corresponds to the energy per unit time which is transferred from the power supply to the load, through the a-b-c coordinates, for a balanced condition.

$$q = 3 * V * I_1 * \text{Sin}\phi_1 \dots \dots \dots (7)$$

$p \sim$ =alternated value of the instantaneous real power – It is the energy per time unity that is exchanged between the power supply and the load, through the a-b-c coordinates.

q = instantaneous imaginary power, corresponding to the power that is exchanged between phases of the load. This component is responsible for the existence of undesirable currents which circulates between the system phases. In the case of a balanced sinusoidal voltage supply and a balanced load, q is equal to the conventional reactive power

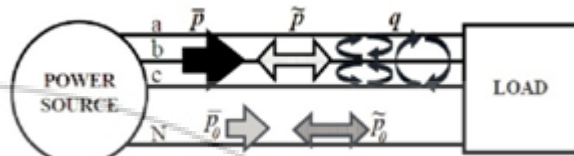


Figure 1: Power components in p-q theory

An important aspect is that only the mean values of the instantaneous real power (p) and of the instantaneous zero-sequence power (p_0) must come from the power supply, as they effectively transfer energy to the load.

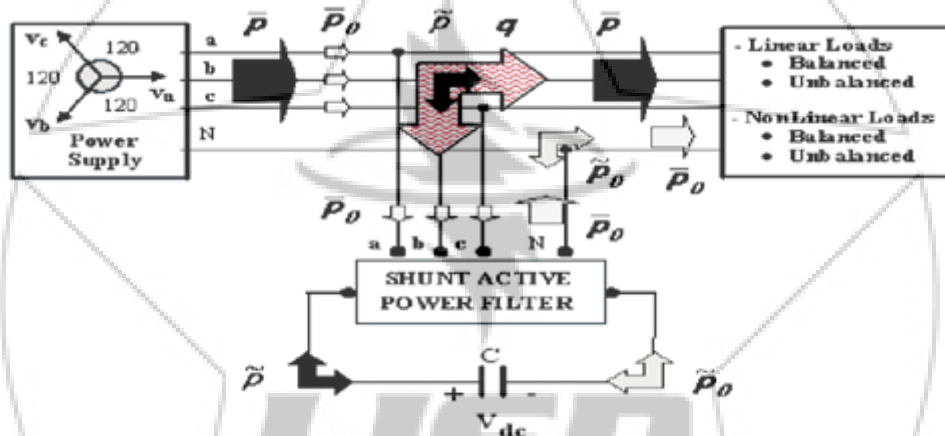


Figure 2: p-q theory power components in a generic three phase power system with shunt active filter

The active filter also permits the power supply to deliver a magnitude p_0 to the load from the phases, without the using the neutral wire. All the other power components (p)

($\sim P, p$ and q) can be compensated with the use of shunt active power filter, as presented in Fig 2.

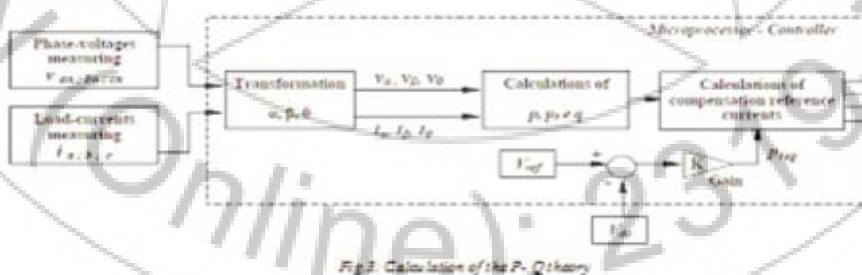


Fig.3. Calculation of the P-Q theory

The p-q controller allows systematic information, to verify the requirement of compensation currents by the active filter. It receives the information of phase voltages, load currents and DC voltage, and proceeds to the calculations based on its control algorithm generating necessary reference compensation currents, which is indicated in Fig.3. The objective of this algorithm is to compensate all undesirable power components. Besides, the source will see the load as if it was a balanced resistive load and the RMS value of the supply currents will be the lower possible to deliver the energy the load needs to work.

3.Reference Current Calculation

The control scheme of the Shunt and Series active power filters must calculate the current reference signals from each phase of the inverter using instantaneous real power compensator. The block diagram is shown in fig. 4. In this case a P-Q controller is applied to the System in generating the switching signals. The Power stage is basically a VSI, controlled similar to a current source. Reference currents calculated by the controller ($i_{ca}^*, i_{cb}^*, i_{cc}^*, i_{cn}^*$) is used by the inverter to

produce the compensation currents (i_{ca} , i_{cb} , i_{cc} , i_{cn}) to compensate harmonics.

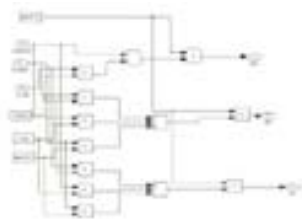


Fig.4 Reference current calculation

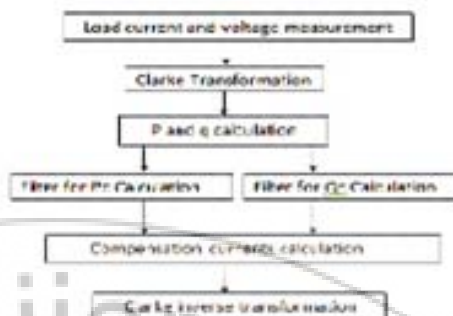


Fig.5 Basic algorithm for calculating power filter based on p-q theory

The basic algorithm commonly used for the calculation of the compensating currents is shown in Fig. 5. In this figure, p_c and q_c are the compensation reference powers. The p-q theory is a suitable tool to the analysis of non-linear three-phase systems and for the control of active filters.

The implementation of active filters based on the p-q theory are cost-effective solutions, allowing the use of a large number of low-power active filters in the same facility, close to each problematic load (or group of loads), avoiding the circulation of current harmonics, reactive currents and neutral currents through the facility power lines.

4.Simulation Design

The P-Q Theory based with and without Shunt Active Power Filter is implemented for harmonic compensation and the various models used for simulating and validating its performance are given under in Fig.6 & Fig7.

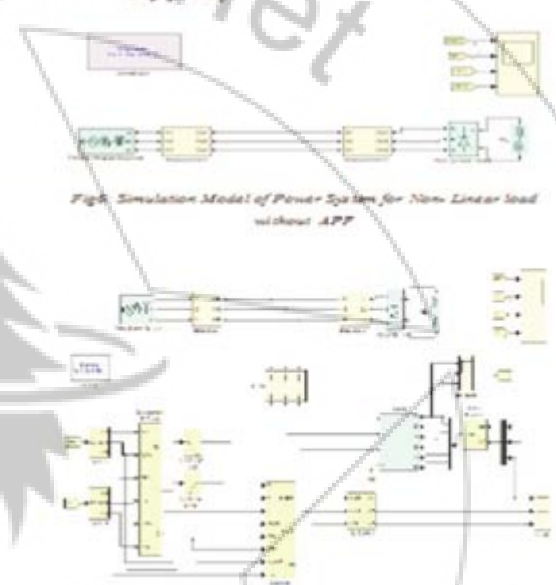


Fig.6 Simulation Model of Power System for Non-Linear load without APF

Fig.7 Simulation Model of Shunt APF using P-Q Theory

5.Simulation Results

The filter topologies discussed in the previous sections were investigated through Matlab®/ Simulink© V-2009b and the results obtained are shown below for an electric network voltage and current responses without Fig.7 & Fig.9 and with an APF in Fig.10 & Fig 11.

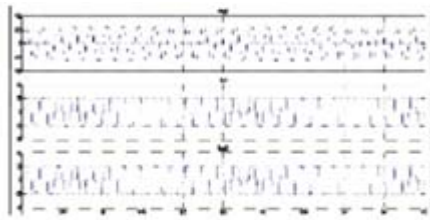


Fig. 2: Waveform Obtained for Source & Load Current before applying APF

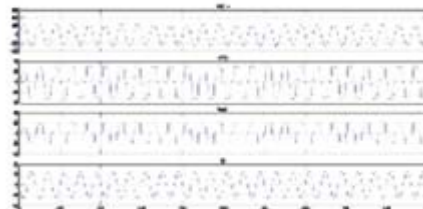


Fig. 10: Waveform Obtained for Source Voltage, Source Current, Load Current, Filter Current After Applying Shunt APF

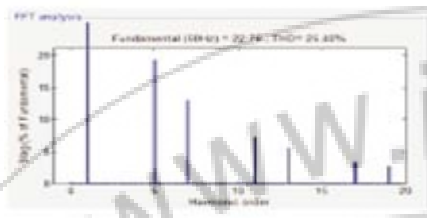


Fig. 9: FFT Analysis Obtained for Source Current Before applying APF (THD % = 22.401%)

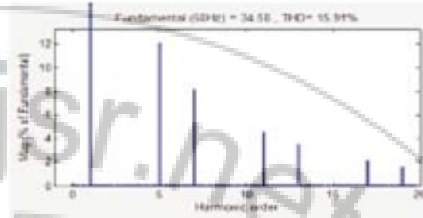


Fig. 11: FFT Analysis Obtained for Source Current After applying APF (THD % = 15.211%)

As the source current & Voltage are in phase, also the source current is almost sinusoidal (very low THD), it can be said that source is providing only active power required by the circuit.

In P-Q theory view, source current is providing only average real power component (P-), while remaining components i.e. real oscillating power P^+ , q^+ & q^- is being provided by APF. From load current and Non linear load RL, it can be said that the effectiveness of APF in compensating of harmonic components of load current depends on the specific load current waveform involved.

Two different waveforms have the same rms harmonic content, but APF may do a better job of compensating for one of the waveforms because of the wave shapes involved. In general the limiting factor for increasing the DC voltage is the voltage withstands capability of the IGBT devices. From harmonic analysis of source current, it can be seen due to uneven switching of compensator large No. of interharmonics are introduced. But it should be noted that these components have very less magnitude.

It is worth to also to note that P-Q based APFs can be used for complete harmonic elimination not selective harmonic elimination.

6. Conclusion

The validity in terms of eliminating p-q theory in terms of eliminating harmonics and Power Factor improvement is conformed from low THD source current which is in phase with source voltage. But p-q theory utilizes large No. of calculation & demands higher processing power resulting in utility to be complex & expensive.

They are predominantly utilized in three phase circuits, thus cannot be used at remote single phase customer. From source currents of both cases, it can be inferred that APF is most effective when the load current waveform does not have abrupt changes. The overall filtering effectiveness depending significantly on the types of loads being

compensated and are very effective for voltage source inverter type loads, even when the distortion is high.

By comparing reference current & source waveforms, it can be conducted that this controller compensation at the cost of high switching frequency, which can result in high switching losses in practical high power applications. In p-q theory has some short comings which need to be addressed like mathematical expression of instantaneous power does not follow power conservation and real & imaginary power needed to be more accurately defined as zero sequence instantaneous power cannot be defined by the theory. In practical approach also it can be noted that p-q theory is unable of providing selective harmonic elimination and specific power factor compensation.

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Author Profile

Mrs. Kirti Vibhute was completing her B.Tech (Electrical Engg) degree from Amravati University, (M.S) INDIA and M.Tech (Power Electronics) from Rajiv Gandhi Prodyogiki Vishwavidyalaya, Bhopal (M.P.) India. Presently she is working as a Assistant Prof. at Shri Dadaji Institute of tech. & Science, Khandwa (M.P.), India