International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 7 Issue 1, January-February 2023 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Simulation of Shunt Active Power Filter Based on p-q Theory

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ABSTRACT

This paper introduces design and simulation of a low cost shunt active power filter, which allows dynamic power factor correction and harmonic compensation for a nonlinear load. One of the most important features of the shunt active filter system proposed is its versatility over a variety of different conditions. The active filter controller is based on the Instantaneous power theory (p-q theory), which monitors the load current and injects equal amplitude and opposite phase compensation currents to neutralise load current harmonics. The application of the positive sequence voltage detector from within the active filter controller is the key component of the system. The positive sequence voltage detector gives incredible versatility to the application of the active filter, because it can be installed and compensate for load current harmonics even when the input voltage is highly distorted and unbalanced. The controller algorithm is carried out using MATLAB Simulink.

KEYWORDS: *Shunt Active Filter, p-q theory, Power Factor Correction, Clarke transformation and Power Quality*

How to cite this paper: Dr. G. Madasamy "Simulation of Shunt Active Power Filter Based on p-q Theory" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-7 | Issue-1, February 2023, pp.1091-1095, URL: www.ijtsrd.com/papers/ijtsrd52791.pdf

IJTSRD52791

INTRODUCTION

The implementation of Active Filters in this modern electronic age has become an increasingly essential element to the power network. With advancements in technology since the early eighties and significant trends of power electronic devices among consumers and industry, utilities are continually pressured in providing a quality and reliable supply. Power electronic devices such as computers, printers, faxes, fluorescent lighting and most other office equipment all create harmonics. These types of devices are commonly classified collectively as 'nonlinear loads'. Nonlinear loads create harmonics by drawing current in abrupt short pulses rather than in a smooth sinusoidal manner.

In India, generators are designed to operate at the fundamental frequency of 50 Hz. Harmonics of frequencies above this value that are created at the load end must be supplied from the generator. The major issues associated with the supply of harmonics to nonlinear loads are severe overheating and insulation damage. Increased operating temperatures of generators and transformers degrade the insulation material of its windings. If this heating were continued to the point at which the insulation fails, a flashover may occur should it be combined with leakage current from its conductors. This would permanently damage the device and result in loss of generation causing widespread blackouts.

One solution to this foreseeable problem is to install active filters for each nonlinear load in the power system network. Although presently very uneconomical, the installation of active filters proves indispensable for solving power quality problems in distribution networks such as harmonic current compensation, reactive current compensation, voltage sag compensation, voltage flicker compensation and negative phase sequence current compensation. Ultimately, this would ensure a polluted free system with increased reliability and quality.

What are Harmonic Filters?

Harmonic filters are used to eliminate the harmonic distortion caused by nonlinear loads. Specifically, harmonic filters are designed to attenuate or in some filters eliminate the potentially dangerous effects of harmonic currents active within the power distribution system. Filters can be designed to trap these currents and, through the use of a series of capacitors, coils, and resistors, shunt them to ground. A filter may contain several of these elements, each designed to compensate a particular frequency or an array of frequencies.

Types of Harmonic Filters involved in Harmonic Compensation:

Filters are often the most common solution that is used to mitigate harmonics from a power system. Unlike other solutions, filters offer a simpler inexpensive alternative with high benefits. There are three different types of filters each offering their own unique solution to reduce and eliminate harmonics. These harmonic filters are broadly classified into passive, active and hybrid structures. The choice of filter used is dependent upon the nature of the problem and the economic cost associated with implementation.

A passive filter is composed of only passive elements such as inductors, capacitors and resistors thus not requiring any operational amplifiers. Passive filters are inexpensive compared with most other mitigating devices. Its structure may be either of the series or parallel type. The structure chosen for implementation depends on the type of harmonic source present. Internally, they cause the harmonic current to resonate at its frequency. Through this approach, the harmonic currents are attenuated in the LC circuits tuned to the harmonic orders requiring filtering. This prevents the severe harmonic currents traveling upstream to the power source causing increased widespread problems.

An active filter is implemented when orders of harmonic currents are varying. One case evident of demanding varying harmonics from the power system are variable speed drives. Its structure may be either of the series of parallel type. The structure chosen for implementation depends on the type of harmonic sources present in the power system and the effects that different filter solutions would cause to the overall system performance. Active filters use active components such as MOSFET-transistors to inject negative harmonics into the network effectively replacing a portion of the distorted current wave coming from the load. This is achieved by producing harmonic components of equal amplitude but opposite phase shift, which cancel the harmonic components of the non-linear loads.

Hybrid filters combine an active filter and a passive filter. Its structure may be either of the series or parallel type. The passive filter carries out basic filtering (5th order, for example) and the active filter, through precise control, covers higher harmonics.

Shunt Active Filters:

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. Fig.1 & 2 show the system configuration of the shunt design. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The aim of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents. This configuration consists of four distinct categories of circuit, namely inverter configurations, switched-capacitor circuits, lattice-structured filters and voltage-regulator-type filters.

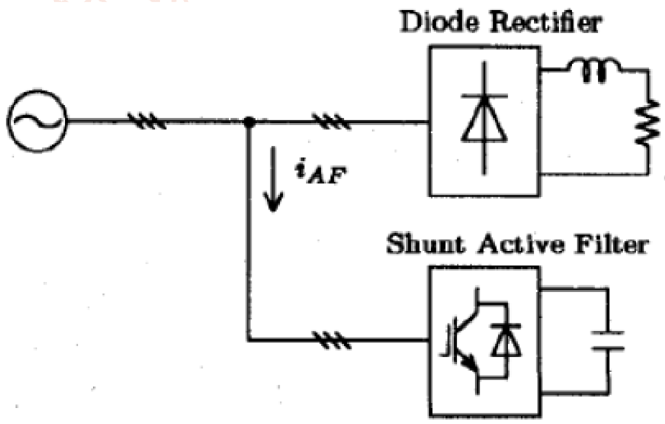

Fig.1 Shunt active filter used alone

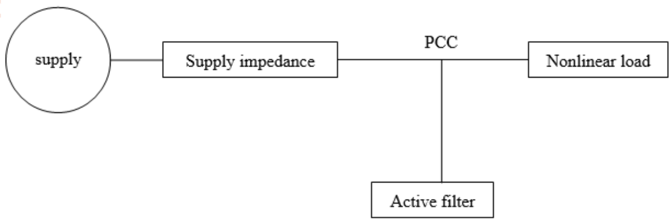

Fig.2 Shunt active filter network configuration

The p-q Theory:

"The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous power theory, or p-q theory. It is 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.

The p-q theory Instantaneous Power Components:

$\overline{p}$ - *Medium value of the instantaneous real power*

It corresponds to the transferred energy per time unit from the power source to the load, through the *a - b - c* phases of the Three-Phase system.

$\tilde{p}$ - *Alternated value of the instantaneous real power* It corresponds to the energy per time unit that is exchanged between the power source and the load, through the *a – b – c* phases.

$\bar{p}_0$ - *Mean value of the instantaneous zero-sequence power* - It corresponds to the transferred energy per time unit from the power source to the load, through the neutral wire and one or more phases.

$\tilde{p}_0$ - *Alternated value of the instantaneous zero sequence power*–It corresponds to the energy per time unit that is exchanged between the power source and the load, through the neutral wire and one or more phases.

q- Instantaneous imaginary power It corresponds to the power that has to circulate between the phases *a – b – c* of the three-phase power system (it does not contribute to any transference of energy from power source to load, but produces undesirable currents).

Definition of α - β Coordinate method

The α - β voltage and current quantities in the α - β coordinate method (α - β components) are defined by the following equation.

The transformation is,

$$V_{\alpha\beta} = \alpha \cdot V_{abc}$$

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

$$I_{\alpha\beta} = \alpha \cdot I_{abc}$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \text{---- (2)}$$

The relation a - b - c phase quantities $\Leftrightarrow$ α - β quantities is shown in equation (1) and (2), where both quantities are demonstrated as vector values.

The α - β currents are,

$$I_\alpha = \frac{2}{3} I_a - \frac{1}{3} I_b - \frac{1}{3} I_c \text{ ------- (3)}$$

$$I_\beta = 0 + \frac{\sqrt{3}}{3} I_b - \frac{\sqrt{3}}{3} I_c \text{ ------- (4)}$$

α -quantity: The currents I_α , -1/2 I_α , -1/2 I_α ,flow out on the phase a,b,c circuits respectively in the same direction. In other words, the current I_α goes out from phase 'a' and the half current 1/2 I_α comes back from phase 'b' and another half current 1/2 I_α from phase 'c'. As a result, the current through the ground path is zero.

β -quantity: The currents $+\sqrt{3}/2\ I_\beta$, $-\sqrt{3}/2\ I_\beta$, flow in phase b,c respectively in the same direction. In other words, the current $\sqrt{3}/2\ I_\beta$ goes out from phase 'b' and comes back from phase 'c'. As a result, the current through phase 'a' and the ground path are zero.

Simulation:

Simulation is a powerful way to reduce development time and ensure the proper fulfilment of critical steps. In this project, simulations were performed, which allowed the study of its behaviour under different operation conditions, and permitted the tuning of some controller parameters together with the optimization of the active filter component values. *Matlab/Simulink* used as simulation tools in this development, as it offered an integrated environment between designing control algorithms and the electrical network models.

The Three-Phase Power System with a Non-linear load without Shunt Active Power Filter. The THD of the system is 23.79% is shown in Fig.3. Fig. 4 shows the power system with Non-linear load, when the Shunt Active Power Filter with Control based on p-q theory was implemented. The THD was brought down to 0.43% is shown in Fig.5. Before the implementation of Shunt Active Power Filter, the Input Source Voltage and Current is distorted by the Non-linear load. Therefore, the THD value is high and the power factor of the system is very low. After the implementation of Shunt Active Power Filter, the distorted Input Source Voltage and Current is compensated by using p-q theory. Therefore, the THD value is very low and the power factor of the system is approaches unity.

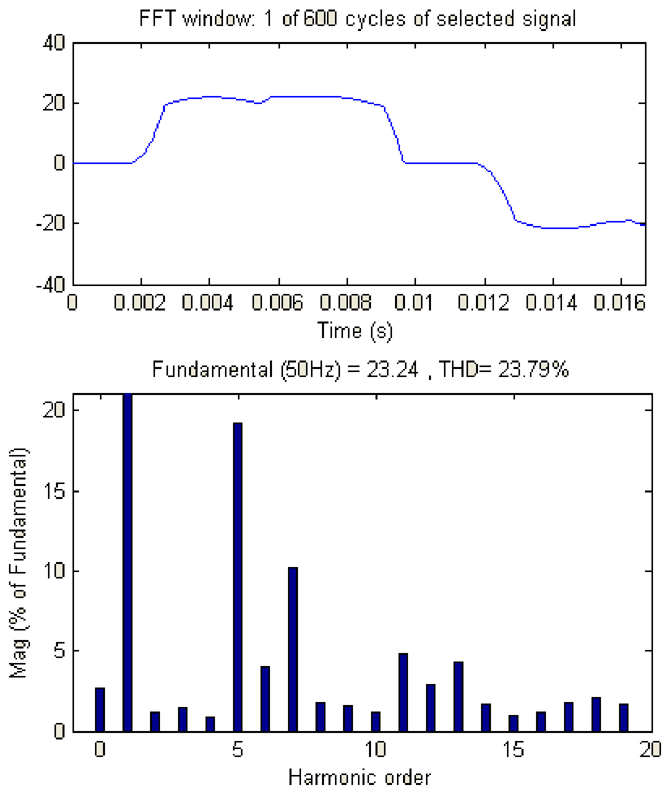

Fig3. FFT and Harmonic order of Input source current without APF.

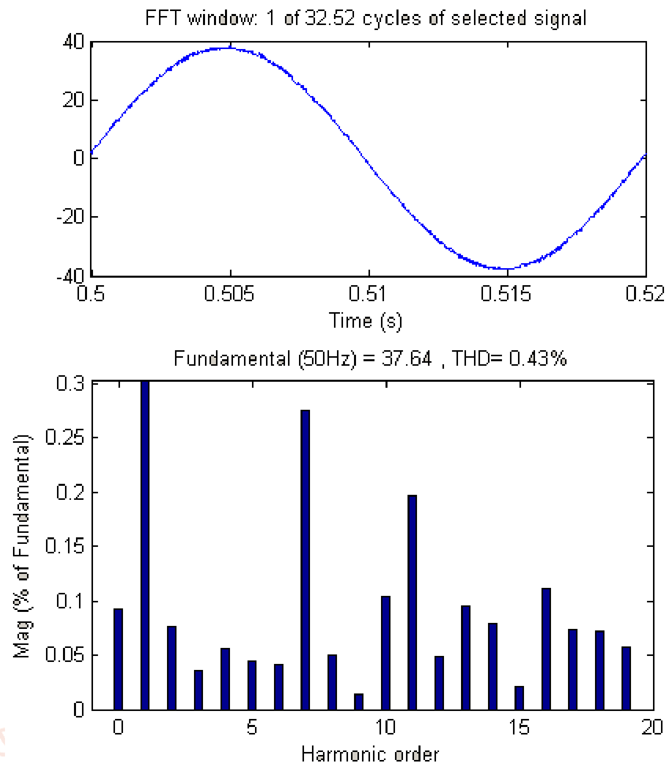

Fig.5 FFT and Harmonic order of Input source current with APF.

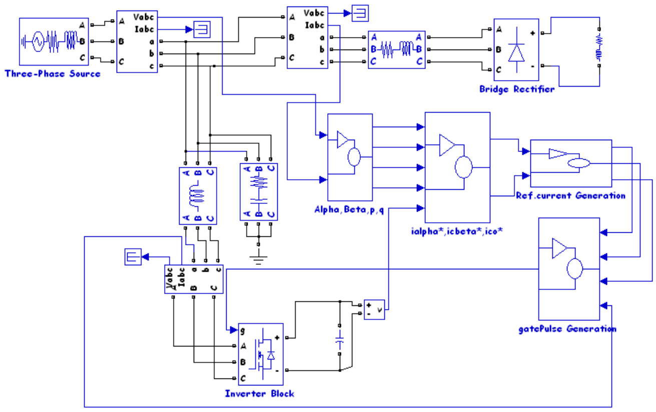

Fig.4 Simulation of Shunt Active Power Filter with Control based on p-q Theory.

The input source current wave form without filter and with filter is shown in Fig.6 and Fig.7. Fig.8 Shows the switching pulse for inverter in the active filter circuit and Fig.9 shows the input voltage and current for phase A. with active filter.

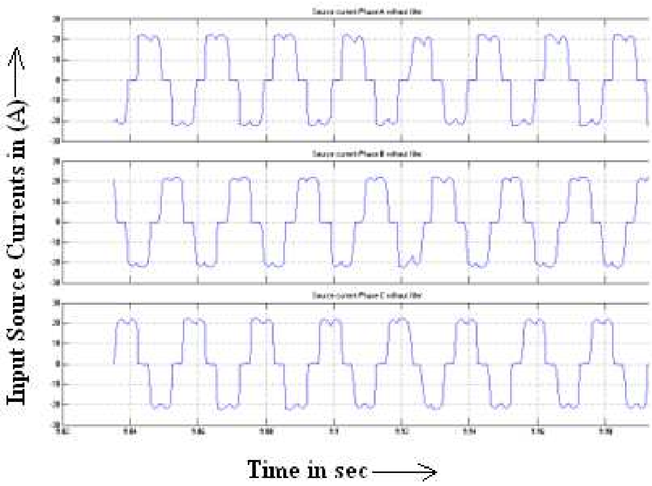

Fig.6 Input Three-Phase Currents (Ia, I_b, Ic) without APF.

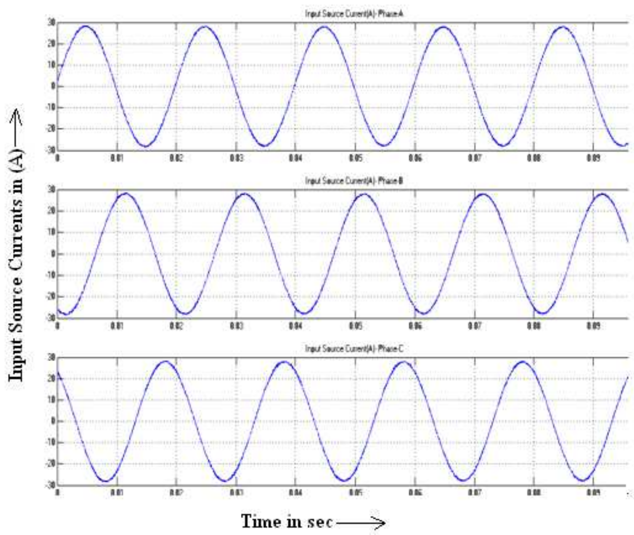

Fig.7 Input Three Phase Source Currents (Ia,Ib,Ic) with APF

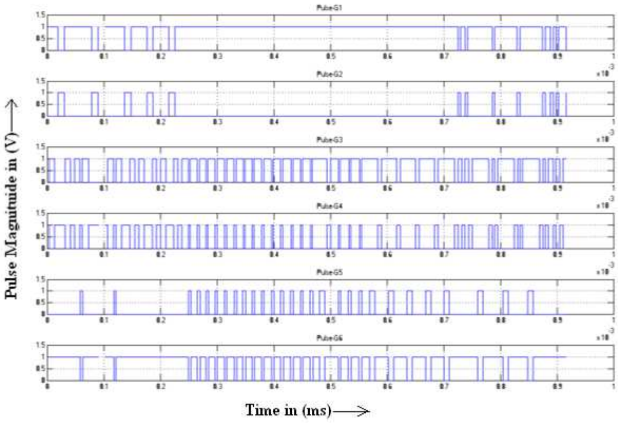

Fig.8 Switching Pulses for Inverter Circuit

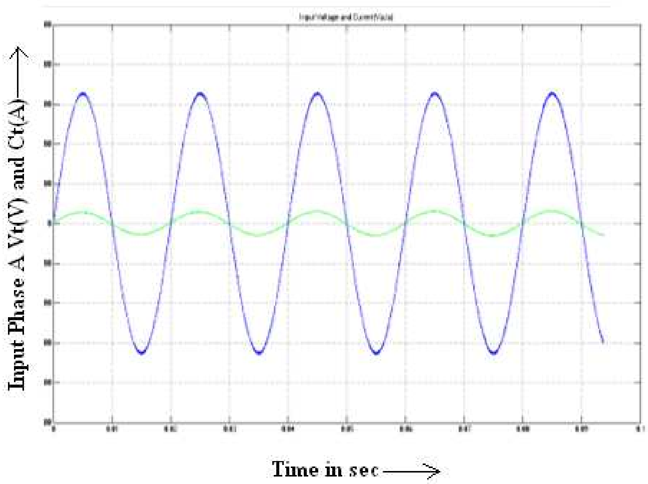

Fig. 9 Input Source Voltage and Current Waveform of Phase A with APF

CONCLUSION:

In this paper, the validity of the p-q theory has been tested through computer simulation using *Matlab/Simulink.* The simulation result shows that without Active Power filter for Non-Linear load the THD is **23.79%** and power factor is 0.9 and with Active Power filter the THD is reduced to **0.43%** and power factor is increased to nearly Unity. The active filter controller based on the p-q theory was tested for three-phase power systems with Non-linear loads. The obtained result shows good steady-state and transitory performances.

REFERENCES

[1] Emílio F. Couto, Júlio S. Martins, João L. Afonso 'Simulation Results of a Shunt Active Power Filter with Control Based on p-q Theory' ICREPQ'03 – International Conference on Renewable Energies and Power Quality Vigo, Espanha, 9-12 de Abril de 2003, paper 394, ISBN: 84 607 6768 x.

[2] J. L. Afonso, C. Couto, J. S. Martins, "Active Filters with Control Based on the p-q Theory", IEEE Industrial Electronics Society Newsletter, vol. 47, nº 3, Set. 2000, pp. 5-10.

[3] H. AKAGI 'Modern active filters and traditional passive filters' Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8552, Japan.

[4] Moleykutty George and Kartik Prasad Basu, Faculty of Engineering and Technology, Multimedia University, 75450 Melaka, Malaysia, Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Malaysia. **'Modeling and Control of Three-Phase Shunt Active Power Filter'** American Journal of Applied Sciences 5 (8): 1064-1070, 2008. ISSN 1546-9239. © 2008 Science Publications.

[5] Antonio Dell'Aquila, Agostino Lecci 'A Current Control for Three-Phase Four-Wire Shunt Active Filters' ISSN 0005–1144 ATKAAF 44(3–4),129–135 (2003).