# Performance Analysis of three phases three wire Series Active Power Filter

**Asma Fatma Arif, Jyoti Shrivastava**

***Abstract***— *the aim of this paper is to investigate and study the performance analysis of the three phase three wire series active power filter. Auto-tuned filters give a better performance for harmonic mitigation, reactive power compensation and power factor correction as compared to the classic filters. This paper presents the simulation analysis to reduce the harmonic in the output voltage to improve the power quality.*

***Index Terms***—*Active power filter, Harmonics, Hysteresis current control, Simulink*

## I. INTRODUCTION

The explosion growth in consumer electronics and domestic appliances has generated a major concern in the electricity supply industry. Non-linear loads such as rectifier, converters, variable speed drives and arc furnace cause high disturbances in power supply system. To minimize these effects in electricity distribution system (non-sinusoidal voltages, harmonic current, unbalanced conditions, etc.) different types of compensations have been proposed to increase the electric system quality. One of that compensation is the active power filter (APF). A series APF that achieves low voltage total harmonic distortion (THD), reactive power compensation and power factor correction is presented. Hence, it is necessary to reduce the dominant harmonics below 5% as specified in IEEE-519-1992 harmonic standards [5]. Active power filter for damping out harmonic resonance in industrial and utility power distribution system have been researched. [5] - [7].

Extensive surveys have been carried to quantify the problems associated with electric power networks having non-linear load. Conventionally passive L-C filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads. However, passive filters have the demerits of fixed compensation, large size and resonance. The increased severity of harmonic pollution in power networks has attracted the attention of power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems. Such equipment, generally known as active filters (AF's) are also called as active power line conditioners (APLC's), instantaneous reactive power compensators (IRPC's), active power filters (APF's) and active power quality conditioners (APQC's).

In this paper the proposed control algorithm for series active power filter is applicable to harmonic voltage source loads as well as to harmonic current source loads. This control algorithm is applied under basic concept of the generalized p-q theory. However, this generalized p-q theory is valid for compensating for the harmonics and reactive power using the parallel active power filter in the three phase power system. To overcome such limits, a revised p-q theory is proposed. This revised algorithm may be effective not only for the three phase three wire series active power filter with harmonic current voltage loads, but also for the combined system of parallel passive filters and active filters.

This paper basically deals with the design and modeling of three-phase three-wire series active power filter for compensation of harmonics.

## II. ACTIVE POWER FILTER

The Active filter topology is now more mature for providing compensation for harmonic, reactive power, or neutral current in ac networks. AF's are also used to eliminate voltage harmonics to regulate terminal voltage, to suppress voltage flicker, and to improve voltage balance in three-phase systems. This wide range of objectives is achieved either individually or in combination, depending upon the requirements and control strategy and configuration which have to be selected appropriately.

Following the widespread use of solid-state control of ac power, the power quality issues become significant. The AF's are basically categorized into three types, namely, two-wire(single phase), three-wire and four-wire three phase configurations to meet the requirements of the three types of non-linear loads on supply systems. Many control strategies such as instantaneous power theory, synchronous frame d-q theory, synchronous detection method and notch filter method are used in the development of three-phase AF's.

Fig.1 shows basic APF block diagram including non-linear load on the three phase supply condition. APF overcome the drawbacks of passive filters by using the switching mode power converters to perform the harmonic current elimination. A voltage source inverter (VSI) is used as the series active power filter.

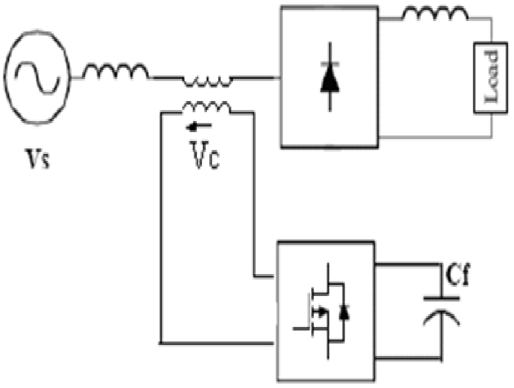

Fig. 1 Active Power Filter

This is controlled so as to draw or inject a compensating voltage from or to the supply, such that it cancels voltage

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harmonics on the load side i.e; this active power filter (APF) generates the distortions opposite to the supply harmonics.

Series active power filter are operated mainly as a voltage regulator and as a harmonic isolator between the non-linear load and the utility system. This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the AC supply and for low power applications. The series active power filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags, and swells on the load side.

## III. REFERENCE VOLTAGE GENERATION

This Section introduces the control algorithm of the series active power filter, which compensates for harmonics and reactive power.

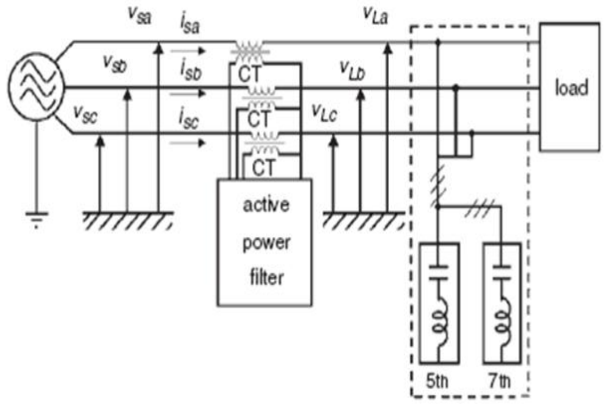

Fig.2 Circuit configuration for series APF

The three-phase voltages $v_a$, $v_b$ and $v_c$ and currents $i_a$, $i_b$ and $i_c$ for the three-phase three-wire power distribution system is shown in Fig. 3.

The three-phase load voltages $v_{L(a,b,c)}$ and the three-phase source currents $i_{s(a,b,c)}$ are represented as:

$$v_{L(a,b,c)} = \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix}, \quad i_{s(a,b,c)} = \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \qquad (3.1)$$

The load voltage vector $v_{L(a,b,c)}$ and the source current vector $i_{s(a,b,c)}$ of (3.1) are transformed into $\alpha\beta 0$ co-ordinates by the substituting (3.3) into (3.2) as

$$v_{L(\alpha,\beta,0)} = T \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix} = \begin{bmatrix} q_{L\alpha} \\ q_{L\beta} \\ q_{L0} \end{bmatrix},$$

$$i_{s(\alpha,\beta,0)} = T \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{s0} \end{bmatrix} \qquad (3.2)$$

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \qquad (3.3)$$

The active power p can be expressed as (3.4) by the inner product of the load voltage vector $v_{L(\alpha,\beta,0)}$ and the source current vector $i_{s(\alpha,\beta,0)}$ of (3.2), where the active power p is the instantaneous active power at the load side of the CT in Fig. 3.2.

$$p = v_{L(\alpha,\beta,0)}\, i_{s(\alpha,\beta,0)} = v_{L\alpha} i_{s\alpha} + v_{L\beta} i_{s\beta} + v_{L0} i_{s0} \qquad (3.4)$$

Also, the reactive power $q_{L(\alpha,\beta,0)}$ is represented as (3.5) by the cross product of $v_{L(\alpha,\beta,0)}$ and $i_{s(\alpha,\beta,0)}$ :

$$q_{L(\alpha,\beta,0)} = v_{L(\alpha,\beta,0)} \times i_{s(\alpha,\beta,0)} = \begin{bmatrix} q_{L\alpha} \\ q_{L\beta} \\ q_{L0} \end{bmatrix}$$

$$q = \left\| q_{L(\alpha,\beta,0)} \right\| = \left\| v_{L(\alpha,\beta,0)} \times i_{s(\alpha,\beta,0)} \right\| \qquad (3.5)$$

Where, q is the instantaneous reactive power at the load side of the CT in Fig.3.

For a three-phase system without zero sequence voltage and current, i.e. $v_a + v_b + v_c = 0$ , and $i_a + i_b + i_c = 0$ , [ $v_{L0} = \frac{1}{3}(v_a + v_b + v_c) = 0$ and $i_{s0} = \frac{1}{3}(i_a + i_b + i_c) = 0$ ], (3.4) and (3.5) can be expressed as follows:

$$p = v_{L(\alpha,\beta,0)} i_{s(\alpha,\beta,0)} = v_{L\alpha} i_{s\alpha} + v_{L\beta} i_{s\beta} \qquad (3.6)$$

$$q_{L(\alpha,\beta,0)} = v_{L(\alpha,\beta,0)} \times i_{s(\alpha,\beta,0)} = \begin{bmatrix} q_{L\alpha} \\ q_{L\beta} \\ q_{L0} \end{bmatrix} = \begin{bmatrix} |0| \\ |0| \\ \begin{vmatrix} v_{L\alpha} & v_{L\beta} \\ i_{s\alpha} & i_{s\beta} \end{vmatrix} \end{bmatrix} \qquad (3.7)$$

From (3.1)–(3.5), the active voltage vector $v_{p(\alpha,\beta,0)}$ and the reactive voltage vector $v_{q(\alpha,\beta,0)}$ are defined as follows:

$$v_{p(\alpha,\beta,0)} = \frac{p}{i_{(\alpha,\beta,0)} \cdot i_{(\alpha,\beta,0)}}\, i_{(\alpha,\beta,0)} \qquad (3.8)$$

$$v_{q(\alpha,\beta,0)} = \frac{q_{(\alpha,\beta,0)} \times i_{(\alpha,\beta,0)}}{i_{(\alpha,\beta,0)} i_{(\alpha,\beta,0)}} \qquad (3.9)$$

The active voltage vector and the reactive voltage vector can be obtained by the vector norm of the three-phase load voltage vector, which is known from (3.9), (3.10). In other words, $v_{p(\alpha,\beta,0)}$ represents the parallel component of the load voltage vector $v_{L(\alpha,\beta,0)}$ to the current vector $i_{s(\alpha,\beta,0)}$ ; $v_{q(\alpha,\beta,0)}$ represents the perpendicular component of the load voltage vector $v_{L(\alpha,\beta,0)}$ to the current vector $i_{s(\alpha,\beta,0)}$ . As a result, the load voltage vector is represented by the sum of the active voltage vector $v_{p(\alpha,\beta,0)}$ and the reactive voltage vector $v_{q(\alpha,\beta,0)}$ as follows:

$$v_{L(\alpha,\beta,0)} = v_{p(\alpha,\beta,0)} + v_{q(\alpha,\beta,0)} \qquad (3.10)$$

The active voltage vector $\mathbf{v}_{p(\alpha,\beta,0)}$ is induced as follows, using the projection of the load voltage vector $\mathbf{v}_{L(\alpha,\beta,0)}$ onto the current vector $\mathbf{i}_{s(\alpha,\beta,0)}$ :

$$\mathbf{v}_{p(\alpha,\beta,0)} = \mathrm{proj}_{i}\mathbf{v}_{L(\alpha,\beta,0)} = \frac{\mathbf{v}_{L(\alpha,\beta,0)}\mathbf{i}_{s(\alpha,\beta,0)}}{\left\|\mathbf{i}_{s(\alpha,\beta,0)}\right\|^{2}}\mathbf{i}_{s(\alpha,\beta,0)}$$

$$= \frac{\mathbf{v}_{L\alpha}\mathbf{i}_{s\alpha} + \mathbf{v}_{L\beta}\mathbf{i}_{s\beta} + \mathbf{v}_{L0}\mathbf{i}_{s0}}{i_{s\alpha}^{2} + i_{s\beta}^{2} + i_{s0}^{2}}\mathbf{i}_{s(\alpha,\beta,0)} \qquad (3.11)$$

$$= \frac{p}{i_{s\alpha}^{2} + i_{s\beta}^{2} + i_{s0}^{2}}\mathbf{i}_{s(\alpha,\beta,0)}$$

The reactive voltage vector $\mathbf{v}_{q(\alpha,\beta,0)}$, which is perpendicular to the active voltage vector $\mathbf{v}_{p(\alpha,\beta,0)}$, is also induced through (3.13)–(3.16):

$$\mathbf{q}_{L(\alpha,\beta,0)} = \mathbf{v}_{L(\alpha,\beta,0)} \times \mathbf{i}_{s(\alpha,\beta,0)}$$

$$\mathbf{i}_{s(\alpha,\beta,0)} \times \mathbf{q}_{L(\alpha,\beta,0)} = \mathbf{i}_{s(\alpha,\beta,0)} \times \left(\mathbf{v}_{L(\alpha,\beta,0)} \times \mathbf{i}_{s(\alpha,\beta,0)}\right) \qquad (3.12)$$

$$= \left(\mathbf{i}_{s(\alpha,\beta,0)}\mathbf{i}_{s(\alpha,\beta,0)}\right)\mathbf{v}_{L(\alpha,\beta,0)} - \left(\mathbf{i}_{s(\alpha,\beta,0)}\mathbf{v}_{L(\alpha,\beta,0)}\right)\mathbf{i}_{s(\alpha,\beta,0)}$$

$$= \left\|\mathbf{i}_{s(\alpha,\beta,0)}\right\|^{2}\mathbf{v}_{L(\alpha,\beta,0)} - p\,\mathbf{i}_{s(\alpha,\beta,0)} \qquad (3.13)$$

$$\mathbf{v}_{L(\alpha,\beta,0)} = \frac{\mathbf{i}_{s(\alpha,\beta,0)} \times \mathbf{q}_{L(\alpha,\beta,0)}}{\left\|\mathbf{i}_{s(\alpha,\beta,0)}\right\|^{2}} + \frac{p}{\left\|\mathbf{i}_{s(\alpha,\beta,0)}\right\|^{2}}\mathbf{i}_{s(\alpha,\beta,0)} \qquad (3.14)$$

After taking a cross product on both sides of (3.12), (3.13) is obtained when the right side of (3.12) is unfolded by means of the relations of inner and cross product. After transposing the current vector component of the right-hand side to the left side in (3.13), (3.14) can be obtained. The second term of the right-hand side of (3.14) is the active voltage vector $\mathbf{v}_{p(\alpha,\beta,0)}$ and the first term of the right-hand side of (3.15) becomes the reactive voltage vector $\mathbf{v}_{q(\alpha,\beta,0)}$ :

$$\mathbf{v}_{q(\alpha,\beta,0)} = \frac{\mathbf{i}_{s(\alpha,\beta,0)} \times \mathbf{q}_{L(\alpha,\beta,0)}}{\left\|\mathbf{i}_{s(\alpha,\beta,0)}\right\|^{2}} = \frac{\mathbf{i}_{s(\alpha,\beta,0)} \times \mathbf{q}_{L(\alpha,\beta,0)}}{\mathbf{i}_{s(\alpha,\beta,0)}\mathbf{i}_{s(\alpha,\beta,0)}}$$

(3.15)

Where $\mathbf{q}_{L(\alpha,\beta,0)}$ is equal to the reactive power, which is defined in the instantaneous reactive power theory. The voltage compensation reference of the series active power filter can be represented as (3.16), using $\mathbf{v}_{p(\alpha,\beta,0)}$ and $\mathbf{v}_{q(\alpha,\beta,0)}$ in (3.8) and (3.9):

$$\mathbf{v}^{*}_{C(\alpha,\beta,0)} = \frac{\tilde{\rho}}{\mathbf{i}_{s(\alpha,\beta,0)}\mathbf{i}_{s(\alpha,\beta,0)}}\mathbf{i}_{s(\alpha,\beta,0)} + \frac{\mathbf{i}_{s(\alpha,\beta,0)} \times \mathbf{q}_{L(\alpha,\beta,0)}}{\mathbf{i}_{s(\alpha,\beta,0)}\mathbf{i}_{s(\alpha,\beta,0)}}$$

(3.16)

The active power and the reactive power can be divided into DC components $\tilde{p}$ and $\tilde{q}$, which are generated from the fundamental components of the load voltages and the source currents, and AC components $\tilde{p}$ and $\tilde{q}$, which are generated from the negative sequence components and the harmonic components of the load voltages and the source currents. If the reactive power q is replaced by the AC component of reactive power $\tilde{q}$, a new voltage compensation reference compensates for the AC component of the active power $\tilde{p}$ and the reactive power $\tilde{q}$ .

The compensation voltage reference in $\alpha\beta 0$ co-ordinates is obtained from (3.16) and the final compensation voltage reference by transforming this compensation voltage reference in $\alpha\beta 0$ co-ordinates into the compensation voltage reference of three-phase co-ordinates. Equation (3.18) is the $\alpha,\beta,0$ /three-phase transformation matrix:

$$v^{*}_{C(a,b,c)} = T^{-1}\begin{bmatrix} v^{*}_{C\alpha} \\ v^{*}_{C\beta} \\ v^{*}_{C0} \end{bmatrix} = \begin{bmatrix} v^{*}_{Ca} \\ v^{*}_{Cb} \\ v^{*}_{Cc} \end{bmatrix} \qquad (3.18)$$

The entire algorithm can be explained as: First, three-phase load voltages and source currents are transformed into $\alpha\beta 0$ co-ordinates. Then, the active power and the reactive power can be calculated. The AC component of the active power $\tilde{p}$ is extracted by simple filtering. The compensation voltage reference in $\alpha\beta 0$ coordinates is calculated by substituting the obtained AC component of the active power, the reactive power and the three-phase currents into (3.16). The final voltage compensation reference for the harmonics and the power factor compensation are obtained by transforming the voltage compensation reference in $\alpha\beta 0$ co-ordinates into the voltage compensation reference in three-phase co-ordinates.

## IV. THE PROPOSED METHOD

Fig.2 shows the basic block of a stand alone active series filter. It is connected before the load in series with the ac mains, using a matching transformer, to elimininate voltage harmonics and to balance and regulate the terminal voltage of the load or line. It can be installed by electric utilities to compensate voltage harmonics and to damp out harmonic propagation caused by resonance with line impedences and passive shunt compensations. It has a self-supporting dc voltage bus with a large dc capacitor. It has become more dominant, since it is lighter, cheaper and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies. It is more popular in UPS-based applications, beacause in the presence of mains, the same inverter bridge can be used as an AF to eliminate harmonics of critical non-linear load.

The Hysteresis current controller method is used as the control technique. The basic implementation of the hysteresis current controller derives the switching signals from the comparision of the current error with a fixed hysteresis band.

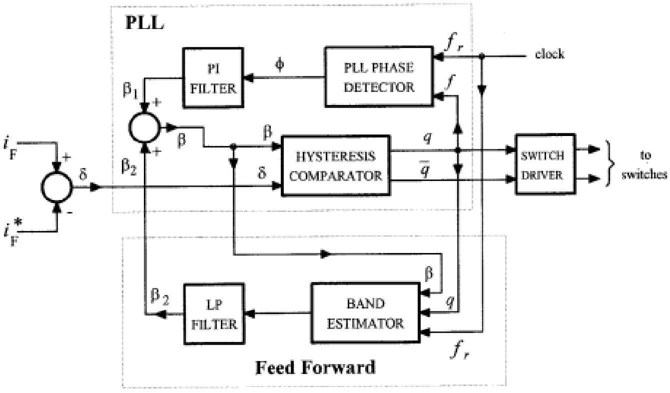

Fig.3 Basic scheme of a Hysteresis Current Controller

Fig.3 shows the simplified scheme of the implementation of such a controller. As can be seen, the controller modifies the hysteresis band by summing two different signals. The first is filtered output of a PLL phase comparator ($\beta_1$), and the second is the filtered output of a band estimation circuit ($\beta_2$). The band estimator implements a feed forward action that helps the PLL-based circuit to keep the switching frequency constant; in this way, the output of the PLL circuit only provides the small amount of the modulation of the hysteresis band which is needed to guarantee the phase lock of the switching pulses with respect to an external clock signal. This also ensures the control of the mutual phase of the modulation pulses. All of these provisions have allowed a substantial improvement in the performance of the hysteresis current controller.

## V. SIMULATION METHOD AND RESULT

For evaluating performances of series active power filter using the voltage reference calculation with the hysteresis current control, simulation study is performed in MATLAB/Simulink environment. Fig. shows the arrangement of power circuit configuration which is made up of non-linear load, series transformer and voltage source inverter. In this section the simulation model of series APF for RLC load and the simulation results is shown.

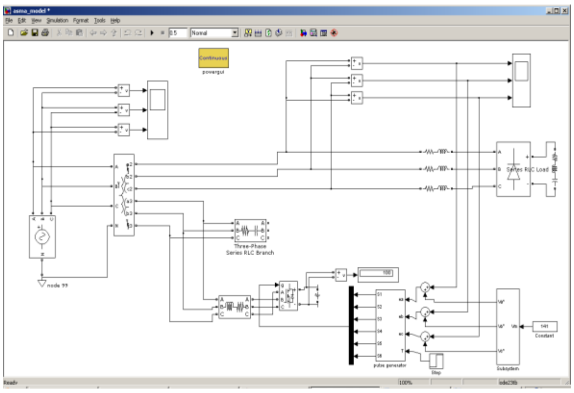

Fig.4 Simulation model for series Active power filter

The presented simulation results were obtained by using Matlab Simulink Power System Toolbox software, for a three phase power system with a series APF. Fig.5 shows the source voltage for the non-linear load containing harmonics.

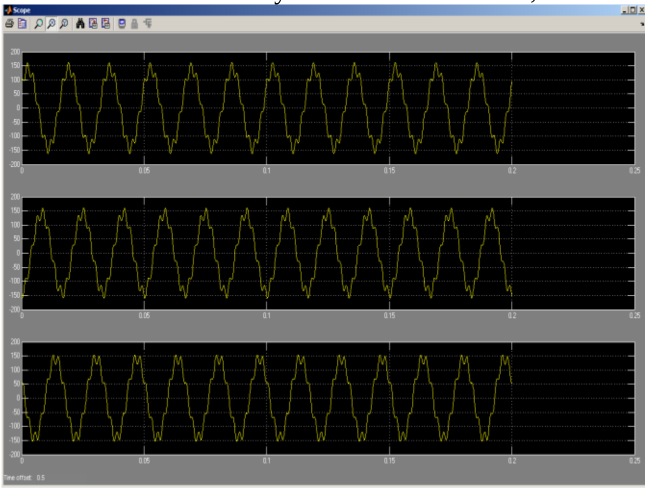

Fig.5 source voltage containing harmonics

Fig.6 shows the improved load voltage for the non-linear RLC load when the compensation is done with series APF. It is observed that all the harmonics are considerably removed after compensation.

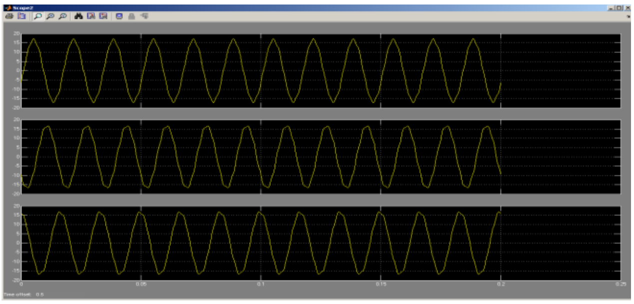

Fig.6 Load voltage after compensation

## VI. CONCLUSION

In this paper, a series active power filter control scheme has been proposed to improve the performance of APF under non-ideal mains voltage scenarios. The substantial increase in the use of solid-state power control results in harmonic pollution above the tolerable limits. Utilities are finding it difficult to maintain the power quality at the consumer end. The computer simulation has verified the effectiveness of the proposed control scheme. The source voltage and load voltage is observed for the RLC load. From the simulation results, the proposed approach was very successful and easily implemented. The harmonics in the source voltage have been removed. Henceforth, improving the power quality of the supply voltage. The input voltage harmonics are compensated very effectively by using the series active power filter.

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