A New Method to Extract Reference Currents for Shunt Active Power Filter in Three Phase Four Wire Systems

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Abstract

In this paper, three phase four wire active power filter is proposed to eliminate harmonic currents both in the phases and in the neutral conductor of un unbalanced three-phase four wire electrical distribution system, feeding three single non-linear loads. A new method for identifying reference currents will be developed. It is based on pq theory using two improvements: multi-variable filter having the advantage of extracting harmonic voltages directly from the $\alpha\beta$ axis and the second improvement consists on the use of fuzzy logic controller to extract current harmonics components. A comparison between classical method and the new approach has been illustrated in order to find the best way to reduce network harmonic currents. The Matlab numerical code is used for all simulations in this paper.

Keywords: *Power quality, Active Filter, Fuzzy logic controller, harmonics compensation, multi-variable filter*

1. Introduction

Power quality is nowadays a major topic because of its significant impact on industrial and commercial power distribution systems. Most of the industrial and domestic devices are sources of power-quality degradation. They cause the current to vary disproportionately with the voltage and are therefore classified as nonlinear loads. As a result, the power utility supplying nonlinear loads has to meet required amount of reactive power serious problems associated with harmonics [1]. In many commercial and industrial installations, electric power is distributed through a there phase four wire system with incorrectly distributed or uncompensated loads. Such systems may suffer from excessive neutral currents caused by nonlinear or unbalanced loads [2, 3]. This type of system has a problem. If nonlinear single phase loads are present or the three phase load is unbalanced, line currents are unbalanced and neutral currents flow. These neutral currents contain both fundamental and triplen harmonic components. In severe cases, the neutral currents are potentially damaging to both the neutral conductor and the transformer to which it is connected. Three phase three wire shunt active power filters cannot effectively reduce or eliminate line harmonics in this situation. Three phase four wire active power filters have been proposed by researchers as an effective solution to these problems [4]. In this paper, a new control scheme with two improvements: multi-variable filter multi-variable filter to extract harmonic voltages and the second improvement consists on the use of fuzzy logic controller to extract current harmonics components of an active power filter in three phase four wire electrical distribution system is proposed to eliminate harmonics both in the three phases and in the neutral conductor of unbalanced three phase four wires electrical distribution system, feeding three single non-linear loads. Analysis and simulation results show improved performance.

2. Circuit Configuration

The main circuit of the shunt active parallel filter shown in Figure1 is implemented using the three-leg split-capacitor topology. A common capacitor is coupled to a dc-bus with the midpoint connected to the neutral wire, while the ac side is connected to the power supply system using three coupling inductors which act as low pass filters [5]. The active power filter operates as a controlled current source generating the load harmonic current. As a result, the current supplied from the mains at the point of common coupling will be sinusoidal. The harmonic current detection is a very important; it determines the performance of active power filter in a certain extent. The filter presented by a PWM converter is controlled with conventional hysteresis regulator.

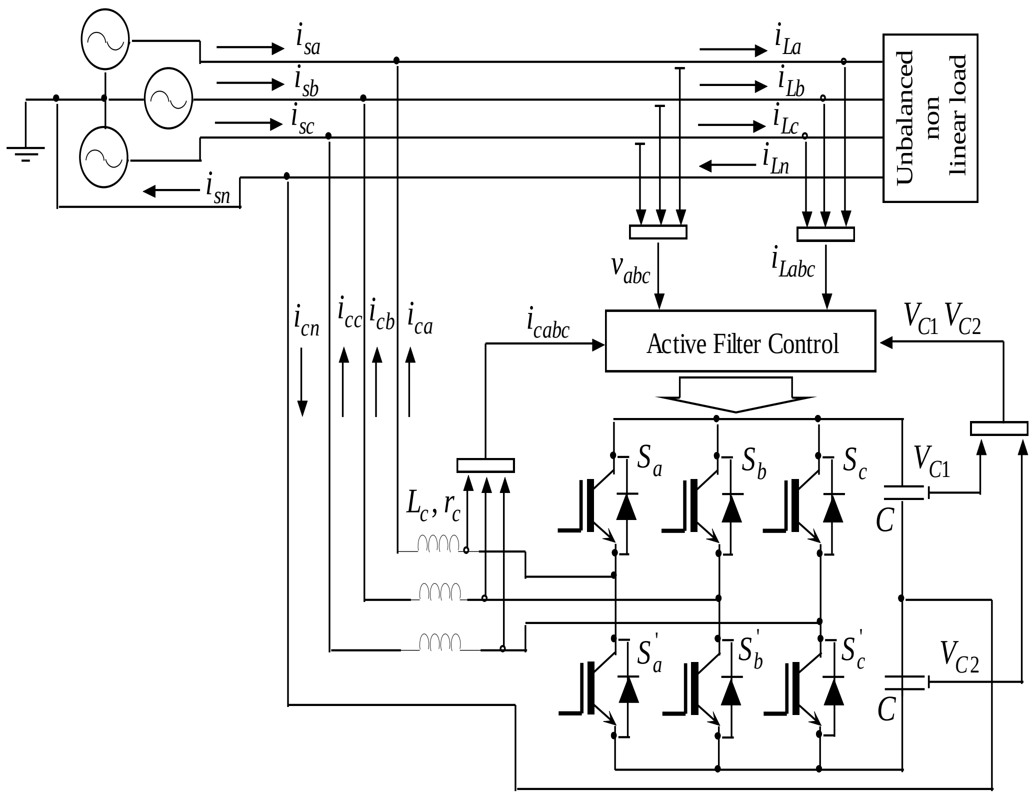

Figure 1. Three Phase Four Wires Active Power Filter Circuit

3. Reference Current Identification

This filter is based on an extension of the instantaneous power theory that considers the existence of zero-sequence phase current components in an unbalanced three phase four wire electrical distribution systems feeding three single non-linear loads. In order to produce a sinusoidal signals voltage phase-locked loop (PLL) is used [6].

3.1 Conventional Instantaneous Powers Theory

Reference current identification can be used with different strategies. One of the most widely used is based on the conventional instantaneous real and imaginary powers theory initiated by Akagi. The theory introduced by Akagi is based on a-b-c phase reference currents computation by transferring three phase voltage and current signal into corresponding α-β-0 components. Simply, the basic p-q theory consist of an algebraic transformation, known as Clarke transformation, of the sensed three-phase source voltage (Vsa, Vsb, Vsc) and load currents (ILa, ILb, ILc) from a-b-c coordinates to the α-β-0 coordinates is shown in (1) and (2) [7].

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

(1)

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix}$$

(2)

$$\left[i_{\alpha\beta 0} \right] = \left[C \right] \left[I_{Labc} \right]$$

(3)

Load side instantaneous real power (pαβ), imaginary power (qαβ) and zero sequence power (p0) are calculated as in (4).

$$\begin{bmatrix} P_\alpha \\ P_\beta \\ P_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} V_\alpha & V_\beta & 0 \\ -V_\beta & V_\alpha & 0 \\ 0 & 0 & V_0 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

(4)

Instantaneous real and imaginary powers include oscillating (AC) and average (DC) components as shown in (5). pαβ and qαβ may be, split into two parts (average values and oscillating values) as:

$$p_{net} = p_{\alpha\beta} + q_{\alpha\beta} + p_0 = \bar{p}_{\alpha\beta} + \tilde{p}_{\alpha\beta} + \bar{q}_{\alpha\beta} + \tilde{q}_{\alpha\beta}$$

(5)

After determining the active and reactive power signals, they are smoothened by passing through a low pass filter.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \frac{1}{V_0 V_\alpha^2 + V_0 V_\beta^2} \begin{bmatrix} V_0 V_\alpha & -V_0 V_\beta & 0 \\ V_0 V_\beta & V_0 V\alpha & 0 \\ 0 & 0 & V_\alpha^2 + V_\beta^2 \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \\ p_0 \end{bmatrix}$$

(6)

Later, they are converted back to three phase reference currents and made available for comparison with actual currents.

$$\begin{bmatrix} i_{ha} \\ i_{hb} \\ i_{hc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

(7)

The neutral current is equal to:

$$i_n = (i_{ha} + i_{hb} + i_{hc})$$

(8)

3.2 New Topology

In a second part of this paper, a new topology for identifying reference currents based on pq theory using two improvements: Multi-Variable Filter developed by Benhabib in 2004, having the advantage of extracting harmonic voltages directly from the $\alpha\beta$ axis. It is presented in order to obtain a good voltage signal without harmonics [9]. The second improvement is: fuzzy logic controller used to extract current harmonics components instead of using a low pass filter.

3.2.1 Multi-Variable Filter: Multi-Variable Filter can be presented by the following transfer function:

$$V_{xy}(t) = e^{j\omega t} \int e^{-j\omega t} U_{xy}(t) dt$$

(9)

After Laplace transformation, we get:

$$H(s) = \frac{V_{xy}(s)}{U_{xy}(s)} = \frac{s + j\omega}{s^2 + \omega^2}$$

(10)

After developing this equation, we obtain the next expression:

$$\hat{x}_\alpha = \frac{k}{s}\left[x_\alpha(s) - \hat{x}_\alpha(s)\right] - \frac{\omega}{s}\hat{x}_\beta(s)$$

(11)

$$\hat{x}_\beta = \frac{k}{s}\left[x_\beta(s) - \hat{x}_\beta(s)\right] + \frac{\omega}{s}\hat{x}_\alpha(s)$$

(12)

The scheme of this filter is illustrated in Figure 2.

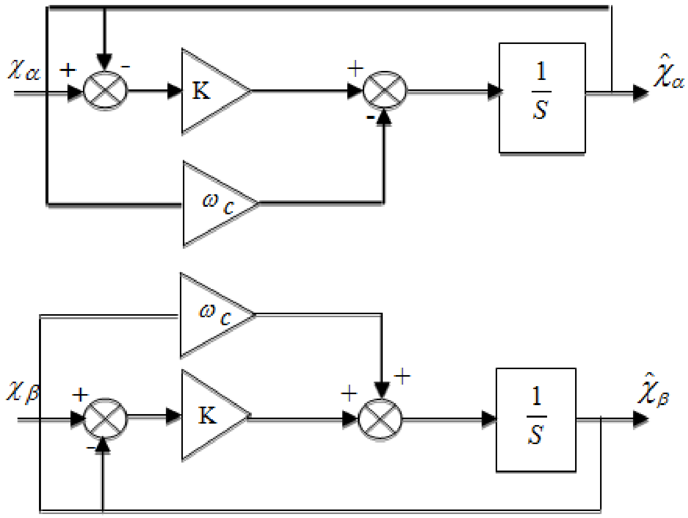

Figure 2. A Multi-variable Filter

3.2.2 Fuzzy logic controller: In recent years, fuzzy logic controllers have generated a great deal of interest in certain applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity [10].

In this part, a fuzzy logic controller replaces the low pass filter used in the instantaneous power theory in order to obtain continuous components of active and reactive power.

Mamdani Fuzzy system has been used in the fuzzy controller. The fuzzy controller is characterized for the following: - Seven fuzzy sets for each input - Seven fuzzy sets for the output - Triangular membership functions Defuzzyfication using the "centroid' method. Figure 3 shows a schematic block diagram of fuzzy inference system or fuzzy controller.

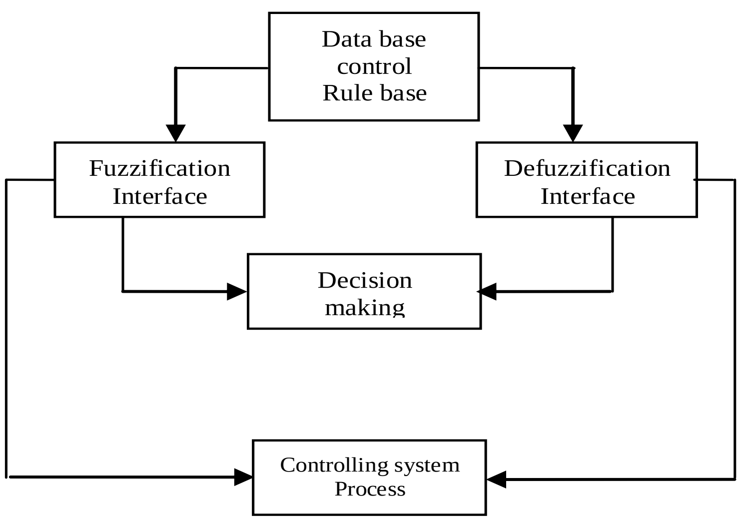

Figure 3. Fuzzy Inference System

4. Simulation Results

The performance of the proposed method is examined with an active filter simulation model using the instantaneous power theory and the results are compared with a multi-variable filter and a fuzzy logic controller replacing the low pass filter. The dynamic response of control strategy (and overall active power filter) is studied by switching three single phase inverter feeding unbalanced loads, simulation results where carried out using Matlab, by the following parameters:

Table 1. Parameters of Simulation

f=50Hz		
V_{s1}=220 v	V_{s2}=271 v	V_{s3}=322v
R_s=1,18e-3 Ω	L_s=37,6e-6H	
R_c=4,3e-3 Ω	L_c=68,67e-6H	
R_f=5e-3 Ω	L_f=300-6H	
R_{l1}=0,2 Ω	L_{l1}=1e-3H	
R_{l2}=0,3 Ω	L_{l2}=2e-3H	
R_{l3}=0,4 Ω	L_{l3}=3e-3H	

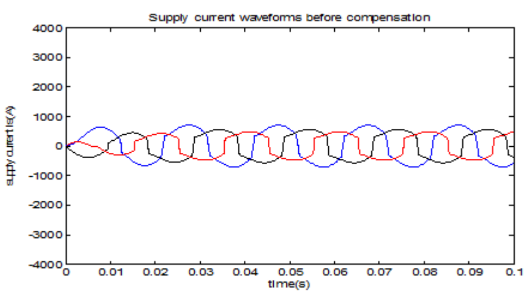

Figure 4.a Supply current waveforms

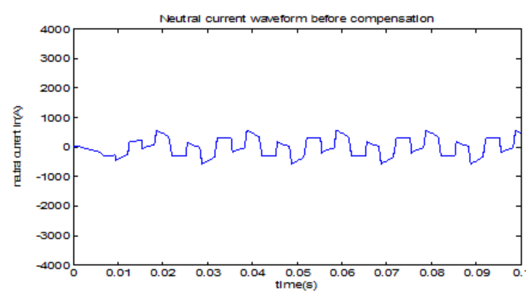

Figure 4.b Neutral current Waveform

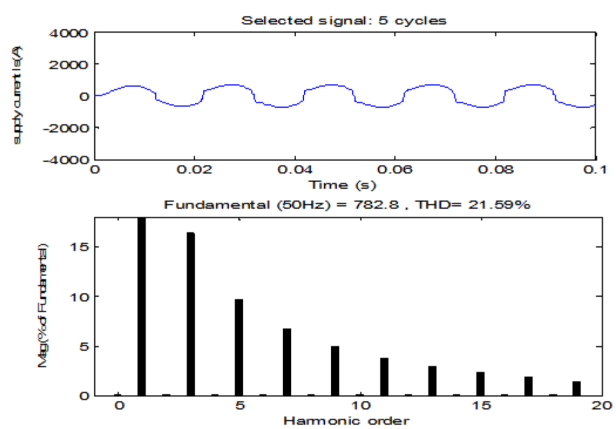

Figure 4.c Supply current waveform with THD

Figure 4. Waves form signal before compensation (without active filter)

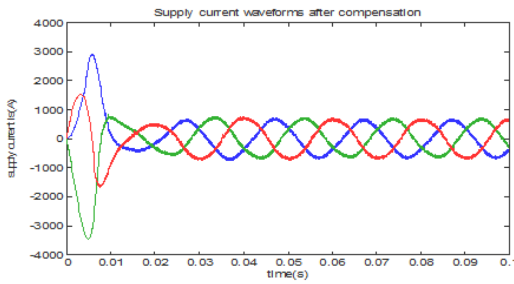

Figure 5.a Supply current waveforms

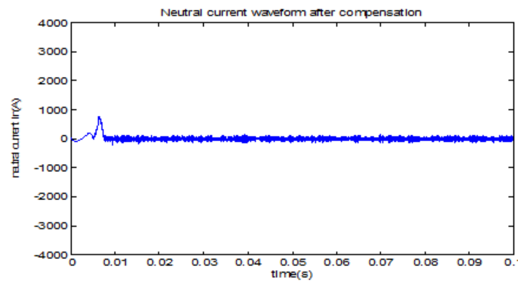

Figure 5.b Neutral current waveform

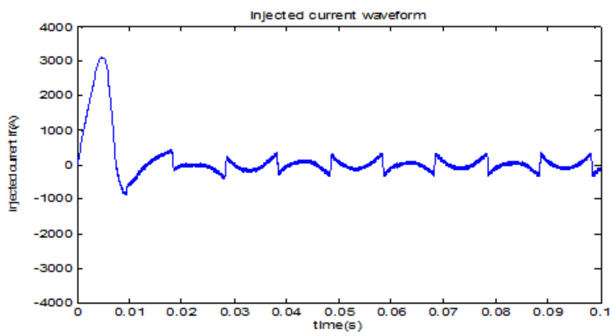

Figure 5.c Injected Current Wave Form

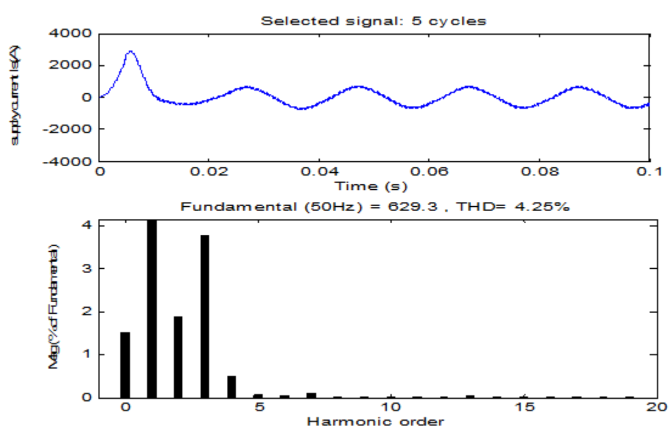

Figure 5.d. Supply Current Waveform with THD

Figure 5. Waves form signal after compensation (instantaneous power theory)

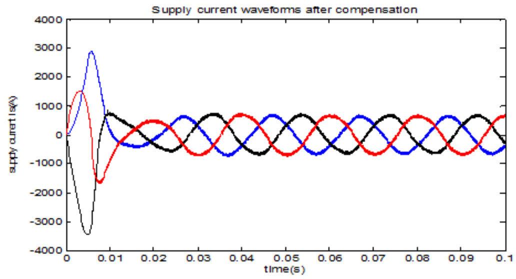

Figure 6.a. Supply current waveforms

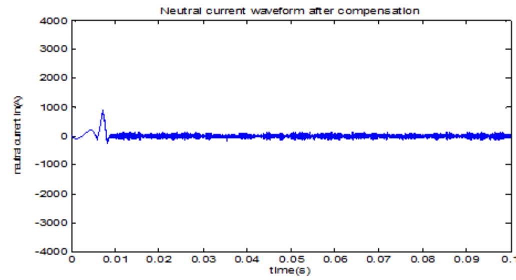

Figure 6.b Neutral current waveform

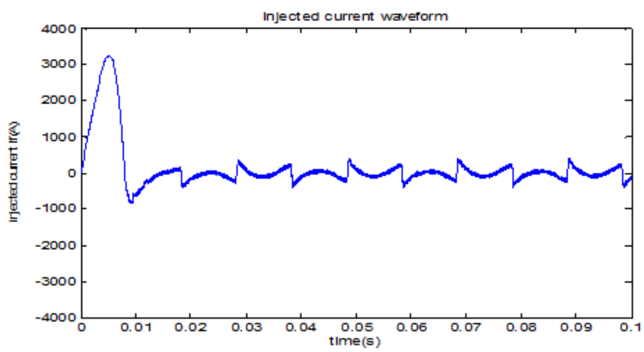

Figure 6.c Injected Current Wave Form

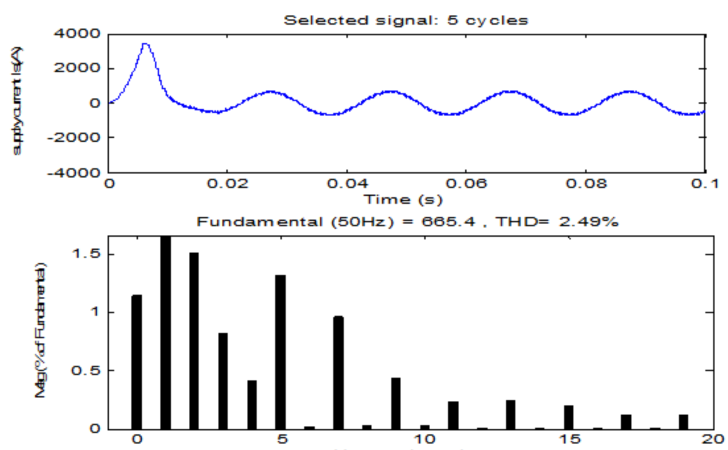

Figure 6.d. Supply Current Waveform with THD

Figure 6. Waves form Signal after Compensation (new topology)

5. Interpretation

Simulation results based on MATLAB software are presented to validate the control strategy. All simulations were realized in the same conditions. From Figures 4.a, 4.b and 4.c, have shown before compensation, it can be seen that the line currents are not sinusoidal and the THD for the first line was 21, 59% before filtering while the neutral current is very important. As it can be seen, from Figures 5.a, 5.b and 5.c have shown after compensation by using instantaneous power theory, that the line currents become sinusoidal and balanced while the neutral current is well reduced. The THD in this case is dropped to 4, 25%. Figures 6.a, 6.b and 6.c, show as well after compensation by using the new control method based on Multi-Variable Filter and Fuzzy Logic Controller, illustrate that the line currents are sinusoidal and well balanced. Moreover the THD is reduced to 2, 49% and the neutral current is much reduced as well. So, on the basis of simulation results it can be concluded that THD is less then 5% which satisfies the CEI norms. Consequently, all methods show the performance of the active power filter, the obtained results have shown a better performance for the new topology based on multi variable filter and fuzzy logic controller used to extract current harmonics components.

6. Conclusion

A digital active filter for three phase and neutral currents harmonic compensation that considers the existence of zero-sequence phase current components in un unbalanced three phase four wire electrical distribution systems feeding three single non-linear loads is applied. The strategy based on generalized instantaneous real and imaginary power concept, using a multi variable filter and a fuzzy logic controller has been illustrated and the effectiveness of those methods was evaluated through digital simulation by a comparison study with the conventional instantaneous real and imaginary powers theory initiated by Akagi. So with the recent improvements in control, the active power filters are capable to better compensate the current harmonics in three phase four-wire electrical networks.

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