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A New Approach of Modular Active Power Filtering

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Abstract

In this paper, a new modular active power filtering approach is proposed to eliminate harmonic currents and compensate reactive power. The method for identifying reference currents is based on FMVs "multi-variable filter". This method uses two (FMVs) having the advantage of extracting harmonic directly from the $\alpha\beta$ *axis, the first FMV (FMV Current) extracts the fundamental and individual harmonic component of the distorted line current signal and injects equal-but- opposite of each harmonic current into the line using a voltage source inverter VSI dedicated to that specific harmonic and the second FMV (FMV Voltage) estimates the fundamental component of the line voltage.*

Moreover the dc-side voltage is controlled by a fuzzy logic controller. The new approach has been illustrated in order to find the best way to reduce network harmonic currents and reactive power compensating of the connected load. All of the studies have been carried out through detail digital dynamic simulation using the MATLAB/Simulink Power System Toolbox.

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

1. Introduction

In recent years, the increasing application of nonlinear loads such as diode/thyristor rectifiers, results in harmonic currents, which is a serious problem to solve. The harmonic current can be suppressed by using a passive or active power filter. The use of active power filters (APFs) to mitigate harmonic problems and to compensate reactive power is dated back to the 1970s [1, 4, 10]. Since then, the theory and applications of APFs have drawn much attention. The APF appears to be a viable solution for eliminating harmonic currents and voltages. It injects equal-but-opposite current as well as absorbs or generates reactive power, thereby controlling the harmonics and compensating reactive power of the connected load. The objective of this research is to develop an efficient and reliable modular active power filter system to realize a cost-effective solution to the harmonic problem. The proposed filter system consists of a number VSI module, each dedicated to filter a specific harmonic of choice. In this paper, a modular active power filtering with two FMVs: "multi-variable filter" to extracts the individual harmonic components of the distorted line current signal and to estimates the fundamental component of the line voltage is proposed in three phase three wire electrical distribution system, feeding non-linear loads. Analysis and simulation results show improved performance.

2. System Configuration

The basic blocks of the proposed modular active filter system connected to the electric distribution system are shown in Figure 1. The system consists of a number of tree-phase voltage-source inverter (VSI) modules connected in parallel for each phase. Each filter module is dedicated to suppress a chosen specific low-order harmonic. The proposed active filter system uses tow FMVs to process the signals obtained from the power line. The method is based on extraction of fundamental component and individual harmonics of a distorted current by one module of FMV (the current FMV) and the fundamental voltage by the other FMV (the voltage FMV). The output of the FMV current is used to generate the modulating signals for the VSI modules. The power rating of the modules will decrease and their switching frequency (bandwidth) will increase as the order of the harmonic to be filtered increases. As a result, the overall switching losses are reduced due to selected harmonic elimination and balanced power rating-switching frequency product [1, 4, 10]. The information made available by the FMV current allows to select harmonic elimination. The output of the second FMV (FMV voltage) is the fundamental component of the line voltage signal. It is used as a synchronizing signal in the reactive power determination and regulation of the voltage source of the inverters modules [2, 6, 7, 9].

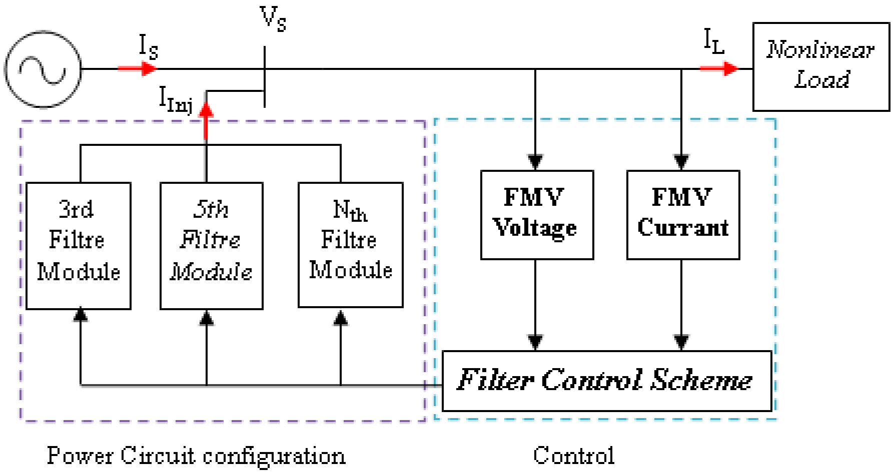


Figure 1. The Proposed Modular Active Power Filter System

3. Multi-Variable Filter

This filter says FMV, was developed by M.Benhabibe [9]. It’s based on the work of Song Hong-Scok and is based on the extraction of the fundamental signals, directly from the αβ axes. However, it can be used very well to isolate the direct or inverse of a particular harmonics order .

The equivalent transfer function of the integration in the synchronous references frame «SRF» is expressed by the equation:

$$V_{xy}(t) = e^{jwt} \int e^{-jwt} U_{xy}(t) dt \tag{1}$$

After Laplace transformation, we get the following equation:

$$H(s) = \frac{\tilde{x_{\alpha\beta}}(s)}{x_{\alpha\beta}(s)} = K \frac{(s+K) + jw_c}{(s+K)^2 + w_c^2} \tag{2}$$

By developing this equation, we obtain the expressions:

$$x_{\alpha}^{\sim}(s) = \frac{K.(s+K)}{(s+K)^2+w_c^2}x_{\alpha}(s) - \frac{K.w_c}{(s+K)^2+w_c^2}x_{\beta}(s) \qquad (3)$$

$$x_{\beta}^{\sim}(s) = \frac{K.w_c}{(s+K)^2+w_c^2}x_{\alpha}(s) + \frac{K.(s+K)}{(s+K)^2+w_c^2}x_{\beta}(s) \qquad (4)$$

$$x_{\alpha}^{\sim}(s) = \frac{K}{s}[x_{\alpha}(s) - x_{\alpha}^{\sim}(s)] - \frac{w_c}{s}x_{\beta}^{\sim}(s) \qquad (5)$$

$$x_{\beta}^{\sim}(s) = \frac{K}{s}[x_{\beta}(s) - x_{\beta}^{\sim}(s)] - \frac{w_c}{s}x_{\alpha}^{\sim}(s) \qquad (6)$$

Where:

$\mathbf{w_c}$: The cut-off frequency of the filter and is defined by: $\boldsymbol{\omega_c = n.\varepsilon.\omega_f}$

$\boldsymbol{w_f}$: The angular frequency of the fundamental component of the input signal,

$\boldsymbol{\varepsilon}$: Constant gain equal to ± 1 (direct component ($\varepsilon = 1$) or reverse ($\varepsilon = -1$).

$\boldsymbol{n}$: The order of the signal component to be filtered ($n = 3, 5, 7, 9$ ...).

$\boldsymbol{x_{\alpha\beta}^{\sim}}$: The output signal of the filter.

$\boldsymbol{x_{\alpha\beta}}$: The input signal of the filter.

$\boldsymbol{K}$: Constant gain.

Figure 2 illustrates the scheme of the multivariable filter.

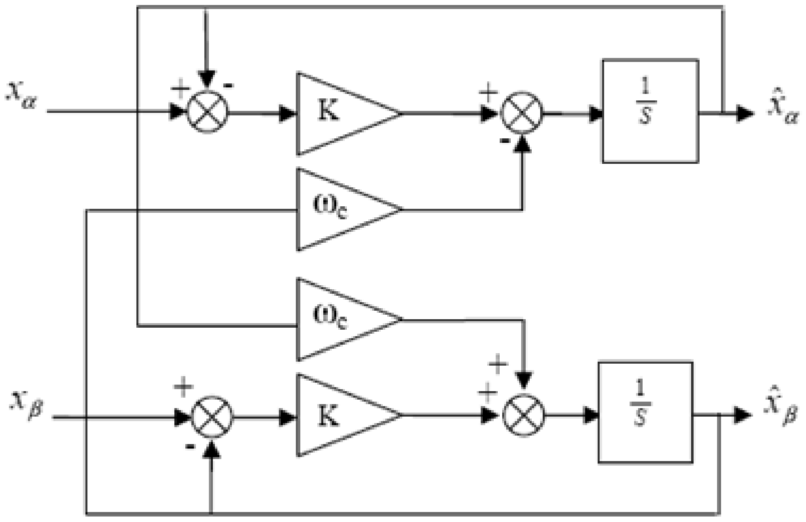


Figure 2. Multi-Variable Filter

3.1 The Behavior of FMV

The strategy developed for this new approach is based on using two FMVs; the first one is used to extract the fundamental and the individual harmonic (3rd, 5th, 7th) components of the distorted line current signal. The second is use to obtain a good voltage signal without harmonics.

In this section, we can present the simulation results concerning the study of the FMV filter to present its performance and benefits. This study justifies our choice to introduce this filter in extracting in the references instead of the conventional extraction filters.

Figure 3 shows the multi-variable filter output results representing the two phase's current component in αβ axis before and after filtering.

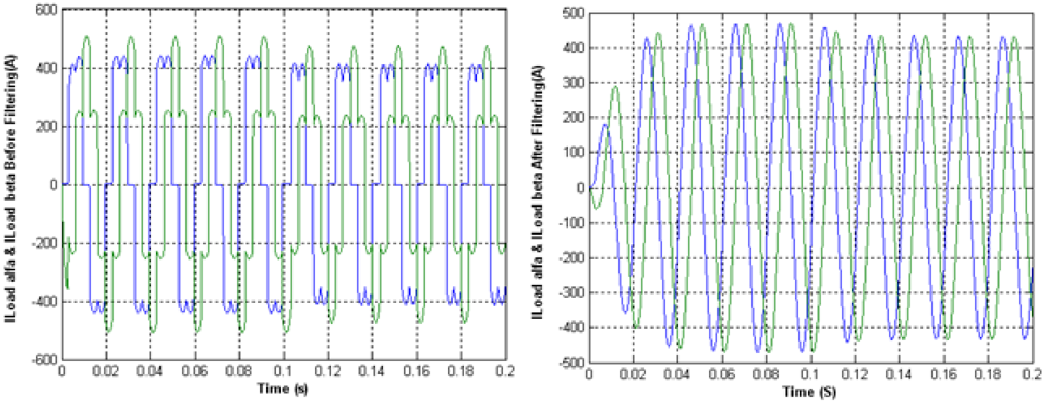


Figure 3. Two Phase Load Currant in αβ Axis before and After Filtering

The simulation results demonstrate the effectiveness of the FMV in this studied case (harmonics and unbalance). It is performing well and perfectly extracts harmonic currents without change of phase or amplitude [2, 6, 7].

4. The Filter Control Scheme

The main function of the controller is to create the PWM switching signals for the connected VSI modules. Figure 4 shows the schematic diagram of the proposed control scheme for the $\mathbf{I_{th}}$VSI filter module. The objective of this controller is to maintain a constant dc-voltage (to compensate for the losses of the filter module) and to inject a compensating current equal to the I_{th}harmonic current of the nonlinear load [8, 11].

In the proposed control scheme, a two-control loop system is adopted, an open-loop and a closed-loop control systems. In the open loop system, the $\mathbf{I_{th}}$ harmonic signal is obtained from the output of the current FMV and then its value is summed by$(-\boldsymbol{V_s}.\boldsymbol{u_{dc}})$, i.e. the gain of the filter module. The output $\boldsymbol{u_{dc}}$ of the fuzzy logic controller is used to maintain the dc-side voltage at its reference value. The closed-loop control based a fuzzy logic controller is used to maintain a constant value of dc-side voltage [3, 4, 8, 12]. The opposite of this signal is used as a current reference signal for that particular $\mathbf{I_{th}}$ harmonic component. The sum of the open loop control signal (current reference signal) and the closed-loop control signal (for regulating dc-side voltage) is used as the modulating signal of the three phases PWM control strategy to create the PWM switching pattern for the switches of the VSC module which is dedicated to the $\mathbf{I_{th}}$ harmonic.

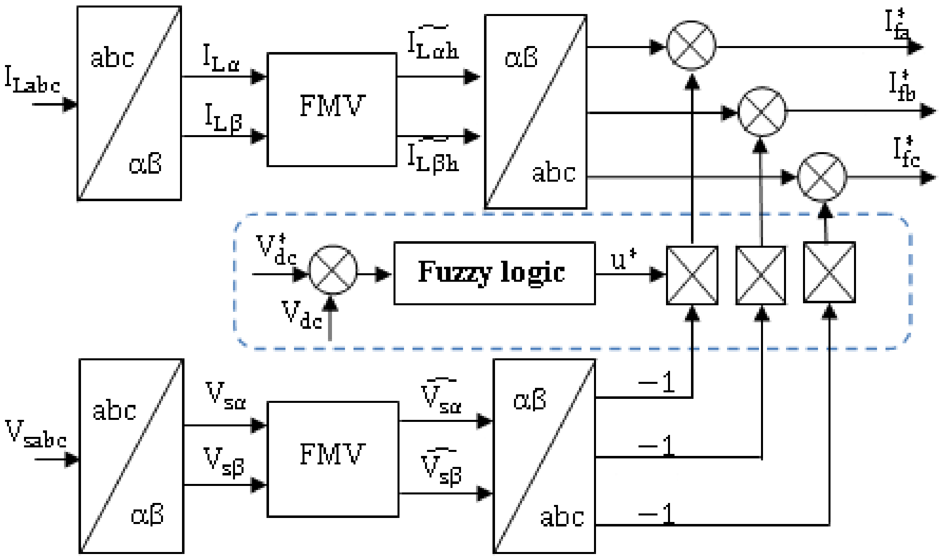


Figure 4. Control Scheme of the l_{th} VSI Filter Module without Reactive Power Compensation

5. Reactive Power Compensation

The presence of reactive power can cause losses in the electrical network, so increases the electricity consumption by customers [8]. The flow of reactive power is incurred a bad cos φ which is induced by the phase shift between current and voltage in each phase of the network. Also single harmonic compensation is not sufficient to correct the cos φ. To remedy this problem, the reactive power compensation is required.

In order to take account of the reactive power using the conventional instantaneous real and imaginary powers theory initiated by Akagi [3, 7, 11], the compensation currents in the αβ axis are expressed by:

$$\begin{bmatrix} \tilde{\mathbf{I}}_{\mathbf{comp\alpha}} \\ \tilde{\mathbf{I}}_{\mathbf{comp\beta}} \end{bmatrix} = \frac{\mathbf{1}}{\mathbf{V}_{\alpha}^{2} + \mathbf{V}_{\beta}^{2}} \begin{bmatrix} -\mathbf{V}_{\beta} . \mathbf{Q}^{-} \\ \mathbf{V}_{\alpha} . \mathbf{Q}^{-} \end{bmatrix} \tag{7}$$

Where: Q^{-} the continus component of the instantaneous reactive power.

Figure 5 shows the proposed control scheme to generate the currents to compensate the reactive power.

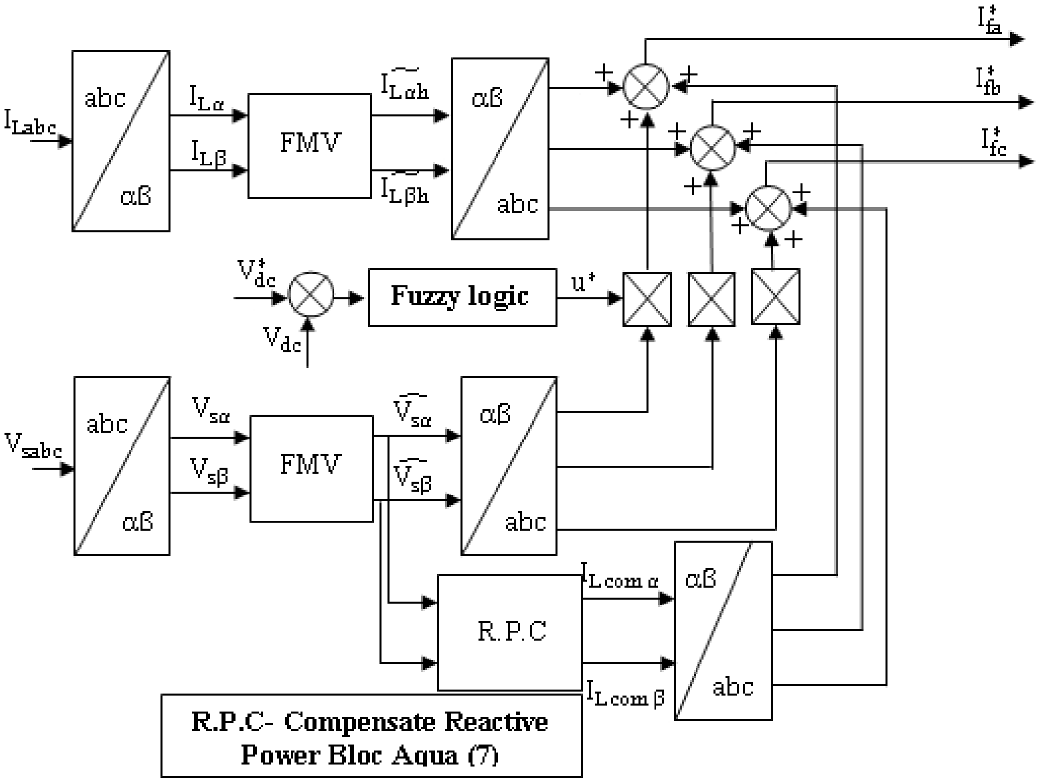


Figure 5. Control scheme of the l_{th} VSI filter module with reactive power compensation.

5. Simulation Results

In order to test the performance of the proposed modular active approach filter in steady-state, the system of Figure 1, was simulated using MATLAB software. Simulation parameters used in this paper are summarized in Table 1.

Table 1. Parameters of Simulation

$f = 50H$		
$V_{sa} = 240\sqrt{2}$	$V_{sb} = 240\sqrt{2}$	$V_{sc} = 240\sqrt{2}$
$R_s = 3.5m\Omega$	$L_s = 0.05mH$	
$R_c = 0.82m\Omega$	$L_c = 0.023mH$	
$R_d = 1\Omega$	$L_d = 2.6mH$	
$C = 8\mu f$	$L_f = 50\mu H$	
$R_f = 5m\Omega$	$\alpha = 20.$ and at $t = 0.1s$ $\alpha = 40$	

5.1 Case 1: Filtering Without Compensation of Reactive Power

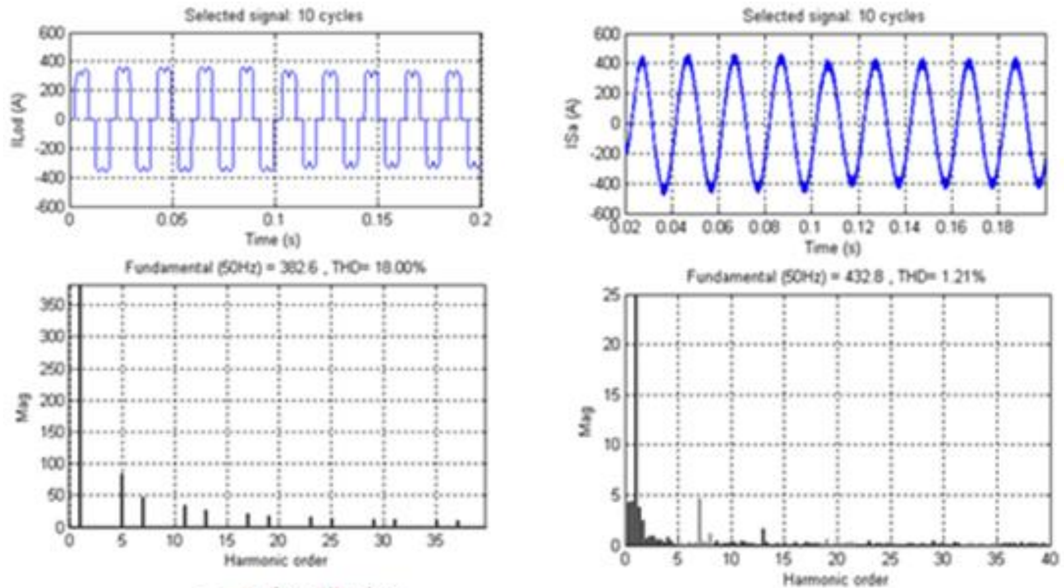
Figure 5 and Figure 6, shows simulation results for three-phase three-wire system, where the nonlinear load draws distorted currents from the source, After APF injects compensating currents then source currents become nearly sinusoidal with low THD.

The harmonics are extracted from the line current signal ($\mathbf{I_L}$) using the FMV Current. The first three dominant harmonics are selected to be suppressed. Control signals for the 3rd, 5th and 7th harmonics are obtained. Each is used to generate the PWM switching pattern for one VSI dedicated to suppress the corresponding harmonic. In this case, 3 VSI are used. Figure 5 shows the waveforms of the phase-a distorted current and its harmonic spectrum with a harmonic distortion rate equal to 18.00%.before filtering, and the THD is decreased to a value of 1.21%.after filtering.

Also as can be seen from Figure 6(b) the line current takes a form very close to a sinusoidal and from Figure 6(e), 6(f) the injected currents harmonic into the line by the active filter modules follow their references. The waveforms clearly illustrate the successful elimination of the selected harmonics from the line current.

From Figure 6(c) we can see the phase shift between current and voltage source, this phase shift make a degradation of power factor that we want to make very closer to unity.

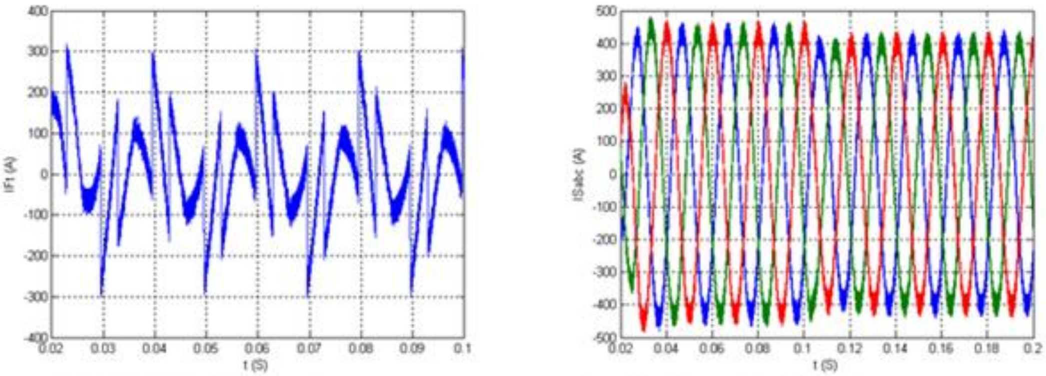
Figure 6(d), shows the DC capacitor voltage is well regulated and maintained at a constant value of 850V with a very limited fluctuation which justifies the effectiveness of the fuzzy logic controller to regulate the DC capacitor of the shunt active filter module.



a. Before Filtering

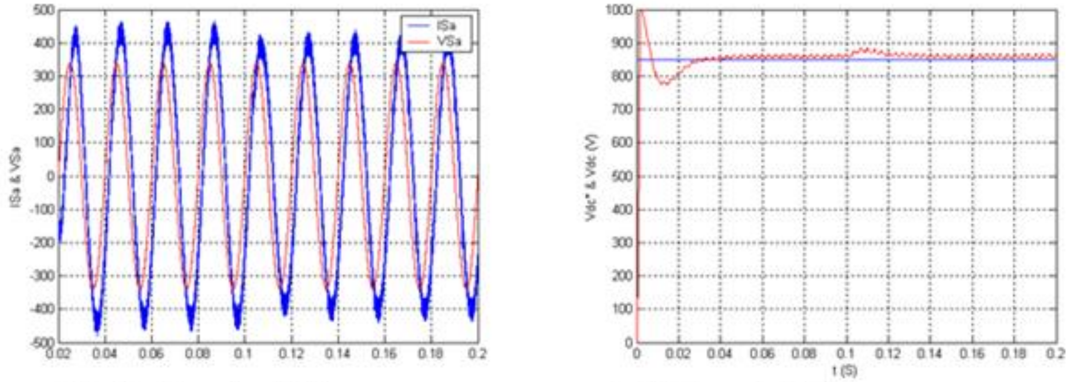
b. After Filtering

Figure 5. The Waveforms of the Phase-a Distorted Current and its Harmonic Spectrum without R.P.C.



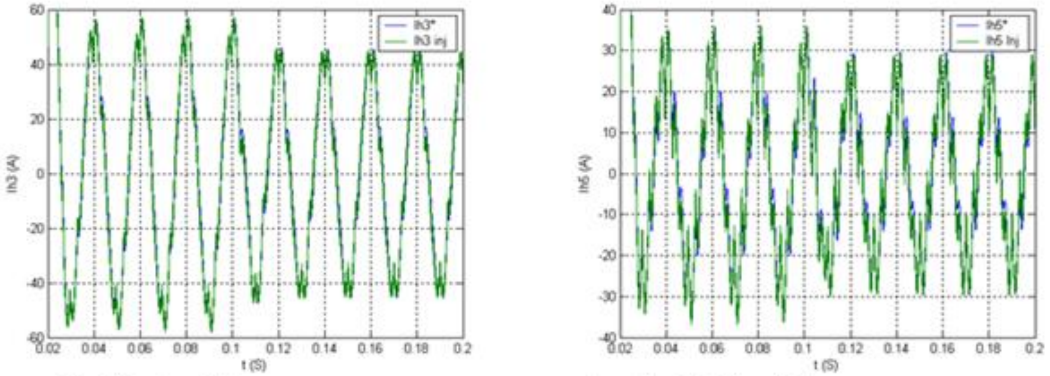
a. The Total Injected Current

b. The Three Line Current



c. The Line Current and Voltage

d. The Capacitor Voltage



e. The 3rd Injected Current

f. The 5th Injected Current

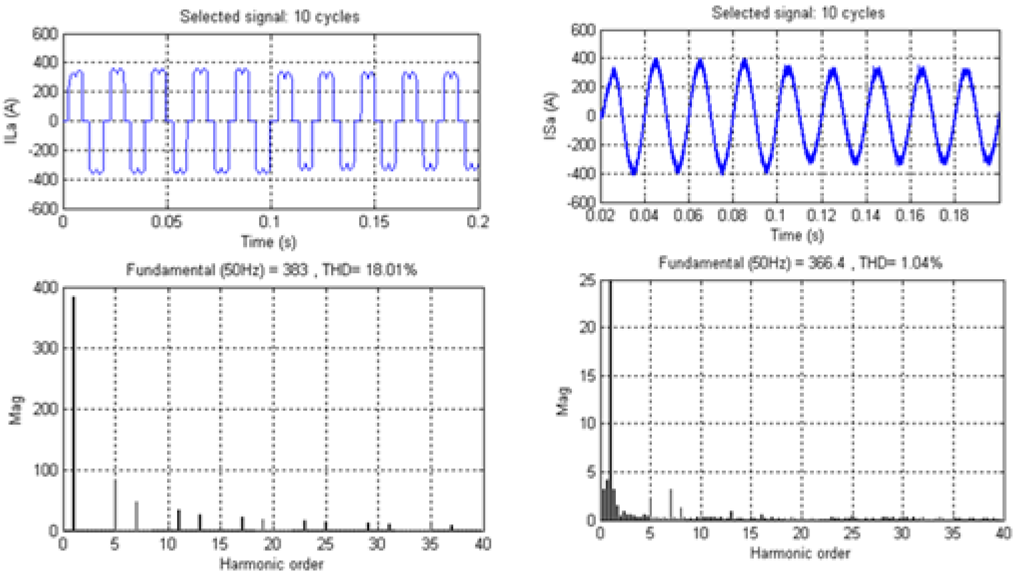
Figure 6. Simulation Results of Modular Active Power Filtering Without Reactive Power Compensation

5.2 Case 2: Simulation Results: Filtering With Compensate of Reactive Power

Now by introducing the bloc of reactive power, compensation we notice that the THD has decreased from 18.1% before filtering to a value equal to 1.04% after filtering compared to that obtained by the Case 1 as illustrated in Figure 7.

Figure 8 shows the variation of active and reactive power before and after filtering without and with reactive power compensation (RPC). It can be seen that the active power is relatively constant, but the reactive power is equal to zero after compensation. The results clearly illustrate the successful and effectiveness elimination of reactive power.

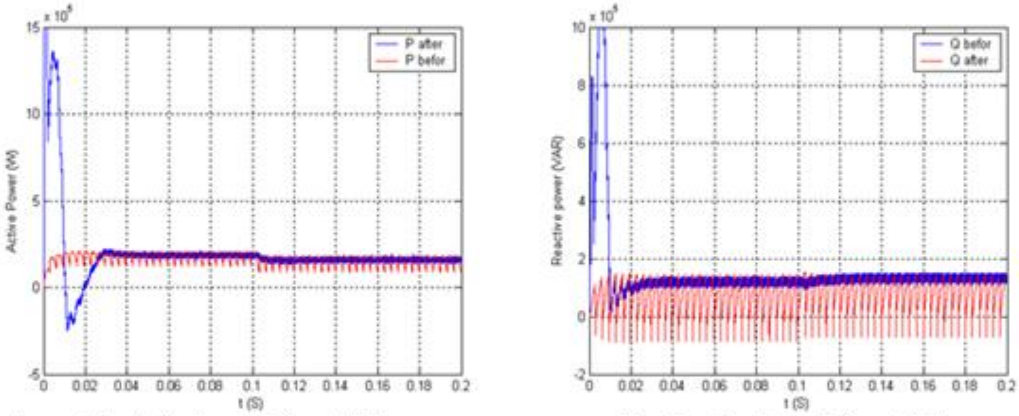
From Figure 9(c) we can see as well that the current and voltage source are approximately in phase



b. Before Filtering

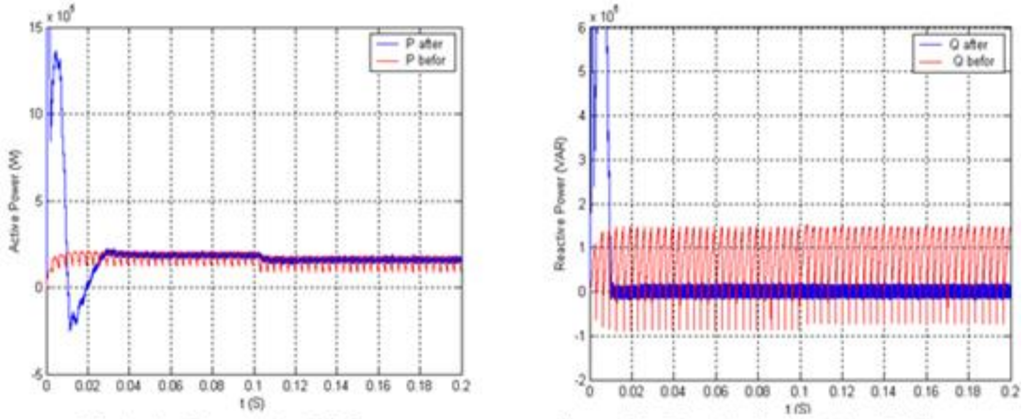
a. After Filtering

Figure 7. the Waveforms of the Phase-A Before and after Filtering



b. The Active Power Before R.P.C

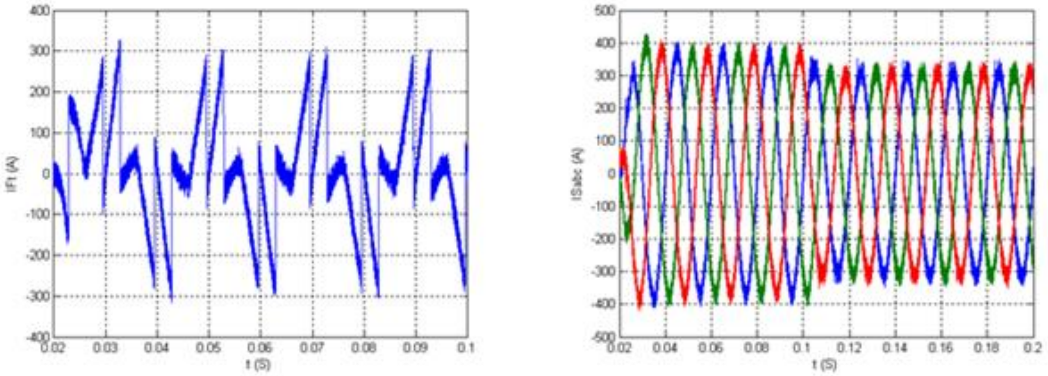
a. The Reactive Power Before R.P.C



c. The Active Power After R.P.C

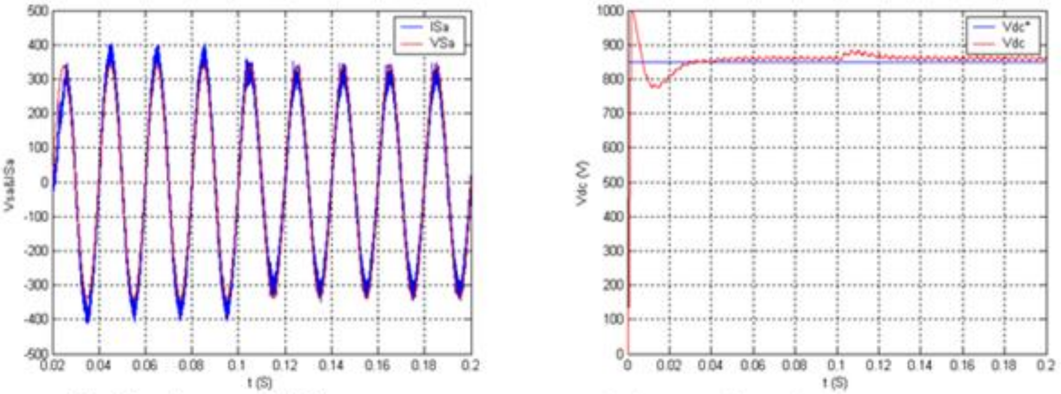
d. The Reactive Power After R.P.C

Figure 8. Active and Reactive Power Before and After R.P.C



a. The Total Injected Current

b. The Line Current



c. The Line Current and Voltage

d. The Capacitor Voltage

Figure 9. Simulation Results of Modular Active Power Filtering With R.P.C.

6. Conclusion

In this paper, a modular active power filter system is proposed which is capable of performing reactive power compensating and harmonic filtering in 3-phase 3-wire distribution system. Based on FMVs "multi-variable filter for identifying reference currents and dc-side voltage controlled by a fuzzy logic controller, the proposed active power filter has the ability to extract the fundamental system voltage in case the line voltage is unbalanced and harmonic polluted. The proposed active filter system has also the ability to extract information on individual harmonic components which allow us not only reducing the THD but also suppressing each harmonic component to meet the requirements of the IEEE 519 standard which emphasis that each harmonic component to be below a certain level.

On the basis of simulation results it can be concluded that with the recent improvements in control, the modular active power filters are capable to better compensate the current harmonics and reactive power in three phase three-wire electrical networks.

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