On the Use of Harmonic Detection Algorithms for Active Power Filtering Control

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Abstract

In the present work a technical review of several algorithms of harmonic currents compensation has been presented. The instantaneous reactive power theory (PQ theory), the Multi-Variable Filter FMV and Synchronous Reference Frame have been analyzed and compared under distorted and unbalanced conditions. The adopted strategy consists in first time in imposing a constant time response then the THD of the fundamental signal delivered by each method is computed; in second time the reversal case is considered; a THD value is imposed then the time response constant of each method will be computed. The simulation results obtained have been verified experimentally using Dspace 1104 platform.

1. Introduction

The electric and electronic equipments are very well-developed in the recent years; generally those devices constitute non-linear loads and absorb currents polluted with harmonics. This fact causes serious problems to the power network sources such as power factor and power quality degradation, loses increasing, the communication interferences ...etc [1]. For that reason, a several and effective solutions have been provided to permit an optimal, economic and safety operating conditions of the power distribution networks.

One of the most popular solutions to eliminate the harmonic presence is the passive filters [2]. The principal kinds of these filters are the single-tuned and the high-pass passive filters [2][3]. The first one is used to filter determined harmonic components or to attenuate their amplitudes, the high-pass filters are used to cancel the high frequency ones. Passive filters are also used to provide fundamental reactive power compensation [4]. Nevertheless this solution is not suitable when the impedance of the non-linear loads varies; in addition it may form series and parallel resonances which will result in amplification of harmonic currents in the power network [5].

In 1976, Gyugyi and Strycula introduced the first power quality devices; denominated Active Filters [6]. According to their connection to the network the active filter can be series, shunt or combined of these types and passif filters to weaken the harmonic component in the network [7].

Figure 1 illustrates the configuration of the shunt active filter type. The active power filter (APF) is connected in parallel with the network and injects in real time the harmonic components of the currents absorbed by the nonlinear loads connected to the network. Thus, the current provided by the source of energy becomes sinusoidal.

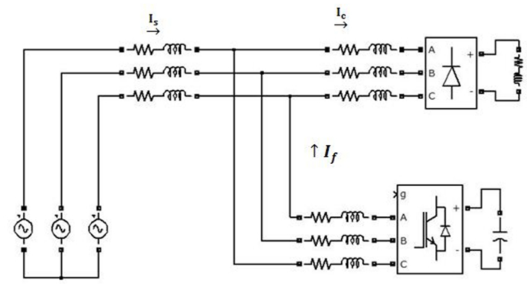

Figure 1. Shunt active filter structure.

We deal in the present paper with an important part that allows to the APF working perfectly. We are going to compare some extraction algorithms which have been used to detect the harmonic components; firstly we will begin by the algorithm based on the instantaneous reactive power theory (PQ theory) [8]; several papers have presented the application of the method; it could be employed for a single-phase system [9, 10, 11], for three-phase or for three-phase four-wire systems with a modified pq theory [12]. Second, we will use the synchronous reference frame method which has many uses too [13, 14, 15], and finally we end by the FVM filter that could be integrated with the PQ theory [16].

Many criteria have been used in the literature to evaluate the performance of each method, some criteria use ideal/unbalanced source voltages and distorted/unbalanced load currents [17]; others use non-symmetrical load and a symmetrical/unsymmetrical voltage [18] -[19]. So it is clearly noticeable that all APF reference detection strategies have been compared with the same conditions but how about the parameters of each algorithm?

In this work, we will attempt to answer to this question and precise which method is more performer than another by considering the following approach: in the first way we impose for them the same time response value then the computed THD% of the extracted fundamentals are compared; in the second way, we imposee a same THD% value then the calculated time response values will be compared.

2. Control Strategies

2.1. Instantaneous Reactive Power Theory

Akagi et al. [8] proposed a solution based on instantaneous values in three-phase power systems with or without neutral wire, known as instantaneous power theory or active-reactive (PQ) theory which consists of an algebraic transformation (Concordia transformation) of the three-phase voltages in the abc coordinates to the $\alpha\beta$ coordinates, followed by the calculation of the PQ values of instantaneous power components:

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

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

Thus, the instantaneous active and reactive power are given by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

In the general case, each power p and q contain a continuous part and an alternative part, which enables us to write:

$$\begin{cases} p = \tilde{p} + \bar{p} \\ q = \tilde{q} + \bar{q} \end{cases} \quad (4)$$

with :
$\bar{p}, \bar{q}$: continuous components related to the fundamental components of p and q.
$\tilde{p}, \tilde{q}$: alternate components relating to the harmonics.

The current references are then given by:

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (5)$$

Finally, it is easy to obtain the reference currents along the abc axes by the inverse transformation of Concordia:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (6)$$

Figure 2 shows the current references computation corresponding to the PQ theory.

2.2. Synchronous Reference Frame Based Controller (SRF)

This method generally applied in filtering applications [13] consists in transforming the current from the abc frame to the dq frame using the Park transformation where this last being synchronized with the source voltages, so:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \times \quad (7)$$

$$\begin{bmatrix} cos(\omega t) & cos(\omega t - \frac{2\pi}{3}) & cos(\omega t + \frac{2\pi}{3}) \\ -sin(\omega t) & -sin(\omega t - \frac{2\pi}{3}) & -sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

As for the theory of the instantaneous reactive power, the terms d and q contain a DC components and a multiple of AC components, such as:

$$\begin{cases} i_d = \bar{i}_d + \tilde{i}_d \\ i_q = \bar{i}_q + \tilde{i}_q \end{cases} \quad (8)$$

The synchronization of the currents with the frequency of the network transforms the fundamental current component into a continue component. However the harmonic components undergo a shift in frequency spectrum. The elimination of the continuous component is carried out by a low/high-pass filter and the harmonic currents references could be obtained by:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos(\omega t) & -sin(\omega t) \\ cos(\omega t - \frac{2\pi}{3}) & -sin(\omega t - \frac{2\pi}{3}) \\ cos(\omega t + \frac{2\pi}{3}) & -sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} \tilde{i}_d \\ \tilde{i}_q \end{bmatrix} \quad (9)$$

Figure 3 summarizes the current references computation corresponding to the SRF method.

2.3. The Filter Multi-Variable (FMV)

Hong-scok Song had defined the equivalent transfer functions of the integration in the synchronous references frame as [16]:

$$V_{xy}(t) = e^{j\omega t} \int e^{-j\omega t} U_{xy}(t) dt \quad (10)$$

The Laplace form of relation (10) is expressed by:

$$H(s) = \frac{V_{xy}(s)}{U_{xy}(s)} = \frac{s + j\omega_c}{s^2 + \omega_c^2} \quad (11)$$

In [21] authors had introduced a constant k in the transfer function $H(s)$ to obtain the FMV with a cut-off frequency, so the previous transfer function H(s) becomes:

$$H(s) = k\frac{(s + k) + j\omega_c}{(s + k)^2 + \omega_c^2} \quad (12)$$

Now it is clear that the FMV is similar to other filters like high Pass-filter or low Pass-filter with a cut-off frequency ω_c and a gain k.

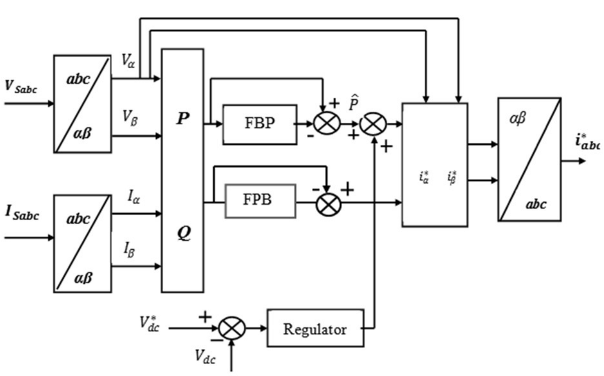

Figure 2. Harmonic current references generation based on the pq theory.

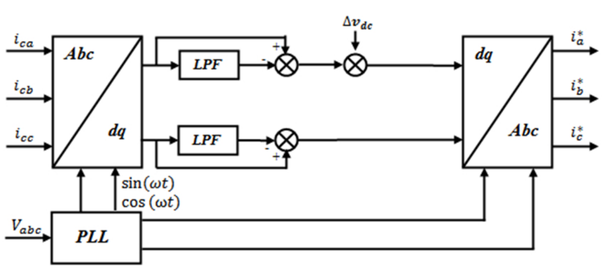

Figure 3. Harmonic current references generation based on the SRF method.

After some simplifications the following expressions could be obtained:

$$\begin{cases} \tilde{x}_\alpha(s) = \frac{k(s+k)}{(s+k)^2+\omega_c^2} x_\alpha(s) - \frac{k\omega_c}{(s+k)^2+\omega_c^2} x_\beta(s) \\ \tilde{x}_\beta(s) = \frac{k(s+k)}{(s+k)^2+\omega_c^2} x_\beta(s) + \frac{k\omega_c}{(s+k)^2+\omega_c^2} x_\alpha(s) \end{cases} \quad (13)$$

The scheme relative to the algorithm based on the FMV is shown in Fig. 4.

Several configurations of the FMV filter were presented in the literature. It is possible to use it directly according to axes $\alpha\beta$ given by (13) to extract the harmonic components from the current signals [22],[16].

3. Simulation Study

The three methods mentioned above have been put in same conditions to show the performance of each technique. First, for the same time response we compare the THD. After that, for the same THD we compare the time response.

In the first case, we impose a constant time response for the three methods and the THD is measured; therefore we took the cut-off frequency $\omega_c = 50Hz$, $\xi = 0.7$ and $k_{FMV} = 190$ to compute the fundamental references of the rectifier line currents as a no-linear load (Fig. 5). The results obtained are shown in the Fig. 6 and summarized in Table 1.

Table 1. Simulation results. The THD of each method when the time response is considered constant.

	PQ & SRF		FMV
$\xi = 0.7, \omega_c = 50Hz$, $k_{FMV} = 190$	LPF	HPF	
Time response (s)	0.0135	0.0134	0.0139
THD %	0.7462	6.2220	0.5734

Table 2. Simulation results. The time response of each method when the THD is considered constant.

	PQ & SRF		FMV
	LPF	HPF	
Parmeters	$\xi = 0.03$ $\omega_c = 50Hz$	$\xi = 0.07$ $\omega_c = 50Hz$	$K_{FMV} = 57$ $\omega_c = 50Hz$
THD %	0.7462	0.7497	0.7162
Time(s)	0.0135	0.2521	0.0446

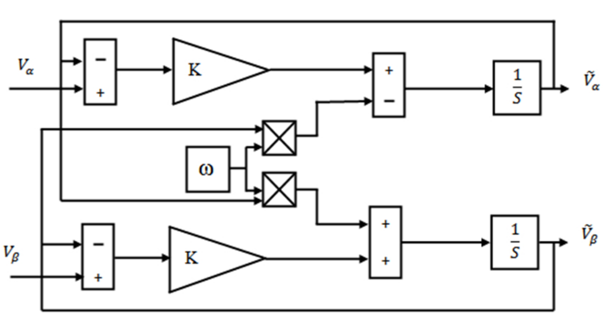

Figure 4. Harmonic current references generation based on the FMV method.

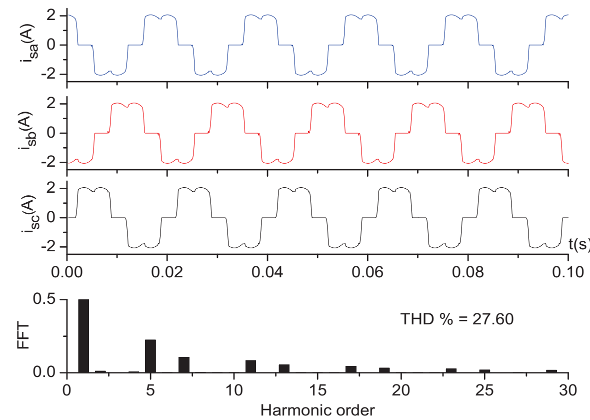

Figure 5. Load currents (top) and their normalized spectrum (bottom).

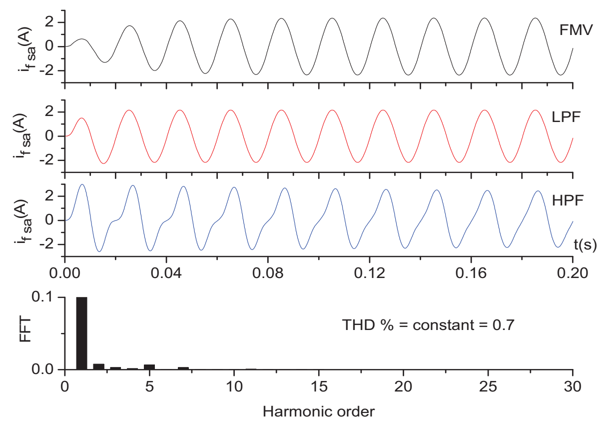

Figure 6. The transient reference of the fundamental component. Top FMV filter, middle LPF et HPF respectively with PQ and SRF methods their normalized spectrum (bottom)

In the second case, the THD is kept constant at 0.7% and the time response calculation for the three methods is summarized in Table 2.

According to [23] the SRF is certainly a particular case of the PQ theory, for that in both cases we noticed the same results for both methods. We can noticed that low pass filter LPF is more perform than the high pass filter HPF used with the PQ and SRF filters. On the other hand, the FMV and the PQ performances can considered close and are directly influenced by the chosen parameters.

The LPF for both methods PQ and SRF when an unbalance is introduced in the voltage source. Table 3 summarized the obtained results where we can see a degradation of the performance of PQ methods as it uses directly the unbalanced voltage in its algorithm. The SFR is not disturbed, as the pulsation ω is obtained using a PLL and at the last we noticed that the performance of the FMV is disturbed but remain acceptable.

4. Experimental validation

For the experimental part, the Dspace 1104 platform is used, in addition to the rectifier as polluted load (FIG.6). Figure 8 shows the transient part of the current fundamental extraction.

Table 3. Simulation results. The THD of each method when the unbalance in the voltage source is introduced.

	THD % i_{load}	THD % $i_{fundamental\ extracted}$		
		PQ	SRF	FMV
$Phase1$	27.96	18.13	1.03	2.89
$Phase2$	23.39	17.26	0.72	2.39
$Phase3$	22.64	20.64	0.71	2.38

Table 4 gives the THD value obtained for the different methods when the time response is considered constant and the Table 5 gives the time response when the THD value is constant. Table 6 summarized the results when the unbalanced is introduced on the voltage source. It is clear that the experimental results are in total concordance with that of simulation ones.

Figure 7. Experimental setup for the extraction of the fundamental components with the different methods.

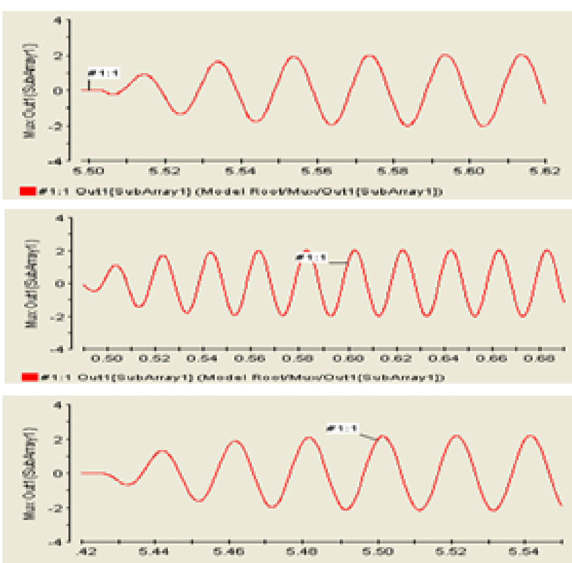

Figure 8. Experimental results. The time response of each method when the THD is considered constant. FMV (top), HPF (middle) and LPF (bottom)

Table 4. Experimental results. The THD of each method when the time response is considered constant.

	PQ & SR		FMV
$\xi = 0.7, \omega_c = 50Hz$, $K_{FMV} = 190$	LPF	HPF	
Time response (s)	0.0220	0.0230	0.0221
THD %	0.8249	6.3676	2.8645

Table 5. Simulation results. The time response of each method when the THD is considered constant.

	PQ & SR		FMV
	LPF	HPF	
Parmeters	$\xi = 0.03$ $\omega_c = 50Hz$	$\xi = 0.07$ $\omega_c = 50Hz$	$K_{FMV} = 57$ $\omega_c = 50Hz$
THD %	0.886	0.8897	0.8894
Time(s)	0.0145	0.2989	0.0650

Table 6. Experimental results. The THD of each method when the unbalance in the voltage source is introduced.

	THD % i_{load}	THD % $i_{extracted\ fundamental}$		
		PQ	SRF	FMV
$Phase1$	27.62	20.46	2.24	2.99
$Phase2$	23.84	19.34	2.09	2.59
$Phase3$	22.44	22.83	2.29	2.46

5. Conclusion

This paper presents a comparative study of three strategies of harmonics detection, the main criteria for the different methods is to have a constant time response and measured the THD in first time, in second time and for the same THD value the time response is measured. From the simulation and experimental results it is clear that the LPF in the case of PQ and SFR is more performer than the HPF and the FMV filter under balanced voltages. On the other hand, the PQ method become obsolete when the unbalance is introduced in the voltage source.

6. References

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