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A novel strategy for shunt active filter control

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ABSTRACT

The present paper proposes the use of an advanced algorithm based on the instantaneous powers theory for harmonics current compensation. A fast and exact computation of harmonic references is more than crucial for any active filter control strategy, especially during the transient time and frequency domains. The proposed method contains mainly two stages, the first one is based on a self-tuning filter (STF) to perform instantaneous synchronized sine and cosine fundamental waveforms. These two signals are used to calculate the instantaneous active and reactive powers using the well-known PQ theory. The second one is based on a new proposed method to accelerate the power ripple cancelation in the PQ active and reactive powers. An analytic study is conducted to show the effectiveness of these methods which is consolidated by simulation and experimental results.

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1. Introduction

Nowadays, the use of electric and electronic equipments (rectifiers, variable speed drives, computers, industrial installations) containing power semiconductors such as Thyristor converters, knows a considerable progression. The nonlinear behavior of those equipments generates harmonics that affect directly the distribution utility operations [1,2]. Indeed, the consequences of this phenomenon could be manifested in: transformer overheating, a reduction in the efficiency of the generation, transmission and utilization of electric energy, malfunctioning of the system or plant components [3,4]. In order to overcome these problems and ensure the electrical sources safety several solutions have been presented in the literature.

One of the most popular solutions to eliminate the harmonic presence of the grid utility is the passive filters [5]. The principal kinds of these filters are the single-tuned and the high-pass passive filters [6]. The first one is used to omit a determined harmonic component or to attenuate its amplitude. However, the high-pass filters are used to cancel the superior frequency order. Moreover, passive filters could be used as a tool for reactive power compensation [7]. Nevertheless, the use of these filters is not suitable when the impedance of the power network varies. In addition, they may cause series or parallel resonances which will result in amplification of harmonic currents in the power network [8].

To overcome the problems of passive filters, the devices introduced by *Gyugyi* and *Strycula* denominated active filters constitute a very useful alternative [9]. According to their connection they may be shunt, series or a combination of the two configurations. The mixture between passive and active filters called hybrid filters, which is considered as an attractive solution to improve filtering performances [10–13].

Active filters are divided into voltage source active filters and current source active filters. The performance of voltage source active filters is better than that of current source active filters [14]. The shunt voltage source active filter which is connected in parallel to the load is one of the most existing configurations. In order to obtain a sinusoidal network current as much as possible, this filter must injects in real time the references of the needed harmonic currents for compensation of the current harmonics caused by the nonlinear loads.

Fast and accurate harmonics current extraction represents a crucial task for the compensation process that includes essentially the references computation of the harmonic currents. A good determination of these references will improve the active power filter performances.

Several identification algorithms have been presented in the literature. They are expressed in terms of time or frequency domains according to the application study [15–17].

In the frequency-domain, many algorithms based on the Fourier transform such as recursive discrete Fourier transforms (RDFT) [18], Kalman filtering (KF) [19], Budeanu and CPC theories are used for on-line calculation of harmonic currents. However, these algorithms are generally attached with a slow time response [20,21].

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The time-domain algorithms are based on the instantaneous determination of the harmonic currents/voltages compensation [22]. The most control strategies used are based on the instantaneous active and reactive powers theory (PQ theory) [23] and the synchronous reference frame method (SRF) [24]. Other methods less popular like the Notch filters method [25] or older ones like the Fryzes theory [20,21] are also used. In general, all these methods use filters to cancel the effect of alternative components caused by harmonics current. Hence, the performance of those methods is a compromise between a fast time response and a perfect harmonics current elimination.

Some other algorithms such as fuzzy control [26–29], neural network algorithm [30], moving average [31–33] have been applied. Those algorithms are quite accurate with other drawbacks like redundancy and computational time.

The present paper deals with the use of an advanced algorithm based on the instantaneous powers theory for harmonics current compensation. To achieve high filtering performances with a fast time response, the proposed strategy consists firstly in the use of a self-tuning filter (STF) in the stationary frame to synthesize a synchronized *sine* and *cosine* waveforms at the fundamental frequency for active and reactive powers calculations. After that, a new method is proposed in order to accelerate the power ripple cancelation in the PQ active and reactive powers to overcome the drawback of transient time response.

2. Description of the proposed method

2.1. The three phase voltages/currents system

The balanced three phase voltages system which takes into account any type of distortion can expressed by:

$$\begin{cases} v_{sa} = \displaystyle\sum_{h=-\infty}^{+\infty} V_h \sin(h\omega t + \phi_h) \\ v_{sb} = \displaystyle\sum_{h=-\infty}^{+\infty} V_h \sin\left(h\omega t + \phi_h - \frac{2\pi}{3}\right) \\ v_{sc} = \displaystyle\sum_{h=-\infty}^{+\infty} V_h \sin\left(h\omega t + \phi_h + \frac{2\pi}{3}\right) \end{cases} \tag{1}$$

The three phase distorted currents form could be represented as follow:

$$\begin{cases} i_{sa} = \displaystyle\sum_{h=-\infty}^{+\infty} I_h \sin(h\omega t + \varphi_h) \\ i_{sb} = \displaystyle\sum_{h=-\infty}^{+\infty} I_h \sin\left(h\omega t + \varphi_h - \frac{2\pi}{3}\right) \\ i_{sc} = \displaystyle\sum_{h=-\infty}^{+\infty} I_h \sin\left(h\omega t + \varphi_h + \frac{2\pi}{3}\right) \end{cases} \tag{2}$$

where:

h denotes the order of the positive and negative harmonic sequences of the voltage or current systems and it also refers to the phasor rotation of the harmonic voltages and currents with respect to the fundamental waveform in a balanced, 3-phase system. The positive (negative) sequence harmonic would rotate in the same (opposite) direction as the fundamental frequency with $h\omega$ speed. The zero harmonic sequences represent the third set of harmonic sequences where harmonic components in the three phase voltage or current systems are in phase with each other. The effect of the zero harmonic sequences is canceled in the active or reactive power calculation and that is why they are not covered in Eqs. (1) and (2).

V_h, I_h, ϕ_h and φ_h are amplitudes and phase angles of the harmonic components of the voltage and current systems respectively.

$\omega = 2\pi f_s$ is the fundamental pulsation of the voltage or current systems.

2.2. The instantaneous reactive power theory

Akagi et al. [23] 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 power theory (PQ theory), which consists of an algebraic transformation (Concordia transformation) of the three balanced phase voltages and the three phase currents in the *abc* coordinates to the $\alpha\beta$ coordinates, followed by the calculation of the p and q values of instantaneous power components:

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

$$\begin{matrix} i_{s\alpha} \\ i_{s\beta} \end{matrix} = \sqrt{\frac{2}{3}} \begin{matrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{matrix} \begin{matrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{matrix} \tag{4}$$

Thus, the instantaneous active and reactive powers values are given by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \tag{5}$$

By replacing Eqs. (1)–(4) in relation (5), we get:

$$\begin{cases} p = \displaystyle\sum_{h_v=-\infty}^{+\infty} \sum_{h_i=-\infty}^{+\infty} \frac{3}{2} V_{h_v} I_{h_i} \cos((h_i - h_v)\omega t + \varphi_{h_i} - \phi_{h_v}) \\ q = \displaystyle\sum_{h_v=-\infty}^{+\infty} \sum_{h_i=-\infty}^{+\infty} \frac{3}{2} V_{h_v} I_{h_i} \sin((h_i - h_v)\omega t + \varphi_{h_i} - \phi_{h_v}) \end{cases} \tag{6}$$

The previous equation shows that each power component contains a continuous part when $(h_v = h_i)$ and an alternative part when $(h_v \neq h_i)$, so:

$$\begin{cases} p = \bar{p} + \tilde{p} \\ q = \bar{q} + \tilde{q} \end{cases} \tag{7}$$

with:

$\bar{p}$ and $\bar{q}$ denote the continuous components related to the interaction of the voltage and current harmonics of the same order $(h_v = h_i)$. Usually in the literature we consider only the fundamental component of the voltage. As we know it is not so correct to consider the network voltages contains only the fundamental components and that gives an erroneous calculation of the current references.

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