Electric Power Systems Research 79 (2009) 1342–1352

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Evaluation of reference current extraction methods for DSP implementation in active power filters

K. Vardar, E. Akpınar*, T. Sürgevil

Dokuz Eylul University, Department of Electrical and Electronics Engineering, Kaynaklar Kampusu, 35160 Buca, Izmir, Turkey

ARTICLE INFO

Article history:
Received 21 April 2008
Received in revised form 25 March 2009
Accepted 14 April 2009
Available online 23 May 2009

Keywords:
Active power filters
Digital signal processor applications
Harmonics detection methods

ABSTRACT

Generation of current references constitutes an important part in the control of active power filters (APFs) used in power system, since any inaccuracy in reference currents yields to incorrect compensation. In this paper, harmonic detection methods for generating reference currents have been evaluated on the basis of three-phase balanced and unbalanced load currents processed in the digital signal processor (DSP). The advantages and disadvantages of several methods found in the literature have been discussed on the basis of simulation results. Three of these methods have been programmed in the TMS320F2812 digital signal processor (DSP) unit and their performances are evaluated from the viewpoint of practical considerations. Finally, instantaneous reactive power method to estimate the APF reference currents is implemented and its practical results obtained under balanced and unbalanced loads are given.

1. Introduction

The APFs have been widely used to control harmonic distortion in power systems. The APFs use power electronics converters (such as PWM voltage or current source converters) in order to inject harmonic components to the electrical network that cancel out the harmonics in the source currents caused by non-linear loads. Fig. 1 shows the single-line diagram of a typical shunt APF compensating the current harmonics of a three-phase load. Besides harmonics compensating capability, APFs are also used in the solution of reactive power compensation and load balancing. They have a significant advantage over the passive filters since they do not cause resonance problems in the network. A conceptual survey on APF topologies, control methods and practical applications can be found in the literature [1–8].

In the process of harmonic compensation, detection of the load current harmonics is one part, while the generation of compensating harmonic currents by means of converter switching is the other part of APF. The performance of active power filters depends on the harmonic detection methods for generating current references, current control method, and dynamic characteristics of APF power converter circuit. Of all these criteria related to design of APF, generation of current references constitutes an important part that affects the filtering performance since any inaccurate phase and magnitude of reference currents yields to incorrect compensation and hence performance degradation [9–11]. Some of the loads such as arc furnaces in power system are varying very fast. Therefore, the response time of APFs when compensating the harmonics of rapidly changing loads should be considered as a critical parameter. So, a fast and accurate detection of harmonic components in current or voltage waveforms is essential in APFs for varying loads. Many harmonic detection methods were proposed and their performances were evaluated in papers that can be found in the literature [12–17].

There are several methods for extracting the harmonics content of a non-sinusoidal load current. In this paper, these methods are simulated in MATLAB and compared to each other in order to specify the advantages and disadvantages in terms of response time and filtering capability against the variations in frequency, phase, and amplitude of load currents. Three methods are also compared in terms of execution times and programming complexity aspects in the DSP unit. In Section 2, the methods of reference current generation are investigated and algorithms are introduced. In Section 3, the performances of these methods are analyzed by using Matlab package program. The results obtained from the DSP programming of the methods are compared and discussed in Section 4. Finally, a three-phase APF implementation by using the IRPT is given in Section 5.

2. Methods of reference current generation

There are several methods for determining harmonic content of the load current. The control reference signal for an APF can be obtained either using frequency domain or time domain techniques. The frequency domain technique investigated in this section is Fast Fourier Transform (FFT). The time domain techniques include Instantaneous Reactive Power Theory (IRPT), Single-phase

* Corresponding author. Tel.: +90 232 4127163; fax: +90 232 4531085.
E-mail address: eyup.akpinar@deu.edu.tr (E. Akpınar).

0378-7796/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2009.04.004

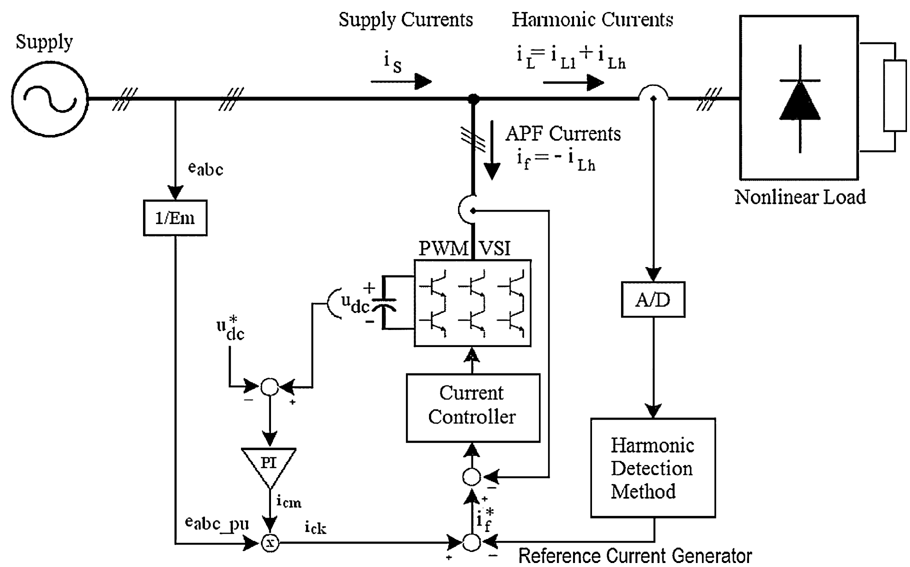

Fig. 1. Single-line diagram of APF with a non-linear load.

Instantaneous Reactive Power method, Synchronous Reference Frame (SRF) method, Generalized Integral method, Adaptive Filter method, Delayless Filtering based on Neural Network, Adaptive Linear Neuron (ADALINE) method and Wavelet method.

Each of these methods are modeled using Matlab package program and the results are compared on these bases: response time to load variations, calculation complexity, noise immunity, accuracy of harmonic current prediction, power frequency variation and unbalanced loading. According to the outcomes of Matlab simulations, three out of those methods are programmed in TMS320F2812 DSP and execution times of these methods are compared.

2.1. Fast Fourier transform

The amplitude and phase information of the harmonic series in a periodic signal can be calculated by using the Fourier analysis [14,15]. Fast Fourier Transform (FFT) is an efficient algorithm for computing the Discrete Fourier Transform (DFT) of discrete signals. The FFT reduces the amount of time for calculation by using the number of sampled points N, which is a power of two. This method is preferred in some digital signal processing applications if the waveform is processed on-line using microcontrollers having a higher clock frequency. The basic operational principal of an APF requires extracting harmonics to be eliminated (or minimized) from the entire current waveform of the load. Therefore, the FFT is a powerful tool for harmonic analyses in active power filters as well. The drawback of this application is the execution time of the algorithm implemented in processor, because it needs sampled data over one period to estimate the spectrum of harmonics. If the load current varies in every period or in every few periods, the FFT algorithm may not provide sufficient information on-line to follow the harmonic content of the load.

2.2. Instantaneous reactive power theory (IRPT)

In a three-phase system, harmonic current components can be found by using the IRPT [14,15] as shown in the block diagram in Fig. 2. The dc and ac components in these instantaneous active and reactive powers are due to fundamental and harmonic currents of the load, respectively. The power values of the dc components are filtered out by two high-pass filters. Thus, the remaining part is extracted as active and reactive powers caused by the load harmonic currents. Here it must be noted that the delay of response is based on filters' performance. Using the output of filters, the reference currents for each phase of the APF are generated, first in stationary αβ coordinates and then in *abc* variables using Clarke's transformation. This method does not take zero sequence components and hence the effect of unbalanced voltages and currents into account. The IRPT is widely used for three-phase balanced non-linear loads, such as rectifiers.

2.3. Single-phase instantaneous reactive power

The application of active power filters in a single-phase system independent of load level also needs the reference waveform of harmonics in load current. In single-phase PQ theory, voltage and current waveforms are expressed in terms of their real and imaginary axis components, which could be corresponding to αβ

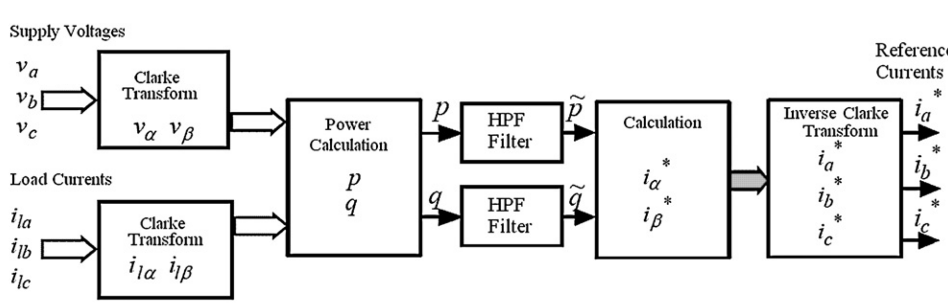

Fig. 2. Block diagram of IRPT method.