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HARMONIC DETECTION WITH NOTCH FILTER USING SWITCHED-CAPACITOR FILTER

Emre Özer

Istanbul University, Department of Electricity and Energy, Vocational School of Technical Sciences, Turkey

ABSTRACT

Harmonics pollution, due to the increasing use of nonlinear loads, such as converters and solid state switching devices, has become a serious problem in power systems. Active power filters have been used effectively to eliminate harmonic components generated by nonlinear loads. Precision of harmonic detection is one of the most important factors of active power filters. This paper describes a harmonic detection method to extract harmonic components in a distorted signal. Experimental results verify its validity.

Keywords: Power Quality, Active Harmonic Filters, Harmonic Detection, Notch filter, Switched-Capacitor Filter.

I. INTRODUCTION

The increasing application of power electronic devices has led to serious concerns about harmonic pollution and the resulting effects on power distribution systems and system equipment. Active power filters (APFs) are current method for mitigating the harmonic currents that causes technical and economic problems in power systems.

The phenomena of harmonic compensation by APFs proposed from the end of the 1960s to the 1970s [1-6]. APFs basically operate by detecting the harmonics and injecting these harmonics with the same magnitude but the opposite phase into the power system. The performance of an APF depends on the inverter characteristics, control strategy, and the accuracy of the reference signal. Obviously, fast and precise harmonic detection is one of the key factors to design APFs.

In recent years, a number of papers describing different techniques for obtaining reference signal have been published. These techniques can operate in frequency or time domain [7-15]. Such classification is given in Table I.

Table I: Classification of the most used harmonic detection methods in APF.

Domain	Harmonic Detection Method
Frequency Domain	Fourier Transform
Time Domain	Synchronous Detection Theorem
	Synchronous Reference-Frame Theorem
	Instantaneous power “pq-theory” and variants
	Sine-Multiplication Theorem

Harmonic detection by using Fourier transformation needs more than one cycle of input signal and also needs time for determination in the coming cycles. Therefore, the harmonic cancellation is delayed. Instantaneous p-q theory can only determine the harmonic current components under balanced load conditions.

All harmonic detection methods mentioned above have their own advantages and drawbacks. They are effective solutions, but all methods need a lot of time for the required determination, which usually is implemented with digital signal processor, hence the cost of the control system is too high.

This paper presents a new method to improve the performance of harmonic detection. The proposed circuit is implemented by using switched-capacitor filter (SCF) to obtain harmonic components from a distorted waveform. This circuit works as a notch filter. As the experimental results show, this circuit enables the harmonic detection with high precision and speed. Therefore the harmonic detection by using SCF is available to improve the compensation performance of active power filters.

II. HARMONIC DETECTION BY USING NOTCH FILTER

The proposed method basically works by filtering fundamental harmonic by using a band-pass filter and subtracting this fundamental component from distorted wave. The proposed harmonic detection method is shown in Figure-1.

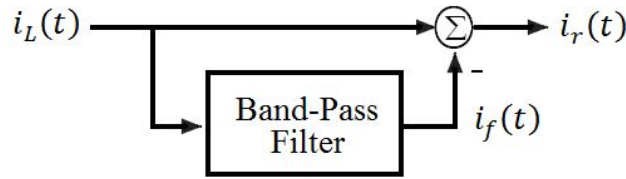


Figure-1: Notch filter by using band-pass filter

The reason for realizing a notch filter by using a band-pass filter is based on the fact that there is a big phase difference of the notch filter around the center frequency. In addition to the big phase difference, it is extremely sensitive to the frequency. Any small drift of the line frequency prohibits the complete compensation due to phase difference emerging from the notch filter.

In order to overcome this problem, a notch filter has been designed by using a switched-capacitor band-pass filter, which is the center of the system as described in Figure-2. The cutoff frequency can be adjusted by an external clock with a typical accuracy of $\pm 0.2\%$.

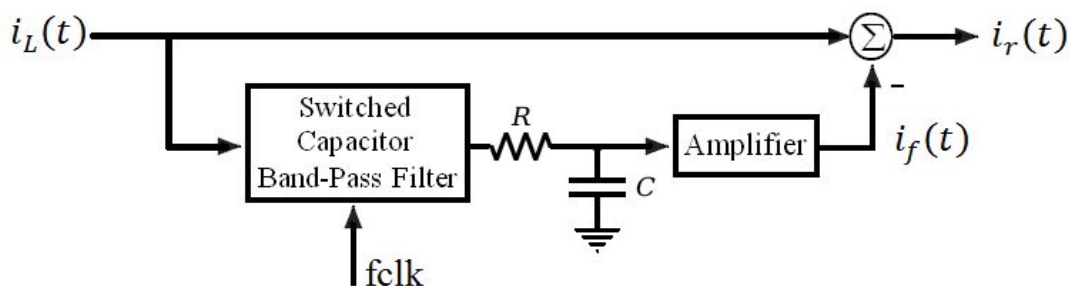


Figure-2: Notch filter by using switched-capacitor band-pass filter

The center frequency of band-pass filter is chosen equal to the line frequency, the bandwidth is 10 Hz and the total gain is 1 in the filter's pass-band. So the fundamental is passed without changing phase and magnitude, but the harmonics are suppressed. To obtain harmonic components, fundamental components are subtracted from the distorted signal.

A single pole RC filter is added in order to remove the high frequency components stemming from the clock at the output of the switched-capacitor filter. If the clock frequency is chosen much higher than the line frequency, then a simple RC filter will be sufficient to remove the high-frequency components. Amplifier is needed to adjust the gain of the total circuit to exact 1(0 dB). The phase shift of these circuits cannot be ignored. Therefore, the fundamental component of the distorted signal and the output of the amplifier are in phase.

With a fourth-order Chebyshev (0.1 dB) switched-capacitor filter, this method achieved 0.1% distortion factor.

III. CONTROL OF HARMONIC DETECTION CIRCUIT

Another problem in the power systems is the drift of the line frequency. When its frequency is changed, the SCF's center frequency must also be changed to track it. The center frequency of a switched-capacitor filter is a certain fraction of the frequency of a square-wave clock. This allows filter designs whose cutoff frequencies are variable over a wide range simply by changing the clock frequency [16]. To provide the SCF to follow the line frequency we have designed a clock generator circuit as shown in Figure-3 so that it is locked to the line frequency and the given circuit can be interpreted as a PLL.

The clock generator circuit consists of five basic functional blocks: two identical eight-order low pass filters, a voltage-controlled oscillator (VCO), a phase-frequency detector (PFD) and a loop filter (LF).

The PFD compares the phase of sine wave at the output of the amplifier with the phase of the fundamental component of reference signal and develops an output signal that is proportional to the phase error. To reject the harmonics of the reference signal before applying it to the PFD an eight order low-pass filter is used. The latter is used to equalize the phase of both signals at inputs of PFD.

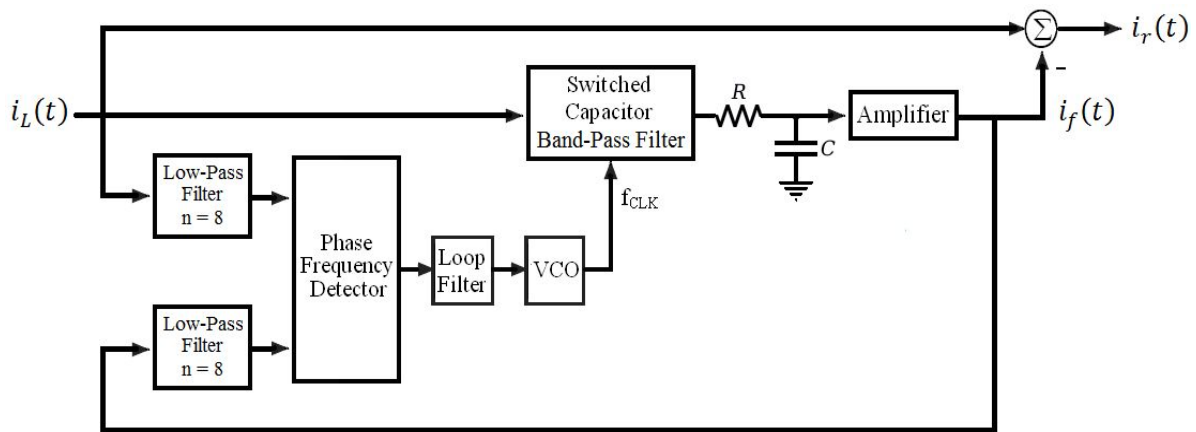


Figure-3: A novel notch filter that its center frequency can follow the line frequency

The output signal of the PFD consists of a dc component and an undesired ac component. Hence ac component is canceled by the loop filter. For this application a first-order, low-pass filter is used. And the VCO oscillates at an angular frequency, which is determined by the output signal of the loop filter.

Considering the operation of the circuit, there are some similarities with a phase locked loop. First we assume that the phase of sine wave at the output of amplifier is equal to the phase of fundamental component of distorted signal. If phase error is zero, the output of the PFD must also be zero. Consequently the output signal of the loop filter will also be zero. This means that the VCO remains to operate at its center frequency. If the phase error was not zero initially, then output of the PFD would develop a nonzero output signal. After some delay the loop filter would also produce a finite signal. Then VCO changes its operating frequency in such a way that the phase error finally vanishes.

Finally, by adding fundamental component sine wave with the same magnitude but the opposite phase into the distorted signal, the harmonic components can be obtained.

IV. EXPERIMENTAL RESULTS

Figure-4 shows the experimental set-up for testing the proposed method. The filter, an MAX267, is a commercially available switched-capacitor that includes two second-order filters. It is operated with ± 5 V power supplies. An input clock and 5-bit programming input sets precisely the filter clock/center frequency ratio. Quality factor Q is also programmed from 0.5 to 64. The MAX267 operates with center frequency up to 57 kHz by employing lower clock/center ratios. In this study, we choose a clock frequency 5 kHz and clock/center ratio 100. The 3 dB cutoff frequency of the RC filter is placed at 70 Hz.

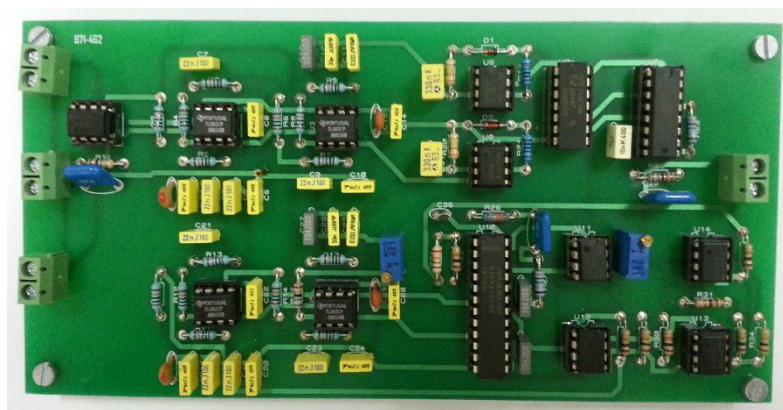


Figure-4: Circuit board

Waveforms are made with Data Acquisition Hardware and LabVIEW software [17]. Figure-5 shows a computer power supply current waveform and its harmonics derived from this circuit. Distortion factor of sine wave at the output of SCF filter, as measured with an HM 8027 distortion meter, is 0.1% [18].

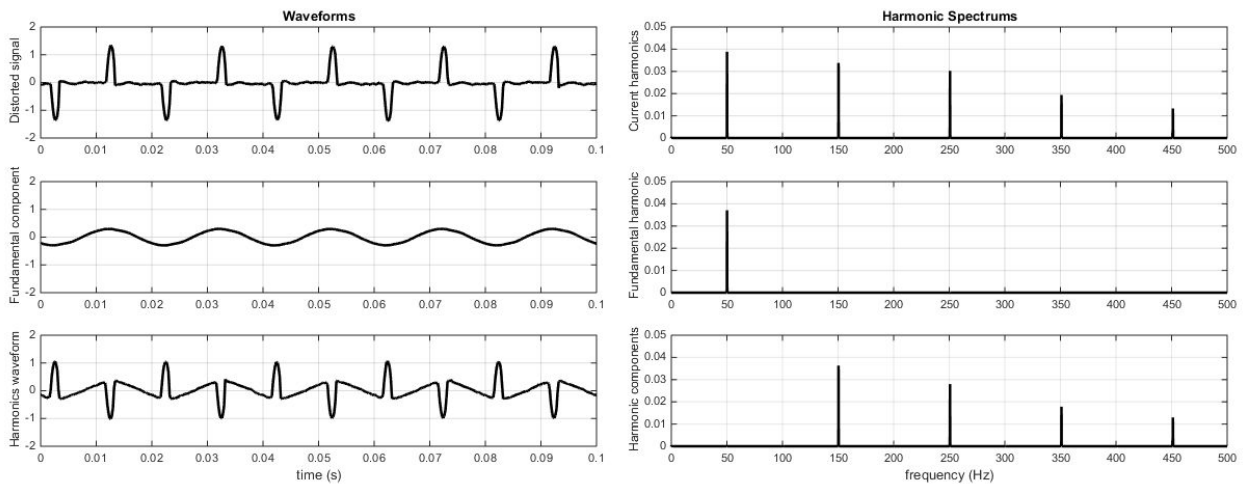


Figure-5: Waveforms and harmonic spectrums

The main part of the system is band-pass filter that consists of switched-capacitor band-pass filter, RC low-pass filter and amplifier. At the same time, the clock frequency of the switched-capacitor band-pass filter is controlled by a feedback circuit. So, the center frequency of the band-pass filter always follows the line frequency.

V. CONCLUSION

In this study, a real-time harmonic detection method for single phase active power filters has been presented. The proposed method basically works by filtering the fundamental component of distorted wave and subtracting this fundamental component from distorted wave. This method uses a fourth order switched capacitor bandpass filter. Its center frequency is set the line frequency, and gain is 1 in pass band. A clock generator circuit is designed for tracking the line frequency. So, the harmonics are suppressed but the fundamental is passed without changing phase and magnitude. The fundamental component of a distorted signal with 0.1% total harmonic distortion was obtained at the output of switched-capacitor filter. As the experimental results show, this circuit enables the harmonic detection with high precision and speed.

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