Study on UPF Harmonic Current Detection Method Based on DSP

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Abstract. Unity power factor (UPF) harmonic current detection method applied to active power filter (APF) is presented in this paper. The intention of this method is to make nonlinear loads and active power filter in parallel to be an equivalent resistance. So after compensation, source current is sinusoidal, and has the same shape of source voltage. Meanwhile, there is no harmonic in source current, and the power factor becomes one. The mathematic model of proposed method and the optimum project for equivalent low pass filter in measurement are presented. Finally, the proposed detection method applied to a shunt active power filter experimental prototype based on DSP TMS320F2812 is developed. Simulation and experiment results indicate the method is simple and easy to implement, and can obtain the real-time calculation of harmonic current exactly.

1. Introduction

With the proliferation of nonlinear loads, a mass of harmonic current and reactive power flow into network, their contributions to the waveform distortion degrade power quality in power transmission and distribution systems. Active power filter (APF) is an effective means that can be used to suppress harmonics and compensate reactive power dynamically [1], and its operating principle is to infuse a current that has equal amplitude and opposite phase to harmonics of load current into network, thereby, the aim to suppress harmonics and purify network is achieved.

The real-time and exact harmonic current detection is the basis to implement APF. Presently, the detection method based on the instaneous reactive power theory is used frequently. This method has some inevitable limits such as complicated coordinates transform, vast calculation, and application to balanceable three-phase sinusoidal circuit [2]. This paper discusses amply the UPF harmonic current detection method, and the optimum project is presented for low-pass filter that can affect the accuracy of detecting. Then, the MATLAB/SIMULINK is used to simulate the proposed detection method. Finally, in order to ascertain the viability of the proposed detection method, a shunt active power filter prototype based on DSP is developed and tested in the laboratory. The simulation and experimental results indicate that this method is simple and easy to implement, and can obtain the real-time calculation of harmonic current exactly.

2. UPF harmonic current detection method

2.1. Principle introduction

The intention of this method is to make nonlinear loads and APF in parallel to be an equivalent resistance. Suppose source voltage is sinusoidal, it can be expressed as

\[ u_s = U_m \sin \omega t \]  

(1)
If the impedance of load-link is resistant, so after compensation, source current can be expressed as
\[ i_s = k u_s = k U_m \sin \omega t \]  
where \( k \) is multiple load (combination of nonlinear load and APF) conductance. After compensation, source current is sinusoidal, having the same shape of source voltage and in phase with it. Meanwhile, there is no harmonic in source current, and the power factor becomes one.

Suppose Fourier Transform of source current before compensation can be expressed as
\[ i_s = \sum_{n=1}^{\infty} I_n \sin(n \omega t + \varphi_n) = ku_s + i_q(t) \]  
where \( i_q(t) \) does not bring active power, namely
\[ \frac{1}{T} \int_0^T u_s i_q(t) dt = 0 \]  
Brings equation (3) into equation (4), so
\[ k = \frac{1}{T} \int_0^T u_s i_s(t) dt = \frac{u_s i_s}{u_s^2} \]  
where the integrals of \( u_s i_s \) and \( u_s^2 \) in single period are equal respectively to the products of their dc components and integral period.

Active power components of current is computed as
\[ i_p(t) = ku_s(t) \]  
Generalized reactive power current (sum of fundamental reactive power current and harmonic current) can be expressed as
\[ i_q(t) = i_s(t) - i_p(t) = i_s(t) - ku_s(t) \]  

The schematic diagram of detection of harmonic and reactive power currents is shown in figure 1, hereinto, the low pass filters can be used to obtain the dc components required in this detection technique.

![Figure 1. The schematic diagram of detection of harmonics and reactive power current.](image)

It is known that this detection method is simply and feasible, besides, can be applied to either three-phase or single-phase circuit [5]. Meanwhile, the design of low pass filter (LPF) will affect the accuracy of detecting.

2.2. The optimum project of low pass filter
Compared to inherent time lag of low pass filter (LPF), the development of high performance microprocessor ignores the time lag of calculation in various detection methods. The dynamic response speed of detecting lies mostly on inherent time lag of LPF. The main factors that affect characteristic of digital filter are the type, the order and the cut-off frequency of filter.

Butterworth filter, Chebychev filter, Bessel filter and Elliptic filter are typical filters. The dynamic response speed and static detection error represent performances of detecting circuit. Given attention to two aforementioned facets, when the cut-off frequency is none too high, Butterworth filter is proposed which has best frequency characteristic at zero [6].

The choice of cut-off frequency has great impact on harmonic current detection in figure 1. Theoretically, the smaller is the cut-off frequency, the higher is the detection accuracy. But, dynamic
response becomes slower. Hence, considering desires of dynamic response and detection accuracy, generally, the cutoff frequency at 20Hz~40Hz can satisfy detecting demands [7].

Otherwise, the order of LPF has also great effect on harmonic current detection. LPF with the same cut-off frequency is characterized by increasing detection accuracy with increasing order, but corresponding time log will become bigger. Besides, high order LPF shall add the components of LPF and increase the cost. In practical circuit design, the order of LPF should not over third [7].

Conclusions testify that the second-order Butterworth LPF with the cut-off frequency at 20Hz~40Hz has better characteristic.

3. MATLAB simulation
The proposed method is simulated using MATLAB7.0/SIMULINK6.0. Various typical simulation results are obtained under ideal mains voltage conditions. Source voltage \( u_s(t) \) employs ideal sine wave having a frequency of 50Hz and amplitude of 5V, and second-order Butterworth LPF with the cut-off frequency at 20Hz is proposed in simulation.

As shown in figure 2, ideal square wave is used as the simulation signal of source current \( i_s(t) \) before compensation, having a frequency of 50Hz and amplitude of 2.5A. Otherwise, nonlinear rectifier is general harmonic source in network. So that harmonic current detection of a single-phase fully-controlled rectifier with resistive load is simulated as an example in figure 3.

![Figure 2](image-url)

**Figure 2.** Source current \( i_s(t) \), source voltage \( u_s(t) \), harmonics and reactive power current \( i_q(t) \), fundamental active power current \( i_p(t) \), using square wave as source current.

![Figure 3](image-url)

**Figure 3.** Source current \( i_s(t) \), source voltage \( u_s(t) \), harmonics and reactive power current \( i_q(t) \), fundamental active power current \( i_p(t) \), using a single-phase fully-controlled rectifier (control angle is 60°) as harmonic source.

Simulation results show that harmonics of source current are detected exactly, and active power components of source current is sinusoidal, having the same shape of source voltage and in phase with it.

4. experiment verification

4.1. Hardware configuration
Shunt APF based on DSP is implemented as a experimental prototype to ascertain the viability of the proposed detection method. The complete schematic diagram of the proposed shunt active power filter is shown in figure 4. The APF consists of four main parts, AC sampling circuit (including transformer and signal processing circuit), DSP TMS320F2812, isolation and driver circuit, and main circuit based on IGBT.

As shown in figure 4, transformer and signal processing circuit sample the voltage and current. The harmonic detection method is implemented on DSP to obtain the reference current \( i^*_c \) and then DSP gives PWM output (TMS320F2812 has the inherent function of PWM output), which can control the switching of IGBT to generate the actual compensation current \( i_c \). In addition, a single-phase
fully-controlled rectifier is used as a nonlinear load that generates harmonics and requires reactive power. A voltage source PWM converter with a dc bus capacitor is used as an APF and the main circuit of APF is built on IGBT. DC-link voltage processing keeps dc-link voltage of PWM converter invariable. Also, due to slow response, control strategy adopts PI control.

![Diagram](image)

**Figure 4.** Schematic diagram of the proposed shunt active power filter.

### 4.1.1. AC sampling circuit.
Potential transformer and current transformer sample source voltage and load current, and the amplitude of the output dc voltage of signal processing circuit ranges from 0V to 3V, and this is required by DSP’s ADC. Here, potential transformer and current transformer select HPT304 and HCT255 respectively, which are used generally in exact measure. The core of signal processing circuit is operation amplifier TLC2274. With the characteristics of low noise and high input impedance, TLC2274 is used generally to amplify tiny output signals of sensors.

### 4.1.2. DSP.
TMS320F2812 is a 32 bit pointing DSP designed newly by TI, having the main frequency of 150Hz [8]. In proposed shunt APF, three functions are implemented on DSP, including A/D conversion, realization of control algorithm (detection method and PI control) and PWM outputs. 12-bit analog-to-digital converter (ADC) obtains simultaneous samples of source voltage and load current. Meanwhile, fast conversion period of 80ns ensure accuracy and real time of sampling. Detection algorithm is implemented by programming on TMS320F2812. Two event manager modules (EV) generate simultaneously 2 × 8 channels PWM signals, with external-maskable power and drive-protection interrupts. So, desired configure of EV can generate PWM outputs to control the switching of IGBT. Besides, serial port peripherals composed of CAN, SCI and SPI can accomplish communication easily.

### 4.1.3. Main circuit of APF.
In practice, main circuit of APF consists of intelligent power module (built-in inherent isolation and drive circuit), dc-link capacitor and ac-link inductance. Here, dc-link capacitor acts as a constant voltage source, and ac-link inductance and the network are in parallel to generate a compensation current that has equal amplitude and opposite phase to harmonics of load current. Intelligent power module (IPM) selects MISUBISHI ELECTRIC PM15RSH120, designed for power switching applications operation at frequencies to 20kHz. Built-in control circuits provide optimum gate drive and protection for the IGBT. Protection logic consists of short circuit, over current, over temperature and under voltage.

Furthermore, the complete system should have other peripheral circuits to ensure the order of system, such as power supply circuit, watchdog-monitoring circuit, LCD circuit, and a series of communication circuits.
4.2. Experiment results
Proposed detection method is applied to the aforementioned experimental prototype, and experiment results are shown in Figure 5. Hereinto, the control angle $\alpha$ of single-phase rectifier is 60°.

![Figure 5. Load current $i_L(t)$, harmonic and reactive power current $i_q(t)$, actual compensation current $i_c(t)$, source voltage $u_S(t)$, and source current $i_S(t)$ waveforms for harmonics compensation.]

As shown in Figure 5, compared to simulation, the results of harmonic current detection coincide with simulation results in steady state, but have a break in transient state. After compensation, source current is sinusoidal, and has the same frequency and phase with source voltage. Experimental results testify that UPF harmonic current detection method based on DSP is effective and feasible.

5. Conclusion
A harmonic current detection method based on UPF is proposed for the compensation of harmonics and reactive power. Various typical simulation results are obtained under ideal mains voltage conditions. An experimental prototype is developed and tested to ascertain the viability of the proposed method. Based on simulation and experimental results, the following conclusions are drawn.

- The proposed method provides real-time detection of harmonics and reactive power current quickly.
- It has no use for fuzzy coordinates transform and calculation, compared to the detection method based on the instantaneous reactive power theory.
- It works effectively in steady state.
- It is applicable for both three-phase as well as single-phase systems.

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