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Active Power Filter Control Using Adaptive Signal Processing Techniques

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ABSTRACT

In this paper a new Active Power Filter (APF) control method is proposed. Computation of the load harmonic compensation current is performed by the adaptive notch infinite impulse response (IIR) filter. Performance of the proposed scheme has been verified by computer simulation. MATLAB/SIMULINK power system toolbox is used to simulate the proposed system. The simulation results are presented and confirmed the effectiveness of the proposed method.

Keywords: Active Power Filter; Nonlinear Load; Harmonics

1. Introduction

The widespread use of nonlinear devices within the industrial, commercial and residential sectors has resulted in substantial reduction of power quality in electric power systems. Harmonic distortion produced by nonlinear loads causes several problems, such as increased power losses in customer equipment, power transformers and power lines, flicker, shorter life of organic insulation [1]. In recent decades, passive and active harmonic filters have been recognized as the most effective solutions for harmonic mitigation.

The passive harmonic filters (PHF), consisting from capacitors, inductors and resistors have been traditionally used for this task [1, 3]. The main advantages of PHF are design simplicity and low cost. They don't require a regular service and can correct the power factor. But PHF have many disadvantages, such as fixed compensation characteristics, large size and resonance problems.

In recent years, active power filters (APF) have been widely investigated for the compensation of harmonic currents. APF allow to compensating the harmonics and unbalance, together with power factor correction. Modern active harmonic filters have superior filtering characteristics, smaller in physical size, more flexible in application compared to their passive counterparts. They are widely used in industrial, commercial, utility networks and in electric traction systems [1, 2].

Calculation of compensating signals is the important part of APF control and affects their transient as well as steady-state performance. Different control methods have been proposed, ranging from the use of fast Fourier transform (FFT) to the instantaneous P-Q theory, artificial neural networks and adaptive notch filters.

In this paper, an efficient method to obtain compensating signals for the active harmonic filter is considered. The load harmonic compensation is performed by using the lattice-form adaptive notch IIR filter. Simulation results confirm the effectiveness of the proposed method.

2. Shunt Active Power Filter

The active power filters are basically classified into two types: the shunt type and the series type. One of the most popular active power filters is the shunt APF. It's advantages are good current control capability, easy protection, and high reliability over series filters. The single-phase operation scheme of a shunt active filter is shown in **Figure 1**.

For each harmonic of order *h* the nonlinear load is presented by the equivalent Norton circuit, which consists of the current source I_{Lh} with in-parallel impedance Z_{Lh}. The grid is presented by the Thevenin equivalent, which consists of the voltage source U_G with series impedance Z_G.

The shunt active power filter compensates current harmonics by injecting equal but opposite harmonic compensating current, so that the compensated current is

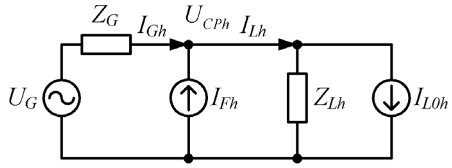

Figure 1. Operation scheme of shunt active filter.

approximately a pure sinusoid. In this paper, we do not consider the actual realization of the active filter. It is assumed to be an ideal controlled current source, proportional to the harmonic components of the load current

$$I_{Fh} = KI_{L0h}$$
$$I_{Gh} = I_{Lh} - I_{Fh}$$

where I_{Lh} is the harmonic of distorted load current, and I_{Gh} is the harmonic of the grid current. The compensating current is proportional to the distorted load current with subtracted fundamental component.

For h harmonic the coupling point voltage U_{CPh} as a function of the load current I_{L0h} can be deduced as:

$$U_{CPh} = \frac{(K-1) Z_{Lh} Z_{Gh}}{Z_{Lh} + Z_{Gh}(1-K)} I_{L0h} \tag{1}$$

Equation (1) shows the coupling point voltage $U_{CPh} \approx 0$ if the parameter K approaches one. In the ideal case K should equal zero for the fundamental harmonic and one for all other harmonics.

3. Calculation of Compensating Signal

The control strategies to generate compensating signals are based on the frequency-domain or time-domain techniques [1, 2, 4, 5].

Control strategy in the frequency domain is based on the Fourier analysis of the distorted current or voltage. The high-order harmonic components are separated from distorted signals and combined to form compensating commands. But the discrete Fourier transform (DFT) loses accuracy in non-stationary situations.

The first group includes calculation methods in frequency domain. Strategy of such control methods is based on the Fourier series: discrete Fourier transform (DFT), fast Fourier transform (FFT).

Commonly used calculation methods in the time domain are the instantaneous active and reactive (P-Q) theory approach, neural network theory, notch filter approach, adaptive signal processing. Most of these algorithms have a much better dynamic response than the DFT.

4. Adaptive IIR Notch Filter

Notch filters have a variety of applications in the field of signal processing for removing single frequency or narrow-band sinusoidal interference.

The magnitude characteristic of the ideal notch filter is defined as:

$$H\left(e^{j\omega}\right) = \begin{cases} 1 & \omega \neq \omega_0 \\ 0 & \omega = \omega_0 \end{cases} \tag{2}$$

where ω_0 is the notch frequency. Notch filter extracts fundamental sinusoid from distorted current waveform without harmfully phase shifting of the high-order harmonics. The ideal notch filter has zero bandwidth. However, zero bandwidth cannot be realized in practice.

The most simple type of adaptive notch digital filter is adaptive line enhancer (ALE) proposed by B. Widrow [6]. The structure of ALE is shown in **Figure 2**.

The adaptation of the finite impulse response (FIR) filter is realized by using the least mean square (LMS) algorithm. Disadvantages of this ALE are a relatively low convergence speed and potential instability.

An infinite impulse response (IIR) filter provides a sharper magnitude response than the FIR adaptive line enhancer. Also it requires much smaller filter length, than the ALE based on FIR filter.

The transfer function of the second order notch IIR filter is defined as:

$$H(z) = \frac{z^2 + a_1 z + 1}{z^2 + \lambda a_1 z + \lambda^2} \tag{3}$$

where λ is the pole zero contracting factor. In general, λ should be close to unity to well approximate Equation (2).

As shown in [7] the transfer function of a single frequency notch filter can be expressed in the form:

$$H(z) = \frac{1}{2}\left[1 + A(z)\right] \tag{4}$$

where $A(z)$ represents a transfer function of the all-pass IIR filter.

The structure of notch filter based on all-pass IIR filter is presented in **Figure 3**.

A lattice-form realization of all-pass transfer function is shown in **Figure 4**.

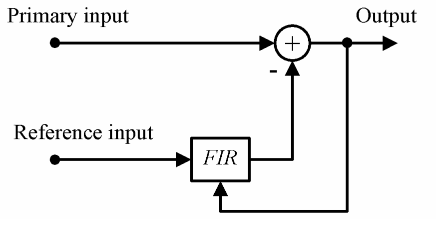

Figure 2. Structure of ALE.

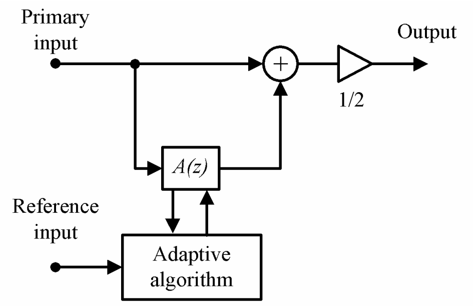

Figure 3. Structure of the notch filter.

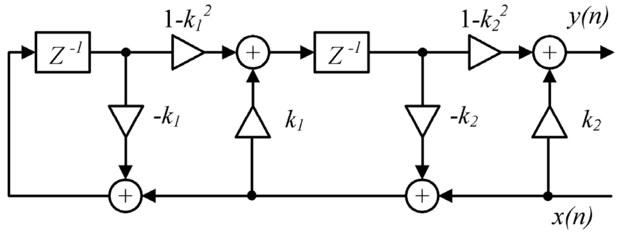

Figure 4. All-pass lattice IIR filter.

In **Figure 4** *x(n)* and *y(n)* are input and output signals, respectively. Transfer function of the lattice IIR filter is the following:

$$A(z) = \frac{Y(z)}{X(z)} = \frac{z^{-2} + k_1(1+k_2)z^{-1} + k_2}{k_2 z^{-2} + k_1(1+k_2)z^{-1} + 1} \tag{5}$$

The polynomials of nominator and denominator of Equation (5) have mirror symmetry. Accordingly, lattice IIR-filter realizes all-pass transfer function with module equal 1 in the all frequency range.

Transfer function of notch filter, shown in **Figure 3** is presented as:

$$H(z) = \frac{1}{2}\frac{\left(z^{-2} + 2k_1 z^{-1} + 1\right)\left(1+k_2\right)}{k_2 z^{-2} + k_1(1+k_2)z^{-1} + 1} \tag{6}$$

where k_1 is the adaptive coefficient, which should converge to $-\cos\omega_0$ to reject a sinusoid with frequency ω_0. Frequency suppression of notch filter can be modified by k_1 and stopband width by k_2.

Adaptive IIR filter in **Figure 3** is adapted using adaptive algorithms related to the lattice FIR filters. The structure of the lattice second-order FIR filter is shown in **Figure 5**. In this article gradient lattice algorithm [8] is used for adaptation purposes. It has been chosen because of its low complexity and high-speed convergence. Update of the coefficients k_1 and k_2, using gradient algorithm, is given as follows:

$$k_i(n+1) = k_i(n) - \frac{2\mu}{D_i(n)}\left(e_i(n) r_{i-1}(n-1) + e_{i-1}(n) r_i(n)\right)$$

where μ is an adaptation step. Parameter $D_i(n)$ is defined as:

$$D_i(n) = \beta D_i(n) + e_{i-1}^2(n) + r_{i-1}^2(n-1)$$

where β is a forgetting factor: $0 < \beta < 1$.

5. MATHLAB-Based Simulation

The system was simulated using MathLab/Simulink to verify the proposed algorithm. Schematic diagram of the proposed controlled shunt APF is shown in **Figure 6**. The linear load is defined as resistance Rlin = 100 Ohms, non-linear load includes two rectifiers with RL load on the dc side. Simulation process is divided into steps: connection of the first rectifier, connection of APF and connection of the second rectifier. All simulation process is presented in **Figure 7**.

The performance of the APF is analyzed by considering of the following cases.

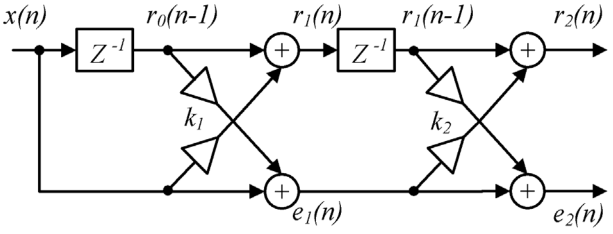

Figure 5. FIR lattice filter.

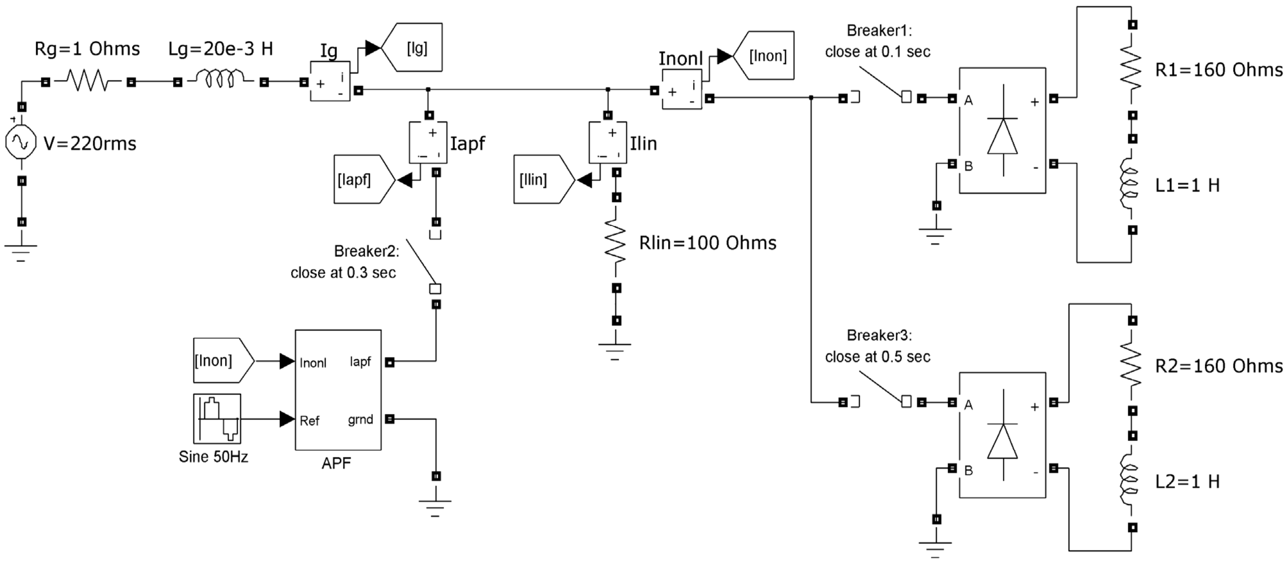

Figure 6. MATHLAB scheme of shunt APF system.

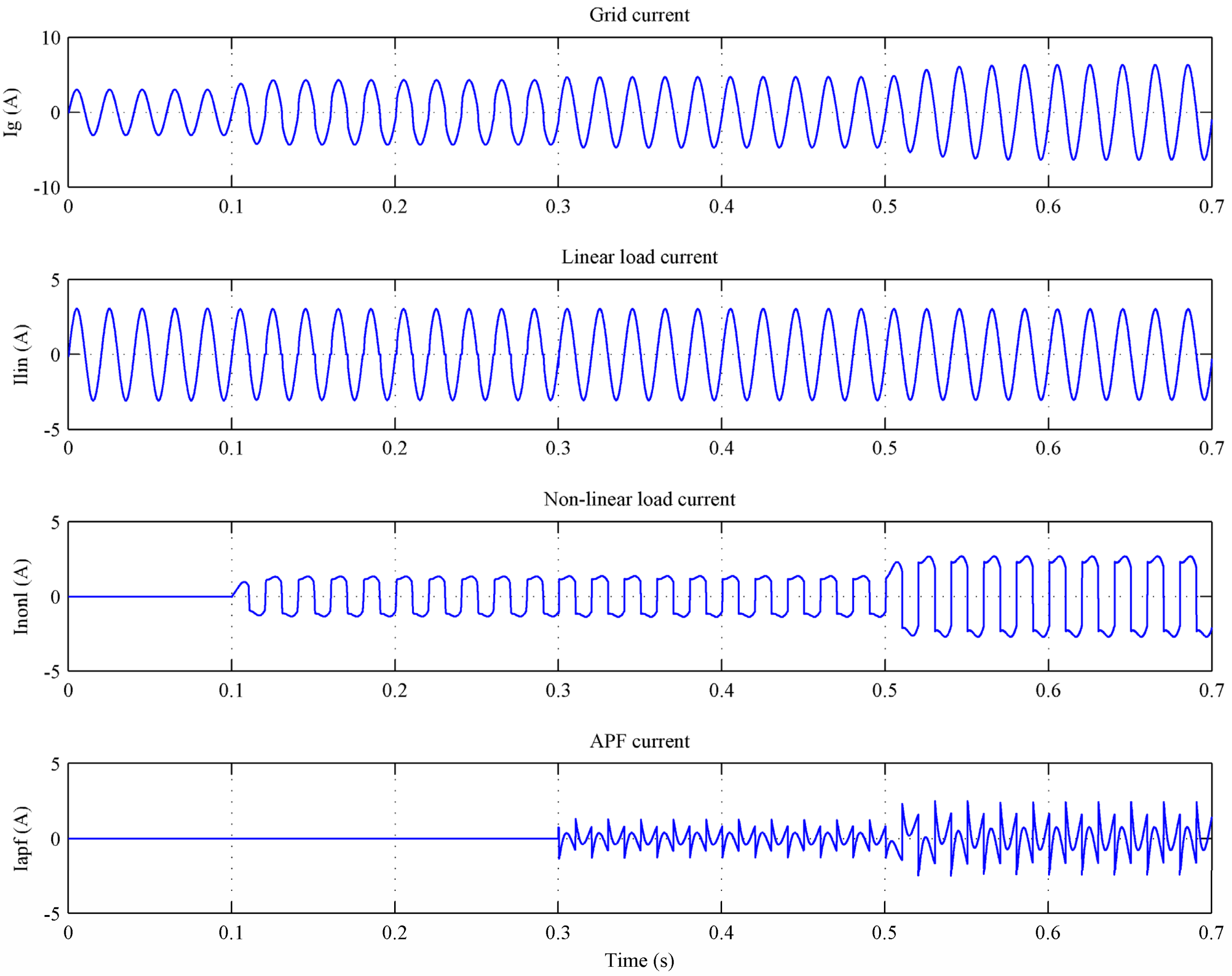

Figure 7. Simulation results.

5.1. Case 1

As shown in **Figure 6** in t = 0.1 sec the first rectifier is connected to the grid. In the 0.3 sec the shunt APF is connected to the grid and starts compensating harmonics component of the non-linear load current. Changing of THD is demonstrated in the **Table 1**. Grid, linear load and non-linear load currents are presented in **Figure 7**.

5.2. Case 2

The nonlinear load is increased in t = 0.5 sec. Proposed technique of calculation compensation signal operates properly without severe transients at the instants of step load change. THD is presented in **Table 2.**

6. Conclusions

In this paper, a novel adaptive method for grid current harmonic compensation is proposed. The load harmonic compensation was performed by using the lattice-form adaptive notch IIR filter. It was shown that adaptive

Table 1. THD before and after 0.3 sec.

Signal name	THD %	
	Before	After
I g	11.29	1.35
I lin	5.44	0.64
I nonl	34.79	40.32

Table 2. THD before and after 0.5 sec.

Signal name	THD %	
	Before	After
I g	1.35	1.98
I lin	0.64	1.14
I nonl	40.32	40.28

notch filter can be successfully employed in active harmonic filter for the sake of harmonic mitigation. The proposed approach does not need any training of the notch filter. Performance of the proposed control system is verified by computer simulation. MATLAB/SIMULINK power system toolbox is used to simulate the proposed system. The simulation results are presented showing the effectiveness of the proposed method.

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