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Harmonic Fractional Detection Based on The LMS Algorithm

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Abstract

In the power system, there are many power electronic equipment in use. There are a lot of harmonics in the power system because of their nonlinear properties. These harmonics have a huge impact on the power grid. To filter out these harmonics, some harmonic detection methods are needed. This work suggests using the LMS algorithm to detect each harmonic in order due to the complexity of all current harmonic detection algorithms or the fact that only the total harmonic components other than the fundamental wave may be discovered. This technique can quickly determine the amplitude and phase size of each harmonic component in addition to having a straightforward procedure. By creating a Matlab Simulink simulation model, the efficacy of this approach is confirmed.

Keywords

Harmonic fractional detection; LMS algorithm; Matlab Simulink simulation.

1. INTRODUCTION

Many converters, switching power supplies, and reactors are finding more applications as a result of the quick advancement of power electronics technology. Due to the extensive application of power electronic devices in the power system, a large number of nonlinear loads have emerged, and the resulting harmonic pollution has become increasingly serious, resulting in a serious distortion of the power system voltage and power, affecting the normal operation of instruments and meters, increasing the loss of power components, and endangering the safe operation of the power system [1-3]. Therefore, how to improve power quality and control harmonics has become one of the most urgent issues in power transmission and distribution technology. To suppress harmonics and compensate for reactive current in the power grid, many new reactive power compensation devices and active power filter devices have emerged in recent years. The requirement for their successful application is whether the harmonics in the system can be detected fast and precisely [4-6].

Common harmonic detection algorithms have their advantages and disadvantages: the fast Fourier transform (FFT) algorithm has high accuracy, but slow response speed [7-8]; The $i_p - i_q$ algorithm has strong real-time performance, but needs 3/2 transformation, and cannot represent zero-sequence components [9-10]; The $d - q$ algorithm requires multiple spatial transformations, and the algorithm implementation is relatively complex [11]. Although some novel harmonic current detection algorithms such as neural network algorithms and genetic algorithms have excellent characteristics, their design, and implementation are complex and have not been widely applied [12-13]. The adaptive harmonic detection method has strong anti-interference performance independent of component parameters, low computational

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complexity, and strong tracking ability. Its weight coefficient can be adjusted to the best according to the actual situation, especially suitable for real-time processing of harmonic problems [14-15]. The traditional adaptive harmonic current detection can only detect the fundamental wave and the harmonic components other than the fundamental wave. In some cases, it is necessary to detect the harmonic components of each order. For example, the hybrid system combined with an active power filter and passive power filter needs to detect the specified order of harmonics to better play the filtering effect, At the same time, it is also necessary to detect the specific harmonic current in power quality assessment and auxiliary relay protection device to judge the fault point and fault type [16-17]. To solve the problems of previous harmonic detection methods, this paper proposes an adaptive harmonic fractional detection method based on the LMS algorithm. This method can not only detect the specified harmonics but also has the advantages of simple structure and small computation in the detection algorithm.

2. THE BASIC PRINCIPLE OF LMS ALGORITHM

Adaptive filtering is an optimal filtering algorithm developed based on Wiener, Kalman, and other linear filters. According to the change of external input characteristic quantity, the adaptive algorithm continuously adjusts its parameters to achieve accurate tracking of reference waveform [18-19]. Because of its superior filtering and adaptive performance, it has been widely used in engineering practice. At present, the adaptive filter has developed a variety of algorithm criteria: steepest descent method, recursive least square (RLS), linear prediction method, least mean square (LMS) method, etc. Because the LMS algorithm is simple and does not need to calculate the inverse matrix or correlation function, most of the research on adaptive algorithms now focuses on the LMS algorithm [20-21].

Figure 1 depicts the adaptive filter's operating principle. The input signal at time n is shown by $x(n)$ in Figure 1, the output signal at this time is shown by $y(n)$, the expected signal is shown by $d(n)$, and the parameters of the adaptive filter are adaptively adjusted by the difference between $d(n)$ and $y(n)$, so that the $y(n+1)$ at time $n+1$ can be closer to $d(n)$.

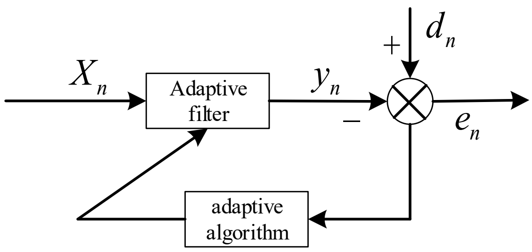

Figure 1. Schematic diagram of adaptive filter

The output signal of the filter is:

$$y(n) = W^T(n)X(n) = \sum_{i=1}^{M} w_i(n)x_i(n) \tag{1}$$

In formula (1), the input vector of the filter at time n is $X(n)$, the tap weight vector is $W(n)$, and the order of the filter is m.

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$$X(n)=[x(n),x(n-1),...x(n-M+1)]^T \tag{2}$$

$$W(n)=[w(n),w(n-1),...,w(n-M+1)]^T \tag{3}$$

The difference $e(n)$ between $d(n)$ and $y(n)$ can be expressed as:

$$e(n)=d(n)-y(n)=d(n)-W^T(n)X(n) \tag{4}$$

The mean square error is:

$$J=E[e^2(n)]=E[d^2(n)]-2E[d(n)W^T(n)X(n)+E[W^T(n)X(n)X^T(n)W(n)] \tag{5}$$

Through the steepest descent method, the weight vector $W(n)$ is adjusted in the opposite direction of the steepest descent direction and gradient direction of the performance surface. The iterative formula is (where μ is called the step factor):

$$W(n+1)=W(n)+\mu(-\nabla J) \tag{6}$$

To calculate the system's ideal Wiener solution using the steepest descent approach, information about the input and anticipated signals must be known. When the expected signal is uncertain, it is necessary to estimate the gradient vector.

The Gradient of the transient mean square error to instantaneous tap vector:

$$\hat{\nabla} J=\frac{\partial(e^2(n))}{\partial W(n)}=-2e(n)X(n) \tag{7}$$

Adjust the weight vector equation for the LMS adaptive filtering:

$$W(n+1)=W(n)+\mu(-\nabla J)=W(n)+2\mu e(n)X(n) \tag{8}$$

LMS adaptive filtering algorithm flow is as follows:

$$y(n)=W^T(n)X(n) \tag{9}$$

$$e(n)=d(n)-y(n) \tag{10}$$

$$W(n+1)=W(n)+2\mu e(n)X(n) \tag{11}$$

3. PRINCIPLE OF HARMONIC FRACTIONAL DETECTION BASED ON THE LMS ALGORITHM

The detected harmonics can be expanded into triangular series as follows:

$$i(n)=\sum_{i=1}^{L}X_i\sin(i\omega t+\varphi_i)=\sum_{i=1}^{L}[A_i\sin(i\omega t)\cos\varphi_i+B_i\cos(i\omega t)\sin\varphi_i] \tag{12}$$

In formula (12), ω is the fundamental angular frequency; X_i is the amplitude of the ith harmonic; A_i and B_i are the amplitude of the sine component and cosine component of the ith harmonic respectively; φ_i is the phase angle of the ith harmonic, and the amplitude and phase angle of the ith harmonic are respectively:

$$X_i = \sqrt{A_i^2 + B_i^2} \tag{13}$$

$$\varphi_i = \arctan\frac{B_i}{A_i} \tag{14}$$

The principle of harmonic fractional detection based on the LMS algorithm is shown in Figure 2. Where: ω is the fundamental angular frequency of the detected harmonic; $a_i(n)$ and $b_i(n)$ ($i = 1,\ldots,L$) represent the sine ($\sin(i\omega n)$) and cosine ($\cos(i\omega n)$) components of the second harmonic, and the values are adjusted with the LMS algorithm; $\hat{a}_i(n)$ and $\hat{a}_i(n)$ represent the converged values of $a_i(n)$ and $b_i(n)$; I_i and ϕ_i represent the amplitude and phase of the second harmonic respectively; y_i represents the ith harmonic detected; y_n is the total harmonic detected; i_n is the total harmonic detected; $e(n)$ represents the difference between i_n and y_n .

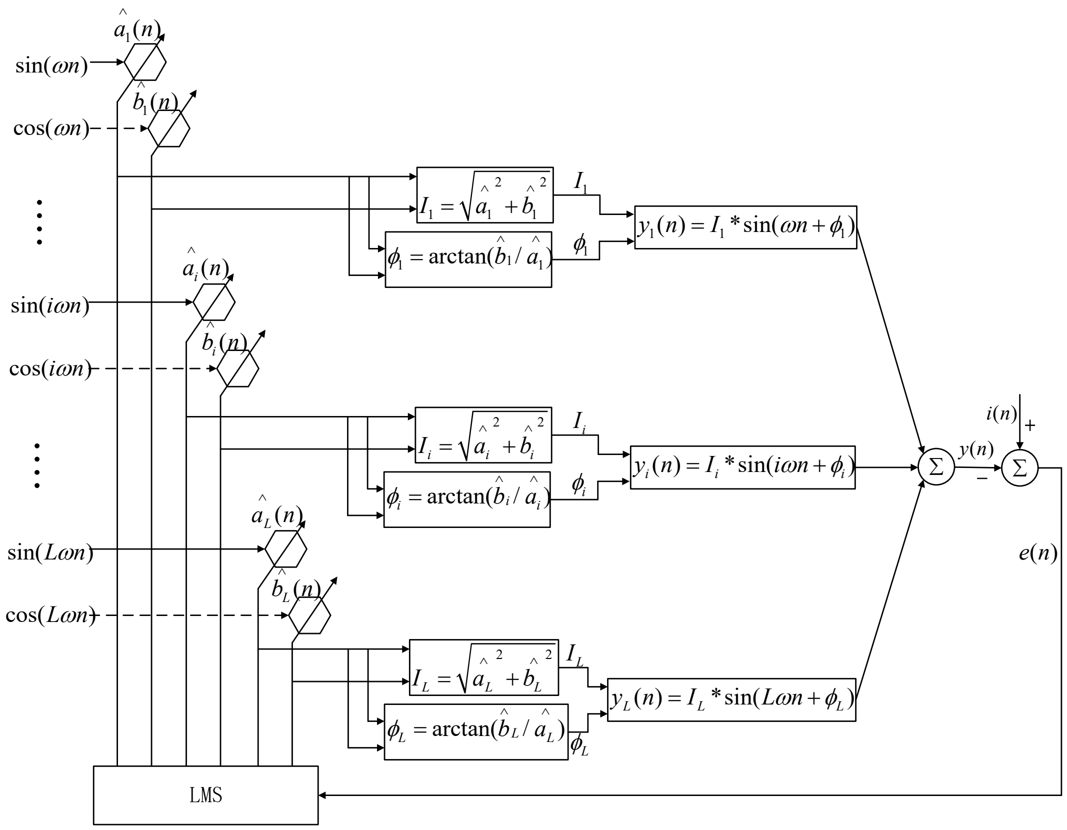

Figure 2. Schematic diagram of harmonic fractional detection based on the LMS algorithm

The total harmonic quantity $y(n)$ detected can be expressed as:

$$y(n) = W_n^T X_n \tag{15}$$

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$$X_n = [\sin \omega t, \cos \omega t, ...\sin i\omega t, \cos i\omega t ... \sin L\omega t, \cos L\omega t]^T \tag{16}$$

$$W_n = [a_1, b_1, ...a_i, b_i ... a_L, b_L]^T \tag{17}$$

The error between the actual harmonic and the detected harmonic is:

$$e(n) = i(n) - y(n) \tag{18}$$

The weight coefficient $W(n)$ is updated by formula (11). When $e(n)$ is small, a group of optimal weight coefficients can be obtained:

$$\hat{W}_n = [\hat{a}_1, \hat{b}_1, ...\hat{a}_i, \hat{b}_i ... \hat{a}_L, \hat{b}_L]^T \tag{19}$$

Therefore, the ith harmonic component detected is:

$$y_i(n) = \hat{a}_i * \sin i\omega t + \hat{b}_i * \cos i\omega t \tag{20}$$

According to the previous formula, the amplitude and phase angle of the ith harmonic component detected are:

$$I_i = \sqrt{\hat{a}_i^{\,2} + \hat{b}_i^{\,2}} \tag{21}$$

$$\phi_i = \arctan \frac{\hat{b}_i}{\hat{a}_i} \tag{22}$$

4. MATLAB SIMULINK SIMULATION OF FRACTIONAL DETECTION BASED ON THE LMS ALGORITHM

Table 1. Detected harmonic parameters

harmonic order	Amplitude/A	phase angle/rad
1	36	-1.22
3	23	-0.73
5	12	-0.19

To verify the effectiveness of the harmonic fractional detection method based on the LMS algorithm, a simulation model is built using Matlab Simulink, as shown in Figure 3. With reference to Reference [22], some harmonics are selected for detection. The harmonic number, amplitude, and phase angle of the detected harmonics are shown in Table 1. The simulation results of harmonic fractional detection based on the LMS algorithm are shown in Figure 4. Where (a) the green waveform in the figure is the detected fundamental component, the blue waveform is the detected fundamental component, the red waveform is the error between the two, (b) the figure is the amplitude of the detected fundamental wave, and (c) the phase angle of the detected fundamental wave; Where (d) the green wave in the figure is the detected third harmonic component, the blue wave is the detected third harmonic component, the red wave is

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the error between the two, (e) the figure is the amplitude of the detected third harmonic, and (f) the phase angle of the detected third harmonic; The green wave in (g) is the detected fifth harmonic component, the blue wave is the detected fifth harmonic component, the red wave is the error between the two, (h) is the amplitude of the detected fifth harmonic, and (i) is the phase angle of the detected fifth harmonic; The green wave in Figure (j) is the harmonic wave superimposed by the detected fundamental wave, the third harmonic wave and the fifth harmonic wave, the blue wave is the harmonic wave superimposed by the detected fundamental wave, the third harmonic wave and the fifth harmonic wave, and the red wave is the error between the two. From the simulation results, the harmonic fractional detection method based on the LMS algorithm can quickly detect the amplitude and phase of each harmonic, whether it is fundamental, third, or fifth harmonic.

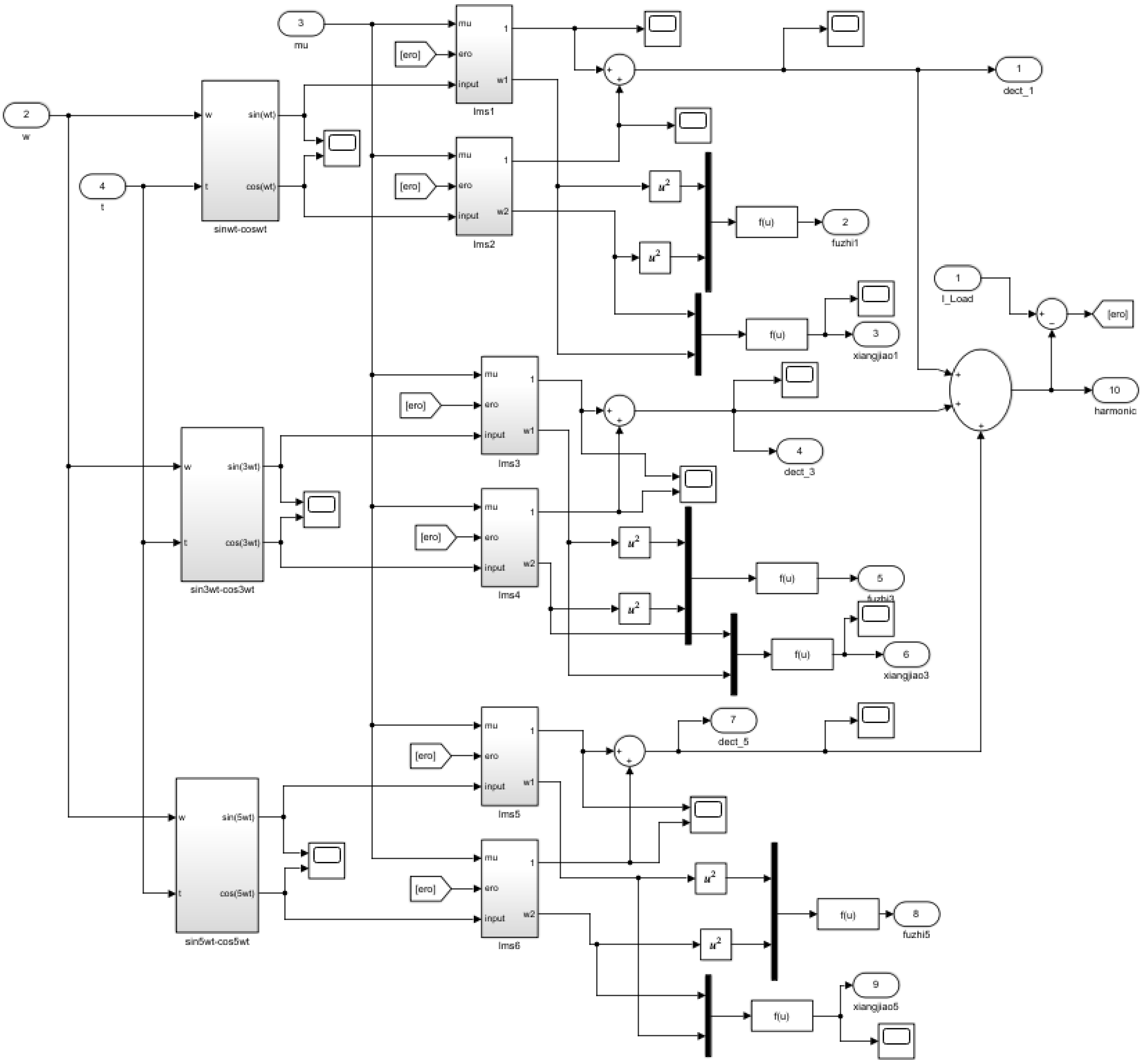

Figure 3. Matlab Simulink simulation model of harmonic fractional detection based on the LMS algorithm

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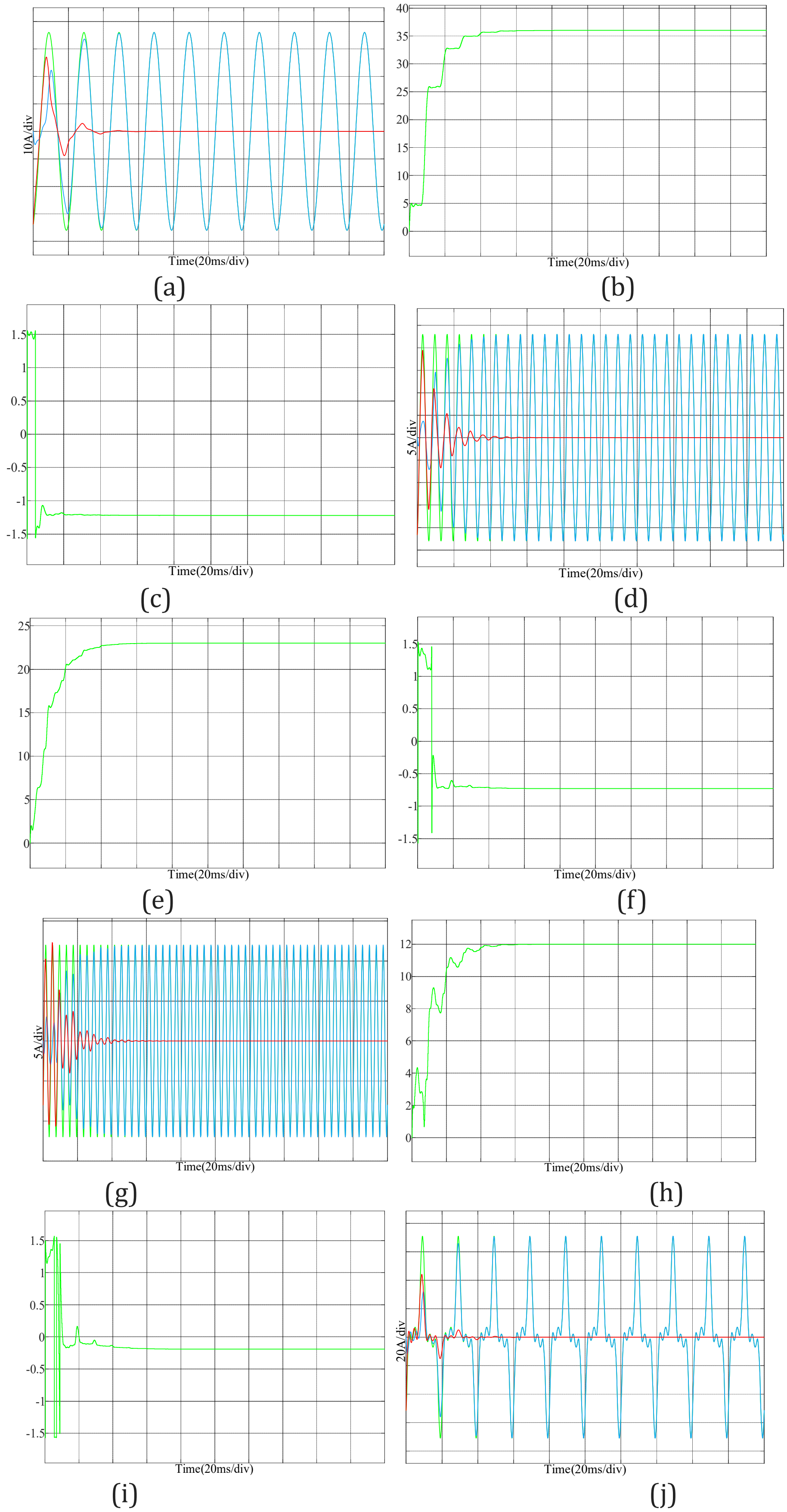

Figure 4. Simulation results of harmonic fractional detection based on the LMS algorithm by Matlab Simulink

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5. CONCLUSION

In this paper, some problems of common harmonic detection methods are introduced. Aiming at these problems, a harmonic fractional detection method based on the LMS algorithm with a simple structure and small calculation amount is proposed, and its principle and formula derivation are introduced. The harmonic fractional detection approach, which is based on the LMS algorithm, has a simulation model constructed in Matlab Simulink. The approach can quickly determine the amplitude and phase size of each harmonic component for the supplied fundamental, third, and fifth harmonic components. The outcomes demonstrate that the suggested harmonic fractional detection approach based on the LMS algorithm works as intended.

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