Power system harmonic processing method based on wavelet analysis

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Abstract. In order to effectively improve the power quality of the power system and reduce the harm caused by the harmonics generated by the power system to the operation of the power grid, the harmonic detection method based on Fourier transform can not realize the shortcoming of time-frequency domain analysis at the same time. Harmonics are analyzed. The wavelet transform is used to decompose the harmonic current in the power system to obtain the fundamental component and higher harmonic component of the signal. Aiming at the abrupt signal in power system, the singularity detection method based on wavelet transform is proposed. The effectiveness of the algorithm is verified by simulation examples. Furthermore, the MATLAB wavelet toolbox is used to decompose the fault signal of the power system, and further remove the high-order harmonics that affect the stable operation of the power system. The simulation results show that the harmonic processing method based on wavelet transform can effectively eliminate harmonics. Interference, protection of faulty lines, ensuring stable operation of the power system.

1. Introduction

In the signal analysis, since the high-frequency component of the reflected signal requires a narrow time window, the component reflecting the low-frequency of the signal requires a wide time window, and the Fourier transform cannot satisfy this requirement, so the wavelet theory is generated. Fourier can only analyze the signal in the frequency domain. The wavelet transform can simultaneously transform the signal in the frequency domain and the time domain, and can effectively analyze and implement the filtering of the harmonics. In power systems, due to the application of a large number of power electronic devices and non-linear components, such as various rectification equipment, converters, AC-DC converter equipment, PWM inverters, and other power electronic equipment for energy conservation and control, harmonic pollution is becoming more and more serious. The more serious it is, the more complicated it is. Harmonics cause additional losses in power equipment, reduce the efficiency of power generation, transmission and power equipment; cause grid resonance; cause relay protection and automatic device malfunction; cause interference to communication system near equipment, etc., seriously affecting power system safety and stability[1]. Harmonics is considered to be one of the three major public hazards in power systems. Therefore, research on eliminating high-order harmonics in power supply and distribution systems has a very positive significance for improving power supply quality and ensuring safe and economic operation of power systems.

The process of signal processing with wavelets is generally divided into four steps: sampling, decomposition, signal processing, and reconstruction. The principle of wavelet analysis is introduced in this paper, and the signal containing harmonics is filtered by Matlab software to reduce the
harmonics. Through the simulation of Matlab simulation, it can be seen that wavelet analysis can be applied well in high-order harmonic processing in power systems.

2. Wavelet Transform and Malat Algorithms

2.1 Signal Decomposition

Let \( \varphi(t) \in L^2(R) \) satisfy the scale function \( \{ \varphi_k(t), \varphi_k'(t) \} \geq \delta_k, k' \in Z \), which is derived from the two-scale equation,

\[
\varphi(t) = 2^{j/2} \sum_n h_0(n)\varphi(2t - n) 
\]
(1)

\[
\varphi(2^j t - k) = 2^{j/2} \sum_m h_0(n)\varphi(2^{j+1} t - 2k - n) 
\]
(2)

Then,

\[
2k + n = m 
\]

\[
\varphi(2^j t - k) = 2^{j/2} \sum_m h_0(m - 2k)\varphi(2^{j+1} - 2k - m) 
\]
(4)

The same can be obtained,

\[
\varphi(2^j t - k) = 2^{j/2} \sum_m h_1(m - 2k)\varphi(2^{j+1} t - m) 
\]
(5)

\[
c_{j,k} = \sum_m h_0(m - 2k)\int_R x(t)2^{-j/2}\Phi(2^{-j+1} t - m)dt 
\]
(6)

\[
= \sum_m h_0(m - 2k)\langle x(t), \Phi_{j-1,m}(t) \rangle 
\]

\[
= \sum_m h_0(m - 2k) \cdot c_{j-1,m} 
\]

\[
d_{j,k} = \sum_m h_1(m - 2k) \cdot c_{j-1,m} 
\]
(7)

Formula (6) and Formula (7) show that scale coefficients \( c_{j,k} \) and wavelet coefficients \( d_{j,k} \) can be obtained by weighted summation of scale coefficients \( c_{j-1,k} \) in j-1 scale space by filter bank coefficients \( h_0(n) \) and \( H_1(n) \). At the same time, the above two formulas also give a decomposition algorithm of signals on orthogonal wavelet basis. This algorithm is called Mallat algorithm. In this algorithm, the process that \( c_0 \) is decomposed into \( d_1, d_2, \ldots, d_n \) and \( c_n \) is called finite wavelet orthogonal decomposition\(^{[2-3]}\). The schematic diagram of the signal decomposition algorithm is shown in Figure 1.

2.2 Signal Reconstruction

For any \( \varphi(t) \in V_{j+1} \),

\[
x(t) = \sum_k c_{j-1,k}\varphi_{j-1,k}(t) 
\]
(8)

Bring the two-scale equation (1)(2) into the above equation, then
\[
\sum_{j} c_{j,k} \sum_{m} h_{0}(m-2k)2^{-j/2} \varphi(2^{-j+1}t - m) + \sum_{j} d_{j,k} \sum_{m} h_{1}(m-2k)2^{-j/2} \varphi(2^{-j+1}t - m) = \\
\sum_{j} c_{j,k} \sum_{m} h_{0}(m-2k)\varphi_{j-1,m}(t) + \sum_{j} d_{j,k} \sum_{m} h_{1}(m-2k)\varphi_{j-1,m}(t)
\]

(9)

The above formula gives the reconstruction formula of \(c_{j,1,m}\) in the \(j-1\) scale space reconstructed by the scale coefficients \(c_{j,k}\) and \(d_{j,k}\) in the \(j\) scale space. Signal reconstruction algorithm diagram shown in Figure 2.

2.3 Signal decomposition initial data input

From equations (8) and (9), when the Mallat algorithm is used for signal decomposition, the initial data \(c_{0}\) needs to be input, i.e., \(x(t)\). The data is theoretically obtained by the inner product method.

\[
c_{0} = \langle x(t), \Phi_{0}, k(t) \rangle
\]

(10)

However, this method is computationally complex and generally not used. Calculated using Shannon's sampling theorem

\[
x(t) = \sum_{k} x(k) \sin c(t - k)
\]

(11)

Substituting the above formula into equation (10),

\[
x_{1}^{(0)} = \sum_{k} x(k) \int \varphi(t - k) \sin c(t - k) \, dt
\]

(12)

Since \(x_{1}^{(0)}\) is too complicated, generally simplifying sinc is regarded as a \(\delta\) function, then the above formula is

\[
x_{1}^{(0)} = \sum_{k} x(k) \varphi(t - k)
\]

(13)

2.4 Implementation of the filter bank

After the analyzed signal passes through the low-pass and high-pass filters \(h_{0}\) and \(h_{1}\), the signal band is divided into two bands of low frequency and high frequency, and then the low frequency and high frequency signals are down-sampled through the next stage filter bank and repeated decompose process (reconstruction is the inverse of decomposition), so as to filter out higher harmonics\(^{[4]}\). The filtered signal decomposition process and the post-filter reconstruction process are shown in Figures 3 and 4, respectively.
3. simulation examples
Gaussian pulse signals, triangular wave signals, and pulse signals are typical signals. Since the signals are mixed with harmonics\(^4\), they are selected as research objects. Using the wavelet toolbox in Matlab to test the three signals separately, we can find a better decomposition method to process the original signal.

The Gaussian pulse signal is decomposed by wavelet transform, and the decomposition is obtained as shown in Figure 5.

Using the wavelet tool to decompose the original Gaussian pulse signal, after several experiments, it is found that the db5 wavelet is the most effective for the four-stage decomposition of the signal. The original signal is divided into high frequency and low frequency signals, and the decomposed low frequency signal is very close to the original signal. And the high frequency signal in the original signal can be effectively filtered out. The triangular wave signal is decomposed by wavelet transform, and the decomposition is obtained as shown in Fig. 6.
Figure 7. Three-stage decomposition of signals using db4 wavelet

Experiments show that the second decomposition of triangular waves by db4 wavelet can achieve better results, and the harmonics are effectively filtered out.

Since the pulse signal contains more low-order harmonics, the difference from the original signal is not very large, so the effect of using wavelet analysis is not particularly obvious. The filtered signal still contains a certain amount of harmonics, so there is a small amount of burr spikes\(^5\). After many experiments, selecting the db4 wavelet to perform a three-level decomposition of the signal can still get better results, as shown in Figure 7.

4. Conclusion
Wavelet analysis\(^7\) is a rapidly developing new field in Applied Mathematics and engineering. After nearly 10 years of exploration and research, an important formal system of mathematics has been established, and its theoretical basis is more solid. Compared with Fourier transform, wavelet transform is a local transformation of space (time) and frequency, so it can extract information from signals effectively. The functions of scaling and translation can be used to analyze functions or signals in multi-scale, which solves many difficult problems that Fourier transform can not solve. Wavelet transform is related to applied mathematics, physics, computer science, signal and information processing, image processing, seismic exploration and other disciplines. Mathematicians believe that wavelet analysis is a new branch of mathematics. It is the perfect crystallization of functional analysis, Fourier analysis, sample analysis and numerical analysis. Signal and information processing experts believe that wavelet analysis is a new technology of time-scale analysis and multi-resolution analysis. It is used in signal analysis, speech synthesis and image analysis. Research on recognition, computer vision, data compression, seismic exploration, atmospheric and oceanic wave analysis and so on has achieved achievements of scientific significance and application value \(^6\). Experiments show that wavelet analysis is a good signal processing tool, which can filter the original signal with harmonics, and can effectively filter out harmonics to a certain extent, especially for high-order harmonics. For harmonics with lower frequency, because the signal is close to the fundamental wave, it is not easy to filter out low-order harmonics, which needs further study.

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