Research on Harmonic Detection and Active Suppression Technology of Power System Based on Wavelet Analysis

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Abstract

With the development of power system and the opening of power market, power quality problems have attracted more and more attention. Due to the popularity of various non-linear loads (harmonic sources), the harmonic pollution of power grid is becoming more and more serious. In this paper, the generalized integral controller is introduced into current tracking control, and the generalized integral control strategy and its error-free characteristic of active power filter are analyzed and studied in detail. Based on the analysis of wavelet theory, from the angle of signal analysis, through comparison with Fourier transform, the superiority of wavelet transform in time-frequency analysis is demonstrated, and the application of wavelet transform in harmonic detection is determined as the research direction of this paper. Finally, the development of wavelet in harmonic detection application is discussed according to the current research results, which provides research ideas for wavelet transform in analyzing effective, accurate and reliable power harmonic detection methods.

Keywords

Wavelet transform; Harmonic detection; Active power filter.

1. Introduction

With the rapid development of power electronics technology, a large number of nonlinear loads (such as traction load of electrified railway, rectification load, electric locomotive, electric arc furnace, frequency conversion speed regulating device, etc.) are connected to the power system. Under the action of system voltage, the power supply current of these nonlinear loads is distorted and contains a large number of harmonic components [1]. However, with the wide application of these power electronic devices, their strong non-linear characteristics inject a large amount of harmonic and reactive power into the power grid, resulting in the decline of power quality and the "grid pollution" problem. A large number of non-linear loads make the harmonic pollution in the power grid more and more serious and complex. The harmonics can reduce the efficiency of the production, transmission and utilization of electric energy; cause the electrical equipment to overheat, generate vibration and noise, and age the insulation. In recent years, wavelet transform has been applied to harmonic detection and achieved fruitful results, but at present almost all of the family of wavelet functions exist aliasing phenomenon in signal analysis, which leads to low accuracy, poor robustness and low resolution [2]. In this paper, wavelet transform is used to improve the fundamental signal extraction, fundamental frequency detection, harmonic tracking, singularity detection and interharmonic identification of power signals, and compare them. Combined with the characteristics of the analysis signal, the realization of wavelet transform in harmonic detection is studied.

2. Harmonic Characteristics of Power System

(1) Harmonic problem and its influence in power system

In power system, harmonics refer to the part of electric quantity whose frequency is integer times of fundamental wave in current expression. It is mainly due to the large number of applications of non-linear loads in the power grid, resulting in voltage and current distortion, which brings serious harm

to electrical equipment. Ideal power systems supply electricity at a single and fixed frequency and voltage level with a fixed amplitude, but in fact these conditions are difficult to meet. Because of the existence of non-linear loads, the current waveform in the power grid often deviates from the sinusoidal waveform and distorts. Under certain power supply system conditions, some electrical loads will have periodic current fluctuations that are not multiple times of the fundamental frequency. In order to continue the harmonic concept without losing its generality, it is called fractional harmonics, or For interharmonics. The degree of voltage distortion depends on the magnitude of the system impedance and harmonic current [3]. The same harmonic load will cause two different voltage distortion values when it is in two different positions in the system. Harmonics can also cause serious interference to communication equipment and electronic devices. Therefore, the harm caused by harmonics to the power system has caused widespread concern, resulting in "harmonic pollution."

(2) Power harmonic detection method

Harmonic detection is the primary problem in harmonic management. In the development of harmonic detection theory, a variety of detection methods have been formed, such as analog filtering, Fourier transform, wavelet transform, instantaneous reactive power theory, neural network and so on. Any function that repeats in a cycle can be represented by the sum of a sinusoidal fundamental wave and a series of higher harmonic components, and the frequencies of these higher harmonic components are integer multiples of the fundamental frequency [4]. According to Fourier's theory, the distortion waveform can be decomposed into the sum of the fundamental wave and a series of harmonics. However, this method has many disadvantages: the filter will produce phase shift, which will lead to distortion of the output signal and affect the compensation effect; The center frequency of the filter is very sensitive to the component parameters and is greatly affected by the external environment. It is difficult to obtain ideal amplitude frequency and phase frequency characteristics. To reduce the harmonic current injected into the power grid, that is, to take measures on harmonic sources to avoid harmonic generation to the greatest extent. Wavelet transform is a kind of time-frequency analysis [5]. At present, it is mainly applied to the detection of voltage and current signal discontinuities and singular points in power harmonic detection. Separation and identification of signal components; Signal noise processing; The estimation of signal development trend, etc.

3. Application Principle of Wavelet Transformin Power Harmonic Detection

(1) Time-frequency analysis principle of wavelet transform

Wavelet analysis can select the accuracy of time or frequency according to needs. Generally speaking, the low frequency part of the signal is relatively flat and contains more frequency components, so the time resolution can be reduced to improve the frequency resolution [6]. It has higher frequency resolution and lower time resolution in the low frequency part and higher time resolution and lower frequency resolution in the high frequency part. Since the power supply of the power system is a stable voltage source, and the amplitude and frequency of this voltage source are fixed, and the operating voltage at each point of the system is close to the rated voltage, the percentage of harmonic voltage has indicated the magnitude of the effective value of harmonic voltage [7]. The results show that when the power supply voltage is symmetric and distortion-free and the load current is symmetrical, both methods can accurately detect the active, reactive and harmonic current components of the fundamental current [8]. In the high frequency part, there are many characteristics of transient transformation. The relative frequency change has little effect on the signal. We can pay attention to the transient characteristics of the signal at a higher time resolution and reduce the frequency resolution. . Since the wavelet transform does not divide the signal band evenly, the low frequency part of the signal can be accurately decomposed, but the frequency resolution in the high frequency band is poor.

(2) Principle of harmonic detection based on wavelet analysis

Harmonic detection is to distinguish high-order harmonics with high resolution and wide frequency band in higher harmonics [9]. By re-adjusting the arrangement of the low-pass and high-pass filters,

a uniform frequency band continuously distributed in order of frequency can be obtained. If the highest frequency in the signal is considered to be 1, a 5-layer wavelet packet decomposition is performed. In the harmonic processing analysis, in order to obtain comprehensive information about the power quality, it is often necessary to collect parameters such as phase voltage, phase current, neutral current and neutral to ground voltage to form a sufficient data source for power quality analysis. In order to effectively distinguish the high-frequency signal, in the actual detection, it is desirable that the frequency window of the low-frequency part is narrow, and the frequency window of the high-frequency part is relatively wide. The detection system constructed according to this principle is a closed-loop continuous regulation system, so its operation characteristics are almost independent of component parameters and have little dependence on device characteristics. The essence of the principle of filtering out harmonics is to provide a release path for harmonics in the circuit, i.e. to retain the fundamental wave and short-circuit the harmonics so that the harmonics can directly flow back to the harmonic source through the filter without being injected into the system [10]. Under this application requirement, wavelet theory has been developed in power harmonic detection. It provides a variable time-frequency window structure, which can improve the performance of harmonic analysis and achieve the purpose of harmonic real-time and accurate detection.

4. Application of Wavelet Analysis in Power Harmonic Detection

(1) Application of wavelet transform

Catastrophe signals belong to the transient characteristics of signals and include important characteristics of signals. The analysis ability of wavelet transform in time domain and frequency domain and the zoom characteristic of wavelet are very sensitive to such signals. It can realize uniform division of frequency bands, further decompose high-frequency components that are not subdivided in wavelet transform, and can analyze signals according to their characteristics. This often requires a high sampling frequency, and then the collected data are processed on-line or off-line by computer. The data throughput of the system is quite large. The change of the detected signal can be tracked in real time, but the premise of this algorithm is that the phase information of the grid voltage must be accurately known. If the grid voltage is ideal, the phase information can be obtained by dividing the grid voltage by its amplitude information; wavelet transform With the characteristics of multi-resolution analysis, from the perspective of frequency, it can filter the high-frequency components layer by layer, making the signal more and more close to the development trend of the signal; when the double-tuned filter is in normal operation, due to the fundamental wave of the parallel branch The impedance is much smaller than the fundamental impedance of the series branch, so the fundamental voltage experienced by the parallel branch is much smaller than the fundamental voltage experienced by the series branch.

In multiresolution analysis, the two-scale relationship between the given orthogonal scaling function ϕ(t) and the wavelet function ψ (t) is:

$$\begin{aligned} \phi(t) &= \sqrt{2}\sum_{k} h_{0k}\phi(2t-k) \\ \psi(t) &= \sqrt{2}\sum_{k} h_{1k}\phi(2t-k) \end{aligned} \tag{1}$$

Where h0k is an orthogonal low-pass real-factor filter corresponding to the orthogonal scaling function ϕ(t), and h1k is a high-pass filter corresponding to the orthogonal wavelet function ψ(t).

In order to further subdivide the decomposed frequency bands, i.e. to further localize time-frequency, the following recursive relations are defined:

$$w_{2n}(t) = \sqrt{2}\sum_{k} h_{0k}\phi(2t-k)$$
$$w_{2n+1}(t) = \sqrt{2}\sum_{k\in z} h_{1k} w_n(2t-k) \quad (2)$$

Noise is the most common interference signal in power system, and also the main barrier for accurate harmonic analysis. It can automatically adjust the sampling density frequency according to the different frequency components of the signal. When the sampling density frequency is high in time domain and space domain, the time-frequency window is sparse when the density frequency is low. However, due to the special situation of harmonic detection, the proportion of harmonic components is relatively large, and it is a periodic signal, so it will have a great negative impact on the regulation of conventional step size. When these conventional variable step size adaptive algorithms are used in harmonic detection, the effect is not obvious. Therefore, the tuning filter is not used when filtering out the higher harmonics. In order to reduce the cost, the high-pass filter is usually used to filter out the harmonics. The high-pass filter has a small impedance to all the higher harmonics and can be above a certain frequency. Harmonic filtering. The other is threshold denoising. The method is to use the threshold value for the highest frequency decomposition coefficient in the signal wavelet decomposition, that is, the part larger than the threshold is reserved, and the coefficient lower than the threshold is zero. Therefore, wavelet analysis, as an emerging mathematical tool, can be widely applied in a short period of time, which shows that it has great potential and broad application prospects.

(2) Main factors affecting the effect of harmonic detection

Harmonic analysis begins with sampling the actual grid signal and establishing a signal model. But the actual sampling requires sophisticated equipment and a specific environment, so establishing a reasonable harmonic signal model is a difficult point. Multiresolution analysis based on wavelet transform. Using multi-resolution analysis, the signal is decomposed at different resolutions, and the signal can be expanded into a scale function and a series of wavelet functions. The performance comparison of such an algorithm depends on the choice of training samples, the selection of the number of hidden layer neurons, and the performance of the training algorithm. According to the form of the main circuit, it can be divided into single main circuit active power filter and multiple or hybrid main circuit active power filter. The latter can increase the capacity of the active power filter, increase the equivalent switching frequency and reduce the switching loss of a single device. Therefore, the harmonic of the power grid contains not only stable fundamental wave and harmonic components, but also some unstable transient signals. It projects the time-varying amplitude of each harmonic into the subspace spanned by the orthogonal wavelet basis function, then estimates its wavelet coefficients by using the least square method, and converts the amplitude estimation problem of the time-varying harmonic into a constant coefficient estimation problem, thus having faster tracking speed.

Wavelet packet has the characteristic of further subdividing the frequency space, decomposing the given signal into more frequency bands, thus further improving the frequency resolution, and projecting the higher harmonic generated in the power system to different scales will obviously show the characteristics of high frequency and singular higher harmonic signals for harmonic analysis. Therefore, wavelet can not only detect abrupt signals but also effectively analyze the content of harmonics when analyzing signals containing transient transformation. The singularity of wavelet transform is used to accurately locate the initial abrupt change point of the transient signal in the time domain, then the same phase point of the abrupt change point is determined in the period when the transient signal is adjacent to the non-interference period, and the transient waveform of the abrupt change point is compared with the corresponding normal waveform point to point to judge the type of transient interference. Active power filters can be divided into voltage type and current type. The main circuit of the voltage type active power filter has a large capacitor connected to the DC side. When it is in normal operation, its voltage remains basically unchanged; in the detection of harmonics,

To realize the time-frequency analysis and distortion-free reconstruction of the signal, the appropriate analysis function should be selected in combination with the signal model and the wavelet function's own characteristics such as orthogonality, vanishing moment, and support set. In addition, because different wavelet basis functions are different in the time-frequency domain, the same problem is transformed by different wavelet basis functions, and the results are quite different. How to select or construct wavelet bases suitable for harmonic detection needs further study.

5. Research on Control of Shunt Active Power Filter

(1) DC side voltage control of shunt active power filter

In order to compensate harmonic current effectively, the DC bus voltage of shunt active power filter must be controlled as a stable value. However, it is difficult for active power filter to control the DC side voltage of the main circuit at a certain constant value in actual operation. When the DC side voltage fluctuation is large, there will be over-compensation or under-compensation. The normal operation of inverters requires a stable DC bus voltage, but this voltage is bound to be affected by the energy status of the grid and load, and fluctuates with the change of working conditions. Thereby, the time domain signal is converted to the frequency domain signal to realize the time-frequency characteristic analysis of the signal. Although the Fourier transform can relate the time domain characteristics of the signal to the frequency domain characteristics, it can only be observed from the time domain and the frequency domain of the signal separately, and the two cannot be organically combined. When the active filter absorbs the active power, its DC side voltage rises; conversely, when the active filter emits active power, its DC side voltage drops. A reasonable selection of the switching function can change the output voltage of the inverter, so that the current value flowing through the inductor can be changed. Fluctuating within a given range allowed. Under-compensation affects the accuracy of the compensation current, and over-compensation increases the disturbing harmonic current of the active power filter.

With proper control (PI regulation control), the DC-side capacitor is taken directly from the AC side of the active power filter and its voltage is maintained at an appropriate value. As shown in Figure 1. Uce is the given value of Uc, Ucr is the feedback value of Uc, and the difference between the two is adjusted by PI to obtain Δip.

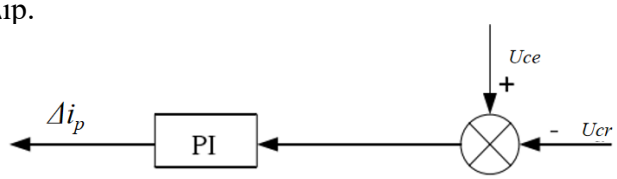

Figure 1 PI regulation control of DC side voltage

The system designed based on PSO and GA can still limit the harmonics to the standard requirements under the worst detuning conditions, while the system designed based on traditional empirical design method has the phenomenon of exceeding the limit of individual harmonics, which also verifies the necessity of taking robustness test of detuning factors as a constraint condition in the design. Table 1 below shows the harmonic contents after the hybrid filter is put into operation.

Table 1 The harmonic content after the hybrid filter is put into operation.

Frequency	PSO optimization method /A	Standard GA algorithm /A
10	2.36	2.33
15	4.22	2.74
20	1.05	1.51

Theoretically, the variation of DC side voltage of APF is determined by the energy flow of APF and power grid. The parallel active power filter system is mainly composed of two parts, i.e. the command current operation and the compensation current generation part, wherein the compensation current generation part comprises a current tracking control circuit, a driving circuit and a main circuit. In this way, a pair of contradictions in signal analysis produce localized contradictions in time domain and frequency domain. Therefore, Fourier transform is only a bridge from time domain to frequency

domain, and cannot judge when a specific signal occurs according to the results of Fourier transform. Experiments have confirmed that the use of combined wavelet detection of harmonics not only achieves better detection results, but also effectively filters out noise interference. Fast wavelet transform is to use the orthogonal wavelet base to decompose the signal into individual components at different scales. The implementation process is equivalent to repeatedly using a set of high-pass and low-pass filters to gradually decompose the signal. Therefore, in order to ensure good compensation current following performance, the voltage of the DC-side capacitor of the main circuit must be controlled to an appropriate value. According to this, the compensation current generating circuit generates a compensation current which cancels the harmonics and reactive currents to be compensated in the load current, and finally obtains the desired power supply current.

(2) Active power filter current tracking control technology

The performance of APF depends largely on the level of the controller. It is very important to design a good controller and choose appropriate control strategy. When the given reference signal is DC, the controlled object can ensure that the output signal has no steady-state error under the action of PI controller. When the reference signal is a sinusoidal signal of a certain frequency, the conventional PI controller can not achieve zero steady-state error output. The selection of wavelet function is also a difficult problem in the application of wavelet analysis to practice. At present, the selection of wavelet function is often based on the comparison of different analysis results through experience or continuous experiments. When the difference between the compensation object and the output of the filter exceeds a predetermined allowable error, the switching element of the main circuit operates. Hysteresis current comparison control is to compare the actual current with the upper and lower limits of the command current and form an annular band with the intersection point as the switching point. In recent years, some scholars have proposed a generalized integral controller for non-direct current signals, which can avoid multiple coordinate transformations, track sinusoidal signals of specific frequencies without steady-state errors, and selectively compensate harmonics of specific frequencies.

The basic principle of hysteresis comparison control mode is to take the difference Δic between the command signal i*c of compensation current and the actual compensation current signal ic output by the main circuit of the active power filter as the input of hysteresis comparator, and control the on-off of power electronic devices through the output of the comparator, thus controlling the change of the actual compensation current IC, as shown in Figure 2.

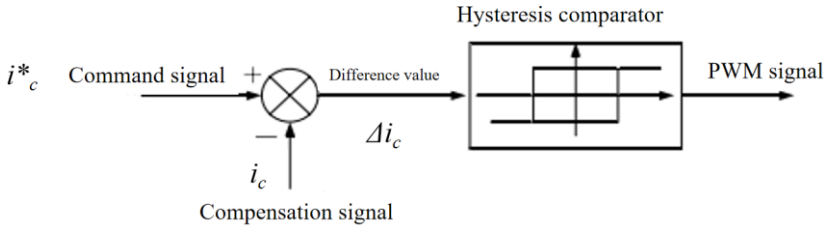

Figure 2 Schematic diagram of hysteresis current control

In order for the output of the controlled object to track the given signal without difference under the action of the controller, the controller must include an integration link. In this control mode, the hysteresis width has a great influence on the following performance of the compensation current. In the engineering application of wavelet analysis, a very important problem is the selection of the optimal wavelet basis function, because using different wavelet basis functions to analyze the same problem will produce different results. The wavelet subband filter is used to replace the low-pass filter in the traditional synchronous geophone. This new type of synchronous geophone not only has the function of amplitude detection, but also has the function of spectrum analysis. When the width of hysteresis loop is large, the switching frequency of switching elements in the main circuit is low, and the requirement for components is not high, but the following error is large; otherwise, when the width of hysteresis loop is small, the following error is small, and only the amplitude of hysteresis loop is integrated, so that the output of the controlled object can track its reference signal without error.

6. Conclusiong

With the development of power system and the opening of power market, power quality problems have attracted more and more attention. Due to the popularity of various non-linear loads (harmonic sources), the harmonic pollution of power grid is becoming more and more serious. Harmonic and its suppression technology has become one of the important research topics in power system. A new adaptive harmonic current detection algorithm with variable step size is proposed, which can ensure that the harmonic detection process has both fast dynamic response speed and high steady-state accuracy. Regardless of the method of governance, it must be based on fast and accurate harmonic detection. It can be said that harmonic measurement is the main basis for the study of harmonic problems, and it is also the core link. Wavelet packet transform has good time-frequency localization characteristics, and can achieve uniform division of signal bands, which is suitable for power system harmonic detection. From the user's point of view, it is desirable to reduce the price of active power filters to a level comparable to that of passive power filters. At present, the price of power electronic devices has become a key technology for popularization and application.

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References

[1] Kuang-Hsiung T, Faa-Jeng L, Jun-Hao C, et al. Intelligent controlled shunt active power filter for voltage and current harmonic compensation in microgrid system[J]. Journal of the Chinese Institute of Engineers, 2018:1-17.

[2] Thao N G M, Uchida K, Kofuji K, et al. An Automatic-Tuning Scheme Based on Fuzzy Logic for Active Power Filter in Wind Farms[J]. IEEE Transactions on Control Systems Technology, 2018:1-9.

[3] Li D, Song M, Hu J, et al. Improved series active power filter with fundamental and harmonic magnetic flux hybrid compensation[J]. IET Power Electronics, 2018, 11(6):1038-1045.

[4] Baocheng W, Lili Y, Ruijing H, et al. Site Selection Strategy of Discrete Frequency Tuned Resistive Active Power Filter for Harmonic Damping in Loop Power Distribution Systems[J]. Transactions of China Electrotechnical Society, 2017, 32(4):241-249.

[5] Das S, Ranjan V. Wavelet Transform Based Filter to Remove the Notches from Signal Under Harmonic Polluted Environment[J]. Journal of the Institution of Engineers, 2017, 99(2):1-7.

[6] Wang H, Xu Z, Wu T, et al. Evolutionary power spectral density of recorded typhoons at Sutong Bridge using harmonic wavelets[J]. Journal of Wind Engineering & Industrial Aerodynamics, 2018, 177:197-212.

[7] Dong B, Shen Z, Xie P. Image Restoration: A General Wavelet Frame Based Model and Its Asymptotic Analysis[J]. SIAM Journal on Mathematical Analysis, 2017, 49(1):421-445.

[8] Wang J Y, An T, Baan W A, et al. Periodic radio variabilities of the blazar 1156+295: harmonic oscillations[J]. Monthly Notices of the Royal Astronomical Society, 2014, 443(1):58-66.

[9] Yuan W, Dong G, Chin K S, et al. Tribology assessment of surface-contact sliding pairs with streak defect under dynamic harmonic excitation loading[J]. Industrial Lubrication and Tribology, 2018:00-00.

[10] Xu Q, Chen D, Xu P, et al. High Power Density Three-Phase Shunt Active Power Filter Design Based on Multiple Magnetic Integrations of LCL Filter[J]. Journal of Circuits, Systems, and Computers, 2017, 26(12):1312-11.