

Research of Basic Wave Extract Based on Wavelet Analysis and Virtual Instrument

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Abstract: This paper used the wavelet multi-resolution decomposition technology to detect the basic wave and harmonic of the power system. The power system signal is decomposed into 7 layers and each layer signal is reconstructed, which can complete the basic wave and harmonic wave separation. Through the simulation, results show that the basic wave voltage frequency of 50 Hz can be accurately extracted, so the wavelet multi-resolution analysis algorithm can be used in the power system harmonic detection. In addition, by using virtual instrument technology, we can realize the basic wave and each harmonic wave extraction and display. Copyright © 2013 IFSA.

Keywords: The power system harmonic, Wavelet analysis, Basic wave extract, Multi-resolution.

1. Introduction

The power system signal fluctuations and flicker is mainly caused by the loads with impact power, such as smelting arc furnace, rolling mill, electric locomotives, arc welding machine, etc. whose active power and reactive power change substantially in operation process. Along with the development of the industrialization, the impact load is increasing whose influence to power quality will not be ignored, because it constitutes the power of pollution seriously prejudicing the power users. The voltage with harmonic is transformed by the orthogonal wavelet transform based on multi-resolution decomposition (Mallat algorithm), and the transform values of higher scale are extracted, thus we obtain the base wave component of the voltage and the change of the tracking harmonic.

2. Algorithm Analysis

Wavelet transform originated with Morlet in 1980 when he analyzed earthquake data. The basic idea of the wavelet analysis is that a bunch of function indicates and approaches a signal or a function, and the bunch of function is called wavelet function department. The definition is as follows:

If function $\Psi(t) \in L^2(R)$ meet the following condition:

$$C_{\Psi} = \int_0^{+\infty} |\hat{\Psi}(w)|^2 \frac{dw}{w} < \infty \quad (1)$$

The function $\Psi(t)$ become a little wave, which can also be thought of as gens function $\{\Psi(t)\}$

generating through expansion and translation of the above function:

$$\Psi_{a,b}(t) = |a|^{1/2} \Psi\left(\frac{t-b}{a}\right) \quad (2)$$

To distinguish, the former is called base wavelet or mother wavelet, and the latter is called the son wavelet or wavelet. To base wavelet $\Psi(t)$, continuous wavelet transform of signal $f(t) \in L^2(\mathbf{R})$ about the base of wavelet is as follows:

$$(W_\Psi f)\Psi_{a,b}(a,b) = |a|^{1/2} \int_0^{+\infty} f(t) \Psi^*\left(\frac{t-b}{a}\right) dt \quad (3)$$

From the function (3), the time window of wavelet automatically become narrow accompanying the decrease of the scale parameter. only can narrow time domain window capture the high frequency transient signal, and son wavelet of wide time domain window reflects the trend of low-frequency signals. It shows that wavelet transform has extremely sensitive "zoom" characteristics, thus wavelet analysis is much better in analyzing and processing the nonstationary and transient signal. Further studies shows that the ratios of son wavelet frequency width and frequency center is a constant though they change, thus wavelet analysis is a "constant Q" frequency analysis. Second, the base wavelet is not fixed, which can be chosen according to data compression, and image processing, signal detection and so on the different purpose.

The sampling rate of band-pass signal depends not on the frequency upper limit but on the bandwidth. The Similar process can be repeated down to the low frequency part after every time decomposition. That is, each level of decomposition of the output signal is broken down into a low frequency as the rough approximation and a high frequency as the details, and each level of output sample rate can be halved. In this way, the original $s(n)$ can be multiresolution decomposition. Here to a three layers of decomposition to give explanation, and the wavelet decomposition relationship as shown in Fig. 1 below.

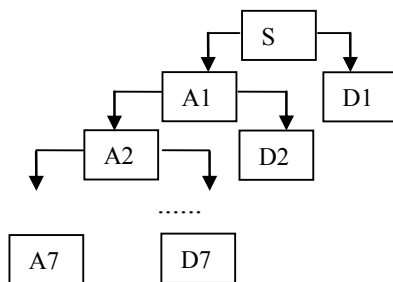


Fig. 1. Multiresolution analysis tree structure.

The ultimate goal of decomposition is to construct a highly approximation in frequency space of orthogonal wavelet base, therefore the different frequency resolution orthogonal wavelet base is equivalent of bandwidth band-pass filter. Low frequency space is continuously decomposed on multiresolution analysis; hence the frequency resolution is becoming more and more high.

Through the Mallat multiresolution analysis, we get the orthogonal wavelet base $\{\psi_{j,k}(t) | \psi_{j,k}(t) = 2^{-j/2} \psi(2^{-j}t - k)\}_{j \in \mathbf{Z}, k \in \mathbf{Z}}$ of the space $L^2(\mathbf{R})$, so for any signal $f(t) \in L^2(\mathbf{R})$ can be expressed as: $f(t) = \sum_{k \in \mathbf{Z}} a_k^j \phi_{j,k}(t) + \sum_{j=1}^J \sum_{k \in \mathbf{Z}} d_k^j \psi_{j,k}(t)$, and $d_k^j(k) = (f(t), \psi_{j,k}(t))$ is orthogonal wavelet transformation.

Decomposition coefficient $a_k^j(k)$ and $d_k^j(k)$ is 2^j scale (the first j layer) which is discrete smooth approximation signal and discrete detail signal, and the recursive computation formula is as follows:

$$\begin{aligned} a_k^j &= \sum_{k \in \mathbf{Z}} \bar{h}_{k-2n} a_k^{j-1} \\ d_k^j &= \sum_{k \in \mathbf{Z}} \bar{g}_{k-2n} a_k^{j-1} \end{aligned} \quad (4)$$

In the equation (4), j is decomposition layers for $j = 1, 2, \dots, J$; J is the summit decomposition. Sequence $\{\bar{h}_k\}$ and $\{\bar{g}_k\}$ as low pass and high-pass filter respectively do filtering operation for different input sequences $\{a_k^{j-1}\}$, then every other point on the results is extracted. Through the decomposition of equation (4), in each 2^j scale (the first j layer), signal is decomposed to approximate part of wavelet coefficients (in the low frequency son bring) and the details of wavelet coefficients (in the high frequency son take). From the point of view of the filter, the frequency band of signal $f(t)$ is entered into a series of wavelet. Power signal often have more harmonic composition, and base wave center frequency is 50 Hz. The whole decomposition process is over when the decomposition frequency bands reach to base wave frequency of the upper limit. The base wave component is reconstructed by low frequency band $a_k^J(k)$ and the harmonic component is reconstructed by high frequency band $d_k^j(k)$, which can real-time track harmonic changes.

3. VI Technology

The concept of virtual Instrument is the NI Company (National Instrument) in the mid 1980's. So-called virtual instrument is to computers as instrument unified hardware platform, make full use of computer operation, storage, playback, calls,

display and intelligent functions such as file management, at the same time, the specialized function of traditional instruments and panel control software, and to combine with computer constitute a from appearance to function are completely the same as the traditional hardware instruments, computer intelligent resources and fully enjoy the new instrument system.

Compared with the traditional instrument, virtual instrument has many advantages: processing and calculation of the amount of the test is more complex and the processing speed is faster, and the test results of expression more rich diversity, can be easily stored and exchanged test data, low prices, technical updates faster. The comparing results are shown as Fig. 2.

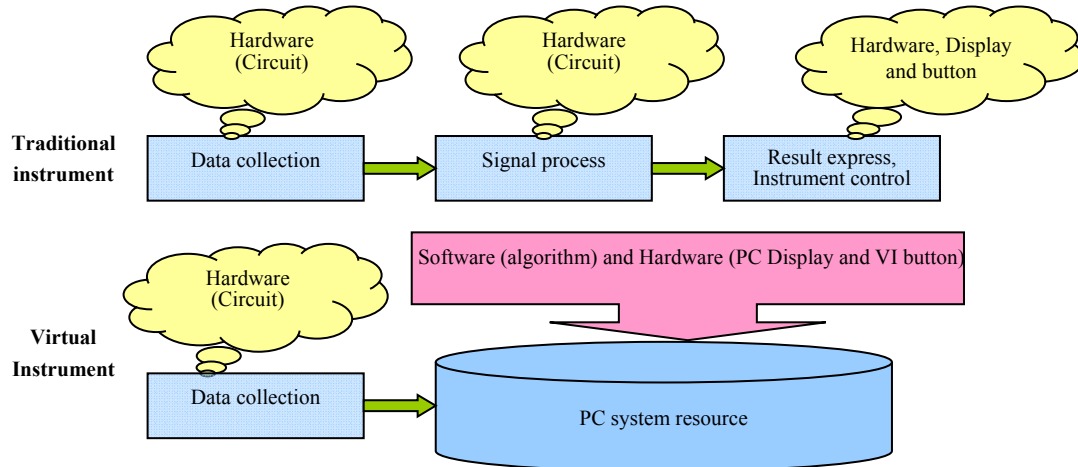


Fig. 2. Comparing between Virtual instrument and traditional d instrument.

Fig. 2 shows the difference between the traditional instrument (such as single computer, DSP, FPGA, etc) and the virtual instrument. From the differences we can see, virtual instrument can use PC advantages, such as high speed processing CPU, big volume storage, and itself high quality screen display, etc. So, the virtual instrument technology is the future progress direction. In the harmonic analysis and detection, we adopt the VI technology can realize upper PC data analysis and management.

Its biggest characteristic is defined by the instrument manufacturer instrument function change of the pattern for users to define their own instrument function, meet the demand of a variety of applications. As a result of the test function of the virtual instrument, is made up of panel controls software, any user can change the software of virtual instrument to change its function and scale, which fully embodies the design thoughts of software is the instrument.

Virtual instrument technology is based on computer technology; the core is computer software technology. One of the most representatives of the graphical programming software is the NI Company launching LabVIEW. It is the first in the world using graphical programming technology for instrument of 32-bit compiler program development system, its goal is to simplify the process of development, improve the efficiency of programming, let scientists and engineers make full use of computer resources and the strong big functions, fast and quickly to finish their tasks, it is called the language of the scientists and engineers.

LabVIEW uses a visualization technology to establish man-machine interface, provides many instrument panel of the control object, such as header, knobs, switches, and coordinate the floor plan. Users can use the editor will control object change for their work in the field of controlled object. LabVIEW offers a variety of powerful toolbox and libraries, and integrate the many instrument hardware bases. LabVIEW to support multiple operating system platforms, on any platform developed by LabVIEW application can be directly portable to other platforms. Comparing VI with the traditional instruments, the differences are shown as Table 1.

Compared with the traditional instruments, the core idea of VI is a powerful resource that would require the use of computer, which makes the hardware implementation of technical software to minimize system cost, enhance system functionality and flexibility. Its exterior features compared with the traditional instruments are quite different, the most prominent feature is the panel and the corresponding controls and indicators, etc, and is no longer posed some physical entity, but by powerful graphics inside the computer environmental and online help set up a virtual panel replacement, known as 'soft panel', from internal features it had a more complex instrument intelligent microprocessor and firmware, now mostly inside the computer software that can be shared, hardware resources, and with its sophisticated data analysis and processing capabilities, to achieve the required test equipment to test all functions.

Table 1. Characters between traditional instruments and virtual.

Virtual instrument (VI)	Traditional instrument
User-defined instrument function	Vendor-defined instrument function
Easily connected with other devices	Easy to connect with other devices
Graphical interface, the computer reads the data and analytical processing	Small graphic interface, artificial read data, a small amount of information
Data can be edited, stored, printed	Data can not be edited
The key is the software	The key is the hardware
Inexpensive, and reproducible and highly configurable	Expensive
System is open, flexible and synchronized with the progress of the computer	Closed system, fixed-function, poor scalability
Technical update soon	Slow technology updates
Based on the structure of the software system, saving development costs	High development and maintenance costs

4. Simulation Analysis

The simulation initial voltage signal:

$$v(t) = \sin \omega t + \sin 4\omega t/2 + \sin 6\omega t/4 + \sin 10\omega t/6$$

Taking four cycles of 0.08 seconds for algorithm analysis and simulation, signal listed is analyzed with Matlab wavelet toolbox of function. Fig. 2 is the simulation voltage initial signals.

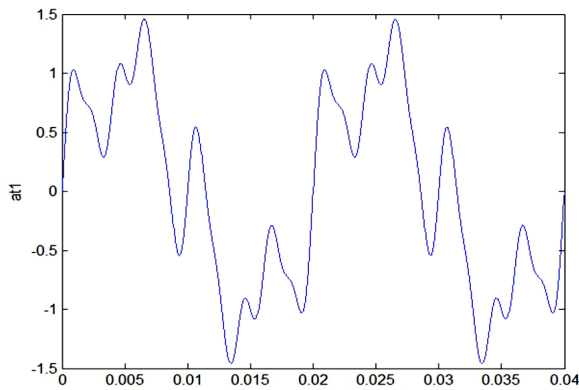


Fig. 3. Voltage initial signals.

In the simulation experiment, 1024 points were taken in 25.6 kHz sampling frequency, and Daubechies wavelet db20 was chosen, signal was decomposed to 7 layers and reconstructed each layer. Mean square root value of series signal a7 can be said of the input signals $v(t)$ base wave, namely

$$V_{rms} = \sqrt{\frac{1}{N} \sum_{k=1}^N a_k^2} \quad (5)$$

The simulation results is shown in Fig. 2. Among d1 ~ d7, a7 said 1 to 7 transformation measure results. From frequency Table 2 by the individual we can see that the base wave power frequency draw by a7. The fundamental frequency component detected with the original signal frequency component of the phase has produced certain offset, because wavelet db20 doesn't have symmetry. We can calculate and gained the frequency 50 Hz, 501 Hz, 298 Hz, 197 Hz from the wavelet in Fig. 3 a7, d5, d6, d7, d7, and they agree with theoretical results (Table 1). That shows wavelet transformation has good localization characteristics in the time domain and frequency domain, so it is suitable for power system harmonic analysis.

The main purpose of harmonic real-time tracking is to track the change trend of harmonics, and amplitude and phase error can relax a little. From figure 3, we can see that wavelet transformation can effectively track harmonic trend by choosing appropriate wavelet. This paper chooses dB 20 wavelet base function. By using LabVIEW to design the virtual instrument platform is shown as Fig. 4.

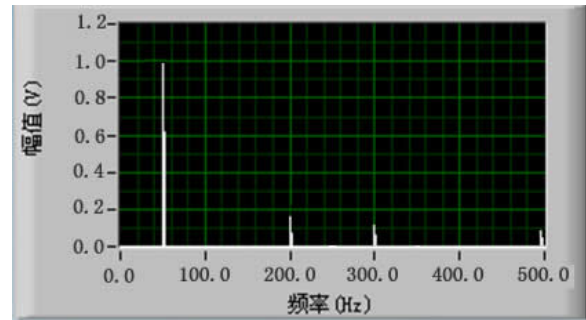


Fig. 4. VI platform.

From the Fig. 4 we can see, 50 Hz, 200 Hz, 300 Hz, 500 Hz frequency component can be better separated, and because the noise interference component can be separated from the initial signal, its frequency is much larger than 500 Hz, the Fig. 4 can not display it within the scale between 0 and 500 Hz. Through the building of the virtual instrument platform, it has very important function to display amplitude of the harmonic component.

5. Conclusions

Through the Matlab simulation, we can see that the wavelet multiresolution decomposition approach is use to analyze the nonstationary power system harmonic signal, and the traditional band-pass filter is replaced by wavelet transformation sub-band filter function, which can not only accurate extract basic signal frequency but also extract the second harmonic, so this provides control and governance voltage fluctuation and flicker for theory basis. In

addition, by using virtual instrument technology, we can realize the basic wave and each harmonic wave extraction and display.

References

- [1]. M. Unser, D. Sage, and D. Van De Ville, Multiresolution monogenic signal analysis using the Riesz–Laplace wavelet transform, *IEEE Transactions on Image Processing*, Vol. 18, Issue 11, 2009, pp. 2402-2418.
- [2]. Huaiwei Liao, Power system harmonic state estimation and observability analysis via sparsity maximization, *IEEE Transactions on Power Systems*, Vol. 22, Issue 1, 2007, pp. 15-23.
- [3]. J. Starck, J. Fadili, and F. Murtagh, The undecimated wavelet decomposition and its reconstruction, *IEEE Transactions on Image Processing*, Vol. 16, Issue 2, 2007, pp. 297-309.
- [4]. Zhao Hui-ling and Zhou Yun, Analysis of wavelet transform in harmonic detection of power, *Electronic Design Engineering*, Vol. 20, Issue 1, 2012, pp. 77-84.
- [5]. Dai Wenwei, Shuyan, and Cao Mingge, Wavelet transform in the application of harmonic detection, *Electronic Measurement Technology*, Vol. 34, Issue 7, 2011, pp. 37-39, 49.
- [6]. He Tian-Xiao, wavelet analysis and multiresolution methods, *CRC Press*, 2000.

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