International Journal of Control and Automation
Vol.8, No.11 (2015), pp.127-134
http://dx.doi.org/10.14257/ijca.2015.8.11.13

Research on Fault Detection of Wind Turbine Based on Wavelet Analysis

Wang Wei, Ma Xiaoping and Wang Qianjin

School of Information and Electrical Engineering, CUMT, Xuzhou 221008, China
wangwei83727@163.com

Abstract

Fast Fourier Transform plays a very important role in signal analysis, but the Fast Fourier Transform traditional mutation fault fan are unable to analyze the trend of fault features, the beginning and the end, and these signals often contain important information, the fault at the same time, the local signal analysis Fast Fourier Transform of fault are also incapable of action. The method of multi scale wavelet theories and Fast Fourier Transform are combined, make up for the deficiency of the Fast Fourier Transform, and the method is applied to the fault diagnosis of fan, and achieved good results, experiments show that, this method can effectively improve the accuracy of fault diagnosis. Wavelet packet analysis due to the high, the low frequency part of the signal local refinement and retention time domain features of the original signal, which has good time-frequency localization characteristics, it can effectively identify the non-stationary signal, to achieve the purpose of fault diagnosis, get more and more extensive application in the field of fault diagnosis. Signal generating fan running most of the non-stationary signal, the wavelet packet analysis technology is used to diagnose the fault has practical significance.

Keywords: *Blower fan, Wavelet packet analysis, Fault diagnosis*

1. Introduction

Fan common mechanical faults in rotor imbalance, rotor misalignment, bearing looseness and rub impact, the fault diagnosis method can be divided into diagnostic information acquisition, fault feature extraction, fault diagnosis and state recognition of three steps. Vibration signal and fault fan generated in the rotation process of the type, extent, site has the close relation, including equipment state information rich, through collecting vibration signals to obtain diagnostic information for fault monitoring and diagnosis is currently the most widely used method [1-2].

Because the fan vibration signal contains rich information on the operation of the equipment, the analysis for fault diagnosis has become the mainstream. Methods of analysis are mainly concentrated in the Fast Fourier Transform, Fourier Transform, neural network, but they are a way of vibration signal analysis. The current main ventilator monitoring system often install multichannel sensor acquisition of fan vibration signal, a big challenge for fault diagnosis process multi-channel vibration signals. The wavelet transform is a new time-frequency analysis method [3]after Fourier Transform, it has higher frequency resolution in the low frequency part and the low time resolution, high in high frequency part of the time resolution and low frequency resolution, wavelet analysis has not only mathematics connotation, but also has important application value.

Wavelet analysis in fault diagnosis applications has just started, many scholars at home and abroad have begun to study [4-5] in this area. The domestic and foreign scholars have conducted in-depth research on theory, method and technology of fault diagnosis, the development of the theory and method of fuzzy expert system and neural network and so on many kinds of diagnosis model, grey theory, based on pattern recognition. The neural

ISSN: 2005-4297 IJCA

network with the input and output nonlinear mapping and parallel processing feature, especially its high degree of self-organization and self-learning ability, make it become a kind of effective method and means for fault diagnosis [6]. Because the wavelet analysis is very suitable for the analysis of non-stationary signals, of course, the analysis of non-stationary signals, it is also effective. Therefore, wavelet analysis can be used as fault diagnosis signal processing is the ideal tool, by which to construct the characteristic factors required for fault diagnosis, or direct extraction of useful information for diagnosis. The fan is the key equipment in the production, to diagnose the vibration fault with this advanced method, can enrich the fan fault diagnosis theory and give better play to the fan in the actual production function. Thus it is an ideal tool for signal processing in fault diagnosis.

2. FFT Transform and Wavelet Transform

There are many treatment methods and tools in signal analysis field, one of the most commonly used is the FFT analysis, and the Fast Fourier Transform (FFT) is the calculation of the Discrete Fourier Transform (DFT) fast algorithm. The basic idea of FFT is a large size DFT decomposed into a plurality of small points of DFT, so as to reduce the amount of calculation [7]. For most of the signal, the FFT analysis is very important, because the frequency components of the signal are very important. The FFT analysis also has its shortcomings, it will be in the time domain signal into frequency domain signal, the time domain information is lost. Through this kind of transformation can not know the exact time of the incident, if the information does not change over a period of time is fixed signal, its shortcomings are particularly prominent. While most signal contains trend of mutation, events start and end features, these features are usually the most important information signal contained, and FFT analysis in the detection of them is helpless.

Wavelet transform from basis function point of view, draw a shift of window function characteristics of the triangle base and short Fourier Transform the Fourier Transform the formation of shocks, basis functions, the realization of signal attenuation; by changing the basis function of the scale factor and displacement factor of time-frequency analysis, is considered a major breakthrough in the tools and methods in recent years, show bright prospects for the analysis of non-stationary signal.

Wavelet transform based wavelet function can be chosen in the following forms

$$\phi_{ab}(t) = \frac{1}{\sqrt{a}}\phi[\frac{t-b}{a}] \quad (1)$$

where a , b are constants and when $a>0$ signal given square integrable $x(t)$, $x(t) \in L^2(R)$, $x(t)$ wavelet transform is defined as

$$WT_x(a,b) = \frac{1}{\sqrt{a}}\int x(t)\phi[\frac{t-b}{a}]dt \quad (2)$$

where a, b and t are continuous variables, so the type is also known as the continuous wavelet transform (CWT). Signal $x(t)$ wavelet transform $WT_x(a,b)$ is a function of a and b, b time shift factor, a is the scale factor. $\phi(t)$ also known as the basic wavelet, or mother wavelet. $\phi_{ab}(t)$ is a family of functions of mother wavelet generated by shift and expansion, called the wavelet basis function, or referred to as wavelet basis.

In the formula(2) , b is to determine the role of $x(t)$ analysis of the time position, i.e. the time center. Effect of scale factor a is the basic wavelet $\phi(t)$ for expansion. By $\phi(t)$ into $\phi(\frac{t}{a})$, when $a > 1$, a is more big, time domain support range. $\phi(\frac{t}{a})$ is becoming larger, on the contrary, when a< 1, the smaller a, a width is narrow. In this way, a and b combined with identified on $x(t)$ analysis of the center position and analysis of the time width.

In the formula(2) , is to determine the role of analysis of the time position, i.e. the time center. Effect of scale factor is the basic wavelet for expansion. By into, when > 1, is more big, time domain support range, is becoming larger, on the contrary, when a< 1, the smaller a, a width is narrow. In this way, a and combined with identified on analysis of the center position and analysis of the time width.

Let $x(t)$ of the Fourier transform for the $X(\omega)$, $\phi(t)$ of the Fourier transform for $\phi(\omega)$, According to the Parsevals theorem the formula (2) can be re expressed as[8]

$$WT_x(a,b) = \frac{\sqrt{a}}{2\pi}\int_{-\infty}^{+\infty} X(\omega)e^{-jwb}d\omega \tag{3}$$

From (2) and (3) the two phase comparison can be seen, $WT_x(a,b)$ in the time domain localization function realization of hope in time domain; frequency domain $X(\omega)$ and $\phi(\omega)$ as the inner product will also reflect local properties $X(\omega)$ at the center frequency, so as to realize the frequency domain localization properties of good.

Therefore, the wavelet transform in the signal analysis has the following characteristics, when a is smaller, the time domain of $x(t)$ observation range narrowed, but the $x(t)$ in the frequency domain observation range is widened, the center frequency and the observed shift to high frequency; on the contrary, when a becomes larger, the $x(t)$ time-domain observation range is widened, frequency range on the narrow, center frequency and analysis of moving to the lower frequency. Its outstanding advantages are that the high-frequency range high time resolution in the low frequency range, high frequency resolution. The ability of localization so in both time domain and frequency domain are.

Therefore, the wavelet transform in the signal analysis has the following characteristics, when a is smaller, the time domain of observation range narrowed, but the in the frequency domain observation range is widened, the center frequency and the observed shift to high frequency; on the contrary, when a becomes larger, the time-domain observation range is widened, frequency range on the narrow, center frequency and analysis of moving to the lower frequency. Its outstanding advantages are that the high-frequency range high time resolution in the low frequency range, high frequency resolution. The ability of localization so in both time domain and frequency domain are.

Wavelet analysis to make up for the lack of FFT analysis, the multi-scale wavelet analysis and FFT analysis are combined for fan, fault detection, can receive the good effect.

3. Wavelet Decomposition and Wavelet Packet Decomposition Principle

Wavelet decomposition is popular to say that the digital signal is decomposed into the superposition of a family of wavelet function, this decomposition can make people in particular time-frequency signal analysis within the range of details. The wavelet function choice functions are displayed[9]:

$$\omega_{s,\tau}(t) = \frac{1}{\sqrt{s}}\omega[\frac{t-\tau}{s}] \tag{4}$$

Let $W_{s,\tau}(\omega)$ be $\omega_{s,\tau}(t)$ Fourier Transform, it must satisfy

$$\int_{-\infty}^{+\infty} \frac{|W_{s,\tau}(\omega)|^2}{\omega} d\omega \prec \infty \quad (5)$$

That is, any shape such as type (1) and satisfy (2) orthogonal function family can be used to form wavelet function, type (2) is called the permit conditions. In the formula(1) in s changes to the function of tension and compression, wavelet form different level; tau changes make the function of translation, the formation of different wavelet place.

Usually the parameter s according to two rules 2^{-k} and 2^k Values, values of τ spacing, formed into two discrete. Digital signal f (T) two into the wavelet decomposition of mathematical expressions are as follows:

$$f(t) = a_{0,0}\omega(t) + a_{1,0}\omega(2t) + a_{1,1}\omega(2t-1) + ... + a_{k,l}\omega(2^j t - l) + ... \quad (6)$$

In the formula, $a_{0,0}\omega(t)$ representation of $f(t)$ the DC component, the zero order wavelet only $\omega(t)$, two level wavelet from $\omega(2t)$ and $\omega(2t-1)$ two shift the wavelet stacking composition, and so on.

The expression in the wavelet decomposition (6), each level of wavelet signal represents the components of different frequency doubling period, all the band just disjoint throughout the frequency axis, so wavelet decomposition can achieve frequency local analysis[10]. On the other hand, because of all the wavelet for a plurality of shift wavelet weighted sums, coefficients of each shift wavelet and reflects the signals of the corresponding frequency band information in each time, namely realizes the local analysis in time domain.

Signal analysis, the main features of the concerns may only reflect on one or several packages, according to the signal frequency band needs analysis, the proper selection of different sized packets to recover the original signal part, extract the characteristic, technology in fault diagnosis is very useful.

4. Multi Scale Wavelet Analysis

Multi scale wavelet analysis is one of the important concept in wavelet analysis, multi-scale it from function space point of view to study the function or signal representation. Multi scale analysis is the role of the signal is decomposed into different spatial part[11]. In addition, it also provides a uniform framework to construct wavelet, but also provides a digital signal decomposition and reconstruction of the fast algorithm.

Assume that the space of $L^2(R)$ a low-pass smoothing function $\phi(t)$, if its integer shift set $\{\phi(t-k)\}_{k\in z}$ satisfying

$$\phi(t-m) \geq \delta(k-m) \quad (7)$$

Then $\phi(t)$ is called scaling function.

Where j is the scale factor; k is the displacement factor. $\{\phi(t-k)\}_{k\in z}$ constitutes a scale space V_j .

When the j changes, translation copy of $\phi(t)$ scaling function of $\{\phi_{j,k}(t)\}_{j\in z,k\in z}$ in different scales are composed a series of scale space V_j.

If a function or a signal $f(t) \in L^2(R)$, $f(t)$ in the projection scale space V_j denoted as $P_i f(t)$, V_j is $L^2(R)$ subspace, V_j only contains the signal, the larger scale so, $P_i f(t)$ called $f(t)$ smoothing approximation in, V_j namely $f(t)$ profile in the scale on the j.

$$a_{j,k} = \langle P_i f(t), \phi_{j,k}(t) \rangle = \langle f(t), \phi_{j,k}(t) \rangle \quad (8)$$

the formula (8) is known as the approximation coefficient, discrete coefficient.

In the analysis of multi scale Mallat, according to the different scale factor j to Hilbert space $L^2(R)$ decomposition for all subspaces of $W_j . V_j$ is to satisfy multi-scale analysis scale space defined. W_j reflects the details of the differences between two adjacent scale spaces, therefore, called $\{W_j\}_{j\in z}$ for wavelet space. So assume that $D_j f(t)$ said projection $f(t)$ in the space on the W_j

$$D_j f(t) = \sum_{k\in z} d_{j,k} \varphi_{j,k}(t) \quad (9)$$

Known as $f(t)$ wavelet transform. Among them

$$d_{j,k} = \langle D_j f(t), \varphi_{j,k} \rangle = \langle f(t), \varphi_{j,k} \rangle \quad (10)$$

The formula (10) is known as Discrete detail. $V_{j-1} = V_j \oplus W_j$ therefore V_{j-1} V_j, W_j this relationship is projected in space $L^2(R)$

$$P_{j-1} f(t) = P_j f(t) + D_j f(t) \quad (11)$$

The multi-scale wavelet decomposition is finished, can be achieved on each frequency band decomposition coefficient layer reconstruction, get the signal corresponding to band. Process of wavelet multi-scale analysis is the process of stripping the band, is the signal wavelet decomposition can be several times, the received signal component at each frequency band, so as to realize the separation of signal characteristics, then each component for processing, according to the characteristics of different frequency band signal, extracting one or several characteristic quantities to characterize the component signal [12].

5. Wavelet Frequency Analysis Technique

Application of multi resolution analysis and wavelet packet analysis technology, can make signal is decomposed into different frequency bands, signal to the frequency band analysis, called the frequency analysis technique [13]. Usually, a user can according to the signal frequency range of interest, the signal is decomposed in a certain scale, so as to extract the corresponding frequency band information. On the other hand, it can also through the statistical analysis of the signal in each frequency band, to form a feature vector to reflect the feature of the signal, if the analysis of signal energy in each frequency band, is known as the frequency band energy analysis.

Fourier analysis can also be used as the frequency band energy spectrum analysis, structure feature vectors of different fault that, in practical diagnosis has been successful. However, the statistical Fourier analysis only on the signal sinusoidal components, the actual diagnosis signals often contain non-stationary components, strictly speaking these signals cannot be described by a sine signal, even if the description of energy said don't face. Application of wavelet for signal analysis, it can describe the non-stationary components in the signal. Especially using the wavelet packet analysis technology, can put the signal decomposition in arbitrary precise frequency, energy statistics in these frequency bands, to form a feature vector, more reasonable.

Wavelet frequency analysis technique and Fourier spectrum analysis technology, its theory basis is the Parseval energy integral equation. Because $f(x)$ in the time domain energy:

$$\| f(x) \| = \int_{-\infty}^{+\infty} | f(x) |^{2} dx \quad (12)$$

$f(x)$ of the wavelet transform is

$$C_{j,k} = W(2^{j}, 2^{j}k) = 2^{-j/2} \int \phi(2^{-j}x - k) f(x) dx \quad (13)$$

The relation of (14) and (15) from the Paseral identity:

$$\int_{-\infty}^{+\infty} | f(x) |^{2} dx = \int | C_{j,k} |^{2} \quad (14)$$

From type to type, the wavelet transform coefficients $C_{j,k}$ has the energy dimension, therefore can be used for energy analysis.

6. Conclusion

Fan fault diagnosis test can be used fan experimental platform, vibration sensor, amplifier, data acquisition system. The vibration sensor to obtain fault signal and amplified by the amplifier, and finally sent to the data acquisition card, and then by the acquisition system to achieve fault signal acquisition and preservation. Then the vibration signal of the fault under the acquisition of wavelet decomposition. After the wavelet details part separated, containing the fault characteristics, characteristics and can further reflect the detailed fault.

Wavelet packet decomposition based on high, low-frequency signals at the same time the equidistant decomposition, realizes the analysis of frequency domain localization can not carry out the analysis of traditional signal, signal reconstruction by selecting the appropriate frequency, can extract the characteristics of signal, to realize the recognition of different fault. Application of wavelet packet decomposition can recognize different fault, shows the superiority of wavelet packet decomposition. Wavelet packet decomposition technology has been more and more widely used in fault diagnosis in fan.

Band wavelet decomposition technology has superiority analysis technology of greater than Fourier in nature. The wavelet energy is more comprehensive, is a true reflection of the actual. Using this technology, re acquisition of fan misalignment and unbalance fault feature vector. Through the multi-scale wavelet transform is applied to the fault diagnosis of fan, and combined with the Fast Fourier Transform, the two complement each other, and achieved good results in fault diagnosis, but also improve the accuracy of fault diagnosis.

References

[1] K. Sun, and L. Shen, “Research on wind turbine fault diagnosis based on wavelet analysis”, Colliery Machinery, 2007, Vol.28, No.8, pp: 200-202.
[2] J. Leng, “Research on fault diagnosis of fan. Colliery Mechanical & Electrical Technogy”, 2003 Vol.17, No.2, PP: 25-27.
[3] S. Jing, “Application of artificial neural network in the fault diagnosis of centrifugal fan”, Colliery Machinery, 2005, Vol.12, No.12, pp: 159-161.
[4] W. Song, “Application of principal component analysis and in fault diagnosis”, China equipment engineering 2001 Vol.10, No.9, pp: 37-38.

[5] H. Hu, “Fault diagnosis for fan based on wavelet analysis”, Journal of Central South University 2007 Vol.38, No.6, pp:1169-1173.
[6] D. E. New land, “Wavelet Anlysis of Vibration, Journal of Vibration and Acoustics”, 1994 Vol.16, No.18, pp: 409 -425.
[7] Z. Geng, “Frequency shift algorithms of wavelet packet and vibration signal processing”, Journal of Vibration Engineering, 1996, Vol.20, No.2, pp: 45- 57. .
[8] J. He and J. Zhao, “Study on non-stationary signal processing machinery monitoring and diagnosis”, Journal of Xi'an Jiao Tong University, Vol.30, No.12, pp: 1996.
[9] B. Liu and S.F. Ling, “On the selection of informative wavelets f or machinery diagnosis”,
[10] Mechanical Systems &Signal Processing, 1999, Vol.13, No.1, pp: 145- 162.
[11] D. Zhang, “Fault diagnosis based on wavelet analysis. Journal of University of Shanghai for Science and Technology”, 2000, Vol.22, No.2,pp: 137 -140.
[12] Z. Chen and G. Luo, “Research on mechanical fault feature extraction based on wavelet analysis”, Mechanical Strength, 2001, Vol.23, No.2, pp: 161-164.
[13] Z. Peng and Y. He, “Study on wavelet multi fractal and its application in vibration signal analysis”, Chinese Journal of Mechanical Engineering, 2002, Vol.3, No.8, pp: 59 -63.
[14] J. Lin, L. Qu, “Feature Extraction Based on Morlet Wavelet and its Application for Mechanical Fault Diangosis”, Journal of Sound and Vibration. 2000, Vol.234, No.1, pp: 135-148.

Authors

Wang Wei, he was born in Xu Zhou, Jiangsu, China in 1983. He received his MS degree in Information and Electrical Engineering from CUMT. He is currently a student working towards his Ph.D. at School of Information and Electrical Engineering, CUMT. His research interests are intelligence optimization and Control, and computer measurement and control technology.

Ma Xiaoping, he was born in Mian Yang, Si Chuan, China in 1961. He received his B.S, M.S. and Ph.D. from the China University of Mining and Technology, China, in 1982, 1989 and 2001. He is working as professor and current Dean in the Department of Information and Electrical Engineering, China University of Mining and Technology. His research area interest includes control theory and applications, network control, computer technology and application.