Research on Fault Feature Extraction for Radar Transmitter Based on HHT

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Abstract—**In order to overcome the difficult in extracting the fault feature of nonlinear and non-stationary signal in radar transmitter, the concepts of Instantaneous Frequency (IF) and Intrinsic Mode Function (IMF), and the specific process of Empirical Mode Decomposition (EMD) and Ensemble Empirical Mode Decomposition (EEMD) based on Hilbert-Huang Transform (HHT) is introduced. HHT is applied in fault feature extraction for radar transmitter in this paper. The rectifier and filter circuit of switching power supply in radar transmitter is simulated for getting the IMF of fault voltage signal by EEMD, and the IF by Hilbert Transform. Simulation result shows that HHT can fully detect the fault feature and accurately locate the fault signal of radar transmitter, and it has the high reliability in fault feature extraction.**

Keywords-Hilbert-Huang Transform; radar transmitter; fault feature extraction; Ensemble Empirical Mode Decomposition

I INTRODUCTION

The fault of radar transmitter concentrated in analog circuit mainly. The analog circuit of transmitter is a complex nonlinear system, and the fault signal is nonlinear, non-stationary and non-Gaussian signal. It's difficult to establish model of the fault signal by using conventional method. Fourier transform is suitable for linear time-invariant system and global analysis. The disadvantage of Fourier transform is the contradiction of localization between time domain and frequency domain. It can't get the enough information in frequency domain if it can get the enough information in time domain, and vice versa. Wavelet transform is the general method for nonlinear and non-stationary signal. Wavelet transform can solve the contradiction of localization between time domain and frequency domain. But the wavelet basis function is finite, the energy of fault signal will be leaked, and the analysis of time-frequency will be influenced as a result of using wavelet transform. At the same time, the wavelet basis function and decomposition scale of wavelet transform are related to sampling frequency of signal. Wavelet transform can't reflect the essential characteristics of signal and don't have self-adaptive ability.

Hilbert-Huang transform (HHT) is proposed by N. E. Huang and his partners in 1998. HHT is suitable for nonlinear and non-stationary signal as a new analysis method, and HHT have self-adaptive ability [1]. HHT overcomes many deficiencies of Fourier transform and wavelet transform. NASA considered HHT to be the most important application in mathematics. HHT broke through the analysis of linear and steady state spectrum based on Fourier transform, and has the epoch-making significance [2]. Therefore, HHT obtained the rapid development in engineering application in recent years.

II PRINCIPLE OF HHT

HHT includes two process of Empirical Mode Decomposition (EMD) and Hilbert transform, and the key process is EMD. All complex date set can be decomposed into a limited number through the EMD steps, and the number of Intrinsic Mode Function (IMF) is usually handful [3]. IMF expresses each of the local frequency structure or oscillation structure of signal. Getting the instantaneous frequency by Hilbert transform directly is meaningless, because general signal contains a variety of oscillation mode. The significant physical interpretation of instantaneous frequency can be given by using Hilbert transform on IMF of HHT.

Therefore, the analysis of signal based on HHT includes the following two steps.

Step1: Get the sum of finite IMF component by preprocessing data and decomposing signal based on EMD. This step is used for spreading the data.

Step2: Get a meaningful instantaneous frequency of signal by using Hilbert transform on each decomposed IMF.

A Instantaneous Frequency

$x(t)$ is a continuous time signal, its Hilbert transform is

$$\hat{x}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x(\tau)}{t-\tau}d\tau$$

The inverse transform formula is

$$x(t) = -\frac{1}{\pi}\int_{-\infty}^{\infty}\frac{\hat{x}(\tau)}{t-\tau}d\tau$$

The analytical signal of $x(t)$ is

$$z(t) = x(t) + j\hat{x}(t) = a(t)e^{j\theta(t)}$$

Among them, $a(t)$ is instantaneous, and $\theta(t)$ is instantaneous phase.

$$a(t) = \sqrt{x^2(t) + \hat{x}^2(t)}$$

$$\theta(t) = \arctan\frac{\hat{x}(t)}{x(t)}$$

The instantaneous frequency is

$$f(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt}$$

Published by Atlantis Press, Paris, France.

$f(t)$ is a single function of t, and it can be seen by the definition of instantaneous frequency. However, there is no definition of single component signal at present. We can't judge whether a function is a single component.

B Intrinsic Mode Function

The necessary condition is given by HHT in order to make the instantaneous frequency meaningful. The function must be symmetrical on the local zero mean. The number of zero-crossing must be same with the number of extreme point. IMF is a function which can meet the following two conditions based on the necessary condition.

Condition 1: The number of zero-crossing and extreme point is equal to or less than 1 in the time range of whole function.

Condition 2: The mean of up and down envelope which is constituted of local maximum point and local minimum point must be 0 at any moment. That is to say, the up and down envelope is locally symmetrical on the time axis.

Condition 1 is the same with the narrow band condition of traditional stationary Gaussian process. There is no minimum greater than zero and maximum less than zero in IMF. Condition 2 is change the traditional global condition into local condition. There is no unhopeful fluctuation due to asymmetric waveform in instantaneous frequency. Therefore, IMF contains only one mode of oscillation instead of complex ride-wave according to the definition.

C Empirical Mode Decomposition

EMD is based on signal characteristic, and don't need to select base function in advance. EMD has strong self-adaptive ability. Filter can decompose arbitrary signal into the sum of some IMF and a remainder, and it's the core of HHT. The process of EMD is based on the following hypothesis [4].

Hypothesis 1: There is a maximum value and a minimum value at least in signal.

Hypothesis 2: The characteristic in time domain is based on the interval of extreme value.

Hypothesis 3: It can get the extreme value through one or more derivation and decomposition results through integration if data sequence is completely lacking.

EMD process contains the following specific steps.

Step 1: Extract all of the local maximum and minimum point from original signal $x(t)$. Use cubic spline interpolation function to simulate the up and down envelope of signal. The up and down envelope should include all of the signal data point.

Step 2: Calculate the average m_1 of up and down envelope. Original data $x(t)$ minus m_1 is h_1.

$$h_1=x(t)-m_1$$

h_1 don't meet the conditions of IMF usually. h_1 is the first IMF component of signal $x(t)$ if h_1 meet the conditions.

Step 3: Make h_1 as the original data if h_1 don't meet the conditions. Repeat the above steps until meeting the conditions. Make

$$c_1=h_1$$

c_1 which meet the conditions of IMF is the first IMF component of signal $x(t)$.

Step 4: The original signal $x(t)$ minus c_1 is remainder r_1.

$$r_1=x(t)-c_1$$

Step 5: Repeat the above steps by making the remainder r_1 as the original signal. The cycle is end when the kth remainder r_k is monotone function after repeating k times.

$$\begin{cases} r_2 = r_1 - c_2 \\ \vdots \\ r_k = r_{k-1} - c_k \end{cases}$$

Get $x(t)$ by the above steps.

$$x(t) = \sum_{i=1}^{k} c_i + r_k$$

Among them, r_k is the remainder of signal. It can reflect the smooth trend of signal in a certain extent.

D Ensemble Empirical Mode Decomposition

The research based on a large amount of data found there is frequency aliasing phenomenon in EMD process when the data is impure white noise. The measure data will fuse signal and noise in a certain extent. It is difficult to avoid frequency aliasing phenomenon during EMD process. Z. Wu and N. E. Huang put forward a data analysis method of noise auxiliary called Ensemble Empirical Mode Decomposition (EEMD) [5].

Principle of EEMD: The time-frequency space is divided into components in different dimensions by filter group when additional white noise distributes in the whole time-frequency space equably. The signal area of different scales will be auto-mapped to appropriate scales which related to background white noise when the signal is added with white noise background of equably distributing. Each independent test may produce a very noisy result. Because each additional noise component includes the signal and additional white noise. The noise is different in each independent test. So the noise will be eliminated when using global average of enough tests. The global average will be considered as the real result finally. The only persistent part is the signal itself, and enough tests are added in order to eliminate the additional noise.

EEMD process on the basis of EMD contains the following specific steps.

Step 1: Add white noise sequence in the measure data.

Step 2: Decompose the sequence added white noise into IMF using original EMD process.

Step 3: Add different white noise in different time, and repeat the above steps.

Step 4: Make the average of decomposed IMF component as the final decomposition result.

III FAULT FEATURE EXTRACTION FOR RADAR TRANSMITTER

The fault signal is gotten by simulating the input rectifier and filter circuit in switching power supply of radar transmitter using the software of OrCAD 16.5. The basic circuit of switching power supply is shown in figure 1.

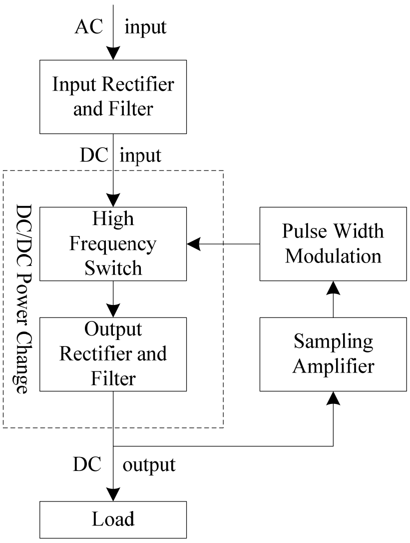

Figure 1 The basic circuit of switching power supply

The input rectifier and filter circuit for simulating is shown in figure 2. The simulation of fault injection is though decreasing filtering inductance value.

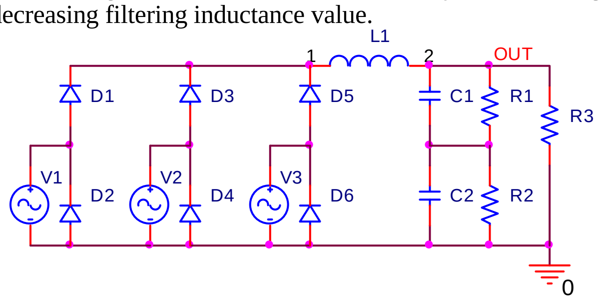

Figure 2 The input rectifier and filter circuit for simulating

Get the voltage value of output node OUT in the input rectifier and filter circuit though simulating. The time of simulation is 1 second. The voltage signal of node OUT in normal circumstance is shown in figure 3, and the voltage signal of node OUT in fault circumstance is shown in figure 4.

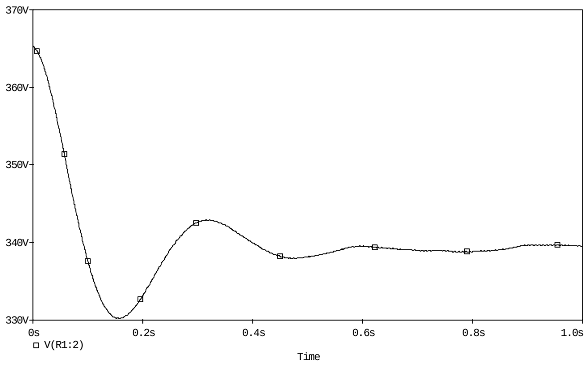

Figure 3 The voltage signal of node OUT in normal circumstance

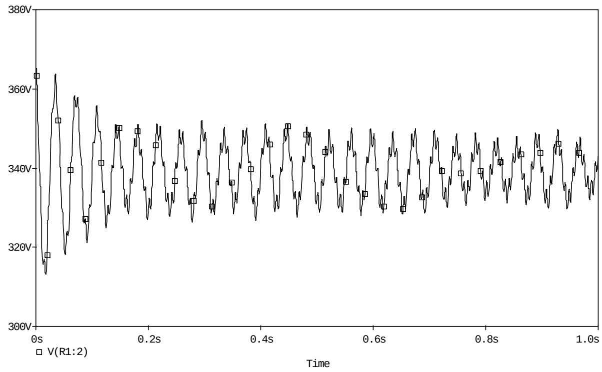

Figure 4 The voltage signal of node OUT in fault circumstance

The IMF of fault voltage signal is shown in figure 5. The IMF is gotten by EEMD process based on the fault voltage of 0 to 150 milliseconds. From top to bottom in figure 5 are the components of IMF 1 to IMF 5, and the last one is component of remainder.

It can be seen from figure 5 that the components from IMF 1 to IMF 5 have gotten more and more smooth. It reflects that the EEMD process has the ability of extracting the fault signal and separating the signal and noise. EEMD has a good performance of noise resistance.

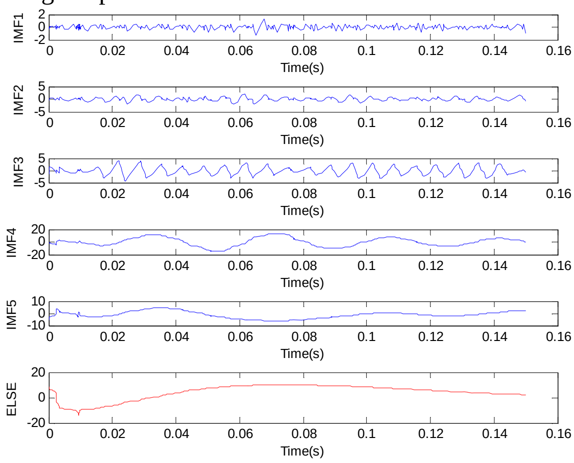

Figure 5 The IMF of fault voltage signal

The component of IMF 4 is concentrated the main energy of fault signal, and it also maintains the main feature of original signal. The Instantaneous Frequency (IF) of IMF 4 can be gotten by Hilbert transform. The instantaneous frequency of IMF 4 is shown if figure 6.

It is obvious that the fault of circuit occurred in 10 milliseconds point. The circuit shows the symptom of fault after working about 10 milliseconds because the value of filtering inductance had changed. At the same time, it can be seen that the input rectifier and filter circuit could wok but cannot meet the requirements of DC input in switching power supply. So extracting the fault feature of radar transmitter based on HHT can accurately find the system failure in good time. It gives the chance to take corresponding measure for debugging and guarantee the normal work of the system.

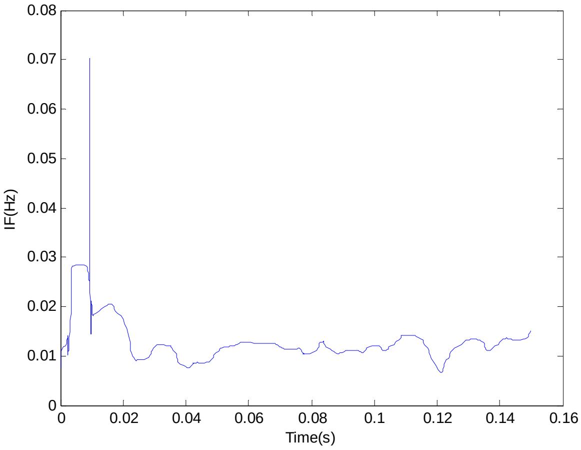

Figure 6 The instantaneous frequency of IMF 4

IV AFTERWORD

HHT can effectively achieve the fault feature extraction for nonlinear and non-stationary signal. It can overcome the shortages of wavelet transform that wavelet transform don't have self-adaptive ability and leaks the energy of signal in process. EEMD as a improved algorithm can avoid frequency aliasing phenomenon in the analysis of impure white noise. HHT can locate and detect the fault based on the analysis of instantaneous frequency and instantaneous amplitude in the common fault signal extraction. It is more effective to diagnose and predict the fault of system by combining HHT with intelligent fault diagnosis technology such as support vector machine, neural network and fuzzy inference in some complex system.

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