Fault identification of wind turbine transmission system based on root mean square and Zoom-FFT

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Abstract: This paper proposed a method based on root mean square and Zoom-FFT (detailed fast Fourier transform) to detect the operation state of the transmission system of wind turbine, which can extract the characteristic information and complete the fault identification. Firstly, the root mean square of the vibration signal was gotten to detect wind turbine failure, and then the method of Zoom-FFT was adopted to determine the fault type. It can also distinguish when and where the failure happened. Simulation and field experiment results validated the effectiveness of the proposed method.

1. Introduction
With the increasing installed capacity of wind power units, the new related monitoring technologies have been put forward[1]. At present, many of the wind turbines have equipped the acceleration sensors to collect corresponding vibration signals from transmission system, which aims to extract the fault feature of the signals, monitoring and diagnosing the condition of wind turbine[2-4]. However, the wind turbine rotates at a variable speed, which is different from the conventional equipment, so these single indicators, such as the root of vibration signal amplitude, maximum, minimum, kurtosis value etc, are not able to fully reflect the running condition of wind turbine.

This paper uses the root mean square (RMS) of vibration signal as an early warning value to determine whether a wind turbine is failure or not. The RMS of all signals are collected at periodic intervals, we utilize them to plot the wind turbine operation of RMS spectrum, and then by observing the amplitude of RMS, the running state of the wind turbine can be easily determined. On the other hand, this paper adopts the methods of time-frequency analysis to analyse the signal data which is collected from fault location, and then the method of Zoom-FFT is used to post-process these signals which is benefit to the next step of analysing the frequency signals from specific frequency bands in details. In the end, through the analysis of specific frequency of Zoom-FFT, the fault type of wind turbine which has occurred can be clearly determined.

2. Mechanism of RMS value of vibration signal
Suppose the measured signal of wind turbine gearbox collected by high speed axis acceleration sensor is

\[ x = (x_1, x_2, \ldots, x_N), \quad N = 1, 2, 3, \ldots \]

then we plug it into the following formula of RMS:
\[ S = \sqrt{\frac{1}{N} \sum_{i=1}^{N} x_i^2} \]  \hspace{1cm} (1)

\( S \) is root mean square.

The \( s_1, s_2, \cdots, s_N \) signals are collected at the same interval time \( T \). The number of signals collected within time \( T_i \) is \( N \), and the root mean square is drawn to RMS spectrum, which the horizontal axis stands for time, and the longitudinal axis stands for RMS value.

The following step is to take out the state characteristic index from the collected acceleration signals. Although the measured voltage signals have both positive and negative values, RMS value can well eliminate the effect from symbols, so it can better reflect the discrete measured error signal; thus, the RMS value is chosen as the main index to determine the running state of wind turbine.

### 3. Refining process of Zoom-FFT in complex frequency domain

Zoom-FFT is utilized to amplify the frequency-domain signal locally, in that way, the frequency band which is beneficial can obtain higher frequency resolution. Therefore, Zoom-FFT is very suitable for the wide frequency range analysis and high frequency resolution[5,6]. The specific steps of Zoom-FFT are as follows, and the detailed steps are shown in Figure 1:

1) According to the principle of sampling theorem, firstly there supposes the input signal is \( X(t) \), which is utilized to prevent the aliasing of the sampled signals. Secondly, we set the high sampling frequency \( f_s \) by simulating the low-pass filter; then we collect enough signal data from them, the length of which is the product of the multiples of the Zoom \( D \) and the length of FFT, \( N_{FFT} \), which can be called \( DN_{FFT} \).

2) Modulate the sampling signal and multiply the original signal with the unit rotation factor.

\[ X(n) = X(n) e^{-j2\pi f_1 n} \]  \hspace{1cm} (2)

In this formula: the \( f_1 \) is the frequency needed to be zoomed, and the \( X(n) \) is the new signal which uses the \( f_1 \) as the zero frequency.

3) Filter the data by using the low-pass digital filter after the process of frequency shift, and then remove the components which need to Zoom. The minimum frequency required for the low-pass filter is \( f_s / (2D) \).

4) Resampling the filtered data, and the sampling frequency is \( f_s / (2D) \). Namely we collect a data every other interval of Zoom multiple, and the interval is \( D-1 \).

5) Use the FFT to calculate the resampling data, the length of which is \( N_{FFT} \).

![Flow chart of Zoom-FFT in complex frequency domain](image)

**Figure 1** Flow chart of Zoom-FFT in complex frequency domain

Let the simulation signal be:

\[ x(t) = 3 \sin(2\pi \times 100t) + 6 \cos(2\pi \times 102t) + 2 \cos(2\pi \times 104t) + 4 \cos(2\pi \times 106t) \]  \hspace{1cm} (3)

The sampling frequency is 8000HZ, the number of sampling points is 1024, and the waveform of the signal is shown in figure 2:
As is shown in Figure 3 and Figure 4, in the traditional FFT transform, the numerical difference in the spectrum of 3 signals $x(t)$ is usually not obvious, which cause showing only one peak, so it cannot clearly identify the signal components of the four frequencies in the original signal. Nevertheless, after the Zoom-FFT transform, not only the frequency in the section of the 100HZ~110HZ band is well amplified, but also we can get four clear peaks from it. The information extracted from them is quite useful for us to determine the fault type lately.

4. Experimental verification and analysis
This experiment takes Hua Rui 1500 model wind turbine for example. Figure 5 shows the position of measuring points. The sampling points are placed in horizontal direction which is next to the bearing side, and the experiment takes the fault data of one month as the sample, the sampling frequency is set to 1024HZ, and we sample them every half hour, including the number of sampling points, which are 16384. After setting these parameters, we calculate the RMS value at the interval of each 16384 points, and then plot the RMS value spectrum. Table 1 shows the parameters of Rolling Bearing, and Table 2 is the Gearbox.
### Table 1 Rolling Bearing Parameters

| Component position | Ball position | BPF | O | BPFI | O | FTF | O | FTFI | O |
|--------------------|--------------|-----|---|------|---|-----|---|------|---|
| High speed shaft (generator side) | 16 | 6.736 | 9.26 | 4 | 0.42 | 1 | 9 |
| High speed shaft (Impeller side) | 13 | 5.124 | 7.78 | 6 | 0.40 | 1 | 9 |
| Gear box sun shaft | 11 | 6.125 | 8.35 | 3 | 0.411 | 0.55 | 4 |

### Table 2 Gearbox Parameters

| Gear position | Position code | The teeth number |
|---------------|---------------|------------------|
| First solar wheel | Zsl | 24 |
| Primary planetary gear | Zp1 | 39 |
| First stage inner gear ring | z1 | 102 |
| Two stage solar wheel | Zs2 | 24 |
| Two stage planetary gear | z2 | 39 |
| Two stage inner ring gear | z3 | 102 |
| Low speed shaft | z4 | 27 |
| High speed shaft | z5 | 102 |

According to figure 6, we can clearly observe the peaks of measuring point H5, in the number of sampling groups 1010, 1012, 1021, and 1023, are larger than RMS, and they have larger warning value, which indicate the failure occurred at that wind turbine components where measuring point H5 itself represents. The failure time can be obtained through the following common formula:

\[ T_i = M \times \left( T + \frac{N}{F_s} \right) \]  \hspace{1cm} (4)

\( T_i \) is the failure time, \( M \) is the number of sampling groups, \( T \) is the interval time, \( N \) is the sampling point, \( F_s \) is the sampling frequency.

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By formula (2), we can conclude that the fault occurred at the position of the high speed shaft after 594.7 hours’ monitoring. And the frequency spectrum can be easily drawn before and after the fault.
occurs. As shown in Figure 7, the amplitude is obviously enhanced at the frequency of 280HZ, and the vibration frequency can be calculated by the formula (5):

\[ f_B = R \times N_{Ball} \]  

(5)

\( f_B \) is the vibration frequency of gearbox high speed shaft, \( R \) is the speed, and \( N_{Ball} \) is the number of balls. It turns out the gearbox high speed shaft is the fault location, but we can not clearly judge which type of the fault is. So in order to solve this question, there adopts the Zoom-FFT spectrum to zoom the peak value of the fault vibration frequency, besides, we analyse these data taken out from the early and middle stage of fault, the peak point of RMS and the data of later stage, which spectrum magnification is set to100, to determine it further.

Figure 8-11 present, after Zoom-FFT transform, each peak of data which is from high speed shaft fault can be subdivided into a combination of several peaks in the frequency domain, and the times of complex frequency domain is 100. Through observation, it is not difficult to find that the peak value in frequency domain spectrum gradually increases with the zoom of fault severity, and the peak value of vibration frequency in the peak equivalent bandwidth is also increasing gradually. On the other hand, in the middle stage of fault, the peak value, the equivalent bandwidth and the number of frequency are obviously increased; while in the later stage of the fault, the frequency of the peak equivalent bandwidth is no longer increased, but the distribution become more mean. Through using the Zoom-FFT analysis, we can conclude gearbox high-speed shaft vibration with different vibration frequency of signal increased significantly in the initial stage to the fault occurrence, it indicates that high speed gear shaft elements experience a change from the process of wearing until the fracture failure, to the next process of a new wearing until the gears are properly joined again. In the meantime, the new vibration frequency to the gear meshing frequency is reduced in the same time, but the number of vibration signal is different.

5. Conclusion

1) The RMS value which is used as the main monitoring index can show the severity and the time of failure. The method based on RMS and Zoom-FFT is proposed, it can detailedly and precisely distinguish the special frequency components of the signal.
2) Simulation and field experiment results validate the effectiveness of this method in improving the fault recognition rate of wind generator, which provide the necessary conditions for the next step of wind turbine's on-line condition monitoring.

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