Motor Fault Diagnosis Based on Wavelet Analysis and Fast Fourier Transform

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Abstract. For the detection of the broken-bar fault of rotor in motors, a traditional method is frequency spectrum analysis for the stator current. However, the frequency components representative of the rotor fault can be easily submerged by the fundamental frequency, so that the detections results are inaccurate. In this paper, the stator current will be decomposed and reconstructed, after that the fast Fourier transform can be applied to the frequency spectrum analysis. It eliminates the influence that the fault characteristic components are flooded by the basic frequency components. The experiment result shows that the existence of a slight fault in rotor can be detected. The method has a good theoretical and engineering application.

Introduction

In recent years, the development of fault diagnosis technology is rapid, and the scientific achievements are emerged constantly. As the main energy and power equipment of modern industry, the role of the motor is self-evident. If the motor which drags the production equipment takes place failure, it will break off the process of production resulting in enormous economic loss. So the researches of the motor fault monitoring and diagnosis have important theoretical research value and significance of project practice. Wavelet and wavelet analysis is a new method which has developed significantly in recent years, it breaks through the limitation of the traditional Fourier transform without any resolution limitations in the time domain, and has good characteristics about time-frequency analysis, especially for the processing of non-stationary signal. The frequency components existing in stator current is \((1\pm 2s)f\) when the rotor of asynchronous motor is broken, while we use wavelet decomposition aiming at the stator current of the fault motor, the decomposition coefficients of corresponding band can be obtained, but the analysis results of frequency points can’t be obtained by carrying out the wavelet decomposition about the stator current of fault motor. Although the fast Fourier transform doesn’t have time resolution, it can get the analysis results of each frequency point. Therefore, this article analyzes the fault about rotor using wavelet analysis combined with fast Fourier transform and makes a good progress.

Mechanisms of Rotor Bar Breaking Fault and Characteristic

The ideal three-phase asynchronous motor stator current frequency is single, which is the power frequency. But when the rotor circuit fails, the stator current spectrum will appear a sideband on twice the slip frequency \((2sf)\) from the power frequency, this phenomenon has been confirmed by the British theoretical scholars Hargis, and the characteristic frequency \((1\pm 2s)f\) is very close to the power frequency \(f\). When power supply frequency is \(f\), the motor stator winding of the asynchronous motor with \(P\) poles will produce Magnetic Motive Force (MMF) of \(m_1\), the fundamental wave expression is shown in Eq.(2.1)
\[ m_1 = K_1 N_1 I_1 \sin(\omega t - p \theta) \]

Where,
- \( K_1 \) — Constant which related to the pole number and winding coefficient,
- \( N_1 \) — Number of the stator turns of winding on each phase,
- \( I_1 \) — Stator current,
- \( \omega \) — Grid angular frequency,
- \( \theta \) — The initial phase angle of rotor winding phase angle that is showed by the mechanical angle,
- \( \phi = \theta - w_r t \)

Where,
- \( w_r \) — The rotor rotating angular velocity,

For bipolar (P = 1) motor, the MMF is shown in Eq.(2.3)

\[ m_1 = K_1 N_1 I_1 \sin((\omega - w_r) t - \phi) \]  

The difference between rotor speed and stator rotating magnetic field is the slip, the rotor winding will produce induced current under the action of the stator rotating magnetic field, and establish a rotor MMF with a balance of the stator MMF, the expression of Rotor MMF is given by Eq.(2.4)

\[ m_2 = K_2 N_2 I_2 \sin((\omega - w_r) t - \phi) \]  

When the rotor winding malfunction, for example, the broken-bar fault, the current MMF of rotor will be modulated by \( \sin 2\phi \), then the MMF of rotor winding will become the following expression

\[ m_2 = K_2 N_2 I_2 \sin((\omega - w_r) t - \phi) \sin 2\phi \]  

Thus,

\[ m_2 = K_2 N_2 I_2 \cos((\omega - w_r) t - \phi) \]  

As MMF of the rotor and stator keep balance each other, we obtain the MMF expression of the rotor (as is shown in Eq. (2.7)) according to the Eq. (2.2) and Eq. (2.6)

\[ m_t = m_2 = \frac{K_2 N_2 I_2}{2} \{\cos[(\omega + 2w_r) t - 3\phi] - \cos[(\omega - 2w_r) t + \theta]\} \]

For the bipolar motor, the slip is given by

That is,

\[ \omega_r = (1 - s) \omega \]

So that the following expression are obtained

\[ m_t = \frac{K_2 N_2 I_2}{2} \{\cos[(3 - 2s) \omega t - 3\phi] - \cos[(1 - 2s) \omega t - \theta]\} \]

According to the Eq.2.9, the first component of MMF contains \( 3\omega t \) and \( 3\theta \), which will bring a zero-sequence electromotive force (EMF) in three-phase stator winding, which have no effect on the power current. The component of the second Magnetic Motive Force (MMF) contains a less \( 2\omega \) component than power angular, this component will make the stator winding of asynchronous motor produce a three-phase current component which is less \( 2\omega \) component than the power angular, and it is very close to the source current frequency, because of its modulation effect, stator current will appear cyclical change, the cyclical pulsing of current will make the stator ammeter pointer swing, also make the torque of motor pulsate subsequently, therefore the speed of the rotor of asynchronous motor will be also volatility by twice the slip. The fluctuation of speed will make the current of asynchronous motor swing between the upper and lower limit (\( \pm 2s \omega \)) with power frequency as the center. Due to modulation effect of the third harmonic in the motor stator, such speed and current fluctuation will make the current of asynchronous motor swing between the upper and lower limit (\( \pm 2s \omega \)) with power frequency as the center.
fluctuations will become more apparent. The ratio of edge band current and base wave current has a
direct relationship with the extent of damage induction motor rotor. The number of rotor broken bars
can be estimated by Eq.2.10
\[ N \approx \frac{2Z_2}{I_1 / I_2 + 2P} \]  
(2.10)

Where, \( I_1 \) and \( I_2 \) are the spectrum amplitude of \( f \) and \((1\pm2s)f\) respectively, \( Z_2 \) is the slot
number of rotor core, \( P \) is the pole logarithm, \( N \) is the number of broken bars of rotor.

**The application of wavelet transform in fault diagnosis**

The stator current will produce the frequency components of \((1\pm2s)f\) when rotor bars are broken
based on the above section. So according to the frequency components of \((1\pm2s)f\) in the spectrum,
we can know the rotor is broken or not. But the amplitude of the frequency components of \((1\pm2s)f\) is
very less than \( f \) when the rotor bars are broken minor, and the slip \( s \) is very little to lead to \((1\pm2s)f\)
is close to \( f \) when the motor is running, so the frequency components of \((1\pm2s)f\) are easy to inundate the
frequency components of \((1\pm2s)f\) when we analysis spectrum by fast Fourier transform. Thus the
existence of the detecting frequency component of \((1\pm2s)f\) becomes very difficult. But in recent
years, the wavelet analysis method is proposed to solve this problem.

Wavelet transform is a local transform in space and frequency, which can obtain the function and
signal detail information by the operation function of compressing or expanding and moving. Finally
we achieve the goal that time is divided carefully on the high frequency place, and frequency is
divided on the low frequency place, so wavelet transform can pick up characteristic signal effectively
from signal. Figure 1 illustrates the process of wavelet decomposition with three layers wavelet
dercomposition.

As is shown in Figure 1, \( S \) is the original signal, \( AA \) and \( AD \) are the low-frequency and the
high-frequency coefficients of the decomposed signal respectively, and the each number represents
the wavelet decomposition layers. The formulate can be got
\[ S = AA3 + AD3 + AD2 + AD1 \]

It is very important to select the appropriate wavelet basis in the process of wavelet analysis. The
waveforms of different wavelet functions are very different, and there is also a great difference
between its support length and regularity. For the same signal, the processing results will have large
differences by different wavelet basis which will affect the final processing results. So the
 corresponding wavelet basis function is selected based on different fault characteristics of signal
when the signal is decomposed. Because the stator current characteristic signal of \((1\pm2s)f\) is
symmetric when the rotors of asynchronous motor are broken, the wavelet basis function of coif5 is
used which has perfect symmetry conduct in the wavelet transforms.

In this paper, \((1\pm2s)f\) frequency band for the fault characteristic signal are better extracted by the
process of filtering, decomposition of the wavelet transform.
Experimental results analysis

In this paper, the asynchronous motor is used, the parameters are as follows: rated power 5.5KW, rated frequency 50HZ, rated voltage 380V, rated current 10A, rated speed 1500 r/m, the stator current signal is analyzed by wavelet decomposition and fast Fourier transform. Firstly, the samples of 4096 is used, and the stator current is transformed by using the fast Fourier transform, then observes whether the stator current have harmonic component near the fundamental frequency in the spectrum diagram. Then, the current signal is decomposed with Coif5 wavelet basis on three layers, and the wavelet decomposition coefficient is extracted which can reflect the fault features, then the wavelet decomposition coefficients of the node is reconstructed, finally, the reconstruction coefficient is transformed by fast Fourier method to observe the spectrum charts whether there are any harmonic component. The current signal of the asynchronous motor rotor stator with broke rotor is shown in Fig2. Figure3 is the frequency domain figure after fast Fourier transform, Figure4 shows the wavelet decomposition coefficient after the three layers wavelet decomposes, Figure5 is the reconstructed figure and complex reconstructed figure of a0 after wavelet decomposition and reconstruction, Figure 6 is the frequency domain figure after wavelet decomposition, reconstruction and fast Fourier transform.

Compared with Figure3 and Figure6, it is difficult to find rotor failure in the frequency domain by fast Fourier transform. However, the harmonic signals of the broken rotor bar can be seen clearly by wavelet analysis and fast Fourier transform in the frequency domain, so that the fault is detected easily.
Summary

About the harmonic that is generated by the stator current when the rotor breaks bars, by taking advantage of the good localization properties of wavelet in time domain and good analysis characteristics of fast Fourier transform in frequency domain, this article proposes a fault diagnosis method based on wavelet transform combined with fast Fourier transform. First the stator current is decomposed with wavelet, which can extract wavelet coefficients that reflect failure features. Then the wavelet coefficients are reconstructed. Finally, implementing fast Fourier transform to reconstruct the signal, then the frequency domain plot of reconstructed coefficient is obtained. Based on the presence of harmonic components in the frequency domain plot, the existence of failure is determined in the rotor. The experimental results show that this method has broad application prospects, as it can easily complete the detection even when the rotor has minor fault, and compensate the shortage of Fourier transform.

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