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Detection of induction motor broken bar fault through envelope analysis using start-up current

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Abstract

This paper has developed a technique for extraction of Low frequency oscillations below 50 hz from start-up motor current transient for detection of broken rotor fault in induction motor through envelope analysis based on instantaneous frequency defined as phase variability. The instantaneous frequency is introduced here as sinusoidal or periodic frequency is quite ineffective in tracking the fast changing frequency and amplitude during start-up motor transient. Envelope is the argument of the analytic signal obtained from complexing the start-up motor current as the real part and its Hilbert transform as the imaginary part. As the envelope works on narrow band frequencies or mono-component signal, it was analyzed using higher order wavelet at higher wavelet level which belongs to the narrow band harmonics / frequency components. In this method , the traditional difficulties in complete masking of the small amplitude harmonics or frequency components close to fundamental during FFT or problems of selecting mother wavelet(not a known priori) for transient analysis based on periodic frequencies have been overcome. Detail coefficients at higher wavelet level below 50 hz are processed to determine Power Detail Density, defined as PDD and Power Detail Energy, defined as PDE for faulty and healthy motor. PDD and PDE have been used here as fault parameters.The method works with higher detectabiliy and higher resolution. It requires less computational time,less processing power for which it can be utilized simultaneously online as well as offline. The method has been validated in a laboratory prototype.

Keywords: Broken bar, Induction motor; Instantaneous frequency; Envelope; Hilbert transform; Wavelet, PDD; PDE.

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1. Introduction

Induction motor, the principal drive in the industry though robust is not free from failure. Generally common failures in induction motor are broken rotor bar and end ring fault, misalignment of rotor, air-gap eccentricity stator winding short and open, bearing failure which are internal apart from external power line or gearbox failure.

As per the survey study [1], the rotor related faults including broken bar fault-present subject of discussion contributes around 5-10% of total failure.

Most of the fault diagnostic techniques used for identification of induction motor faults used, major parts are covered by non-invasive MCSA technique through FFT analysis of motor stator current at steady state based on monitoring of the side band harmonics close to supply frequency , or its other harmonics[2-6] as given in equation (1)

$$f_{fault} = \left(1 \pm 2ks\right) f \tag{1}$$

But right side harmonics may be affected due to speed and load oscillation, motor constructional feature which may produce similar type of harmonics, making diagnosis confusing [7].To avoid researchers concentrated on left side bands. Despite, these band of frequencies may completely masked by power frequency spectral leakage when the motor current have low in amplitude or close to supply frequency when motor operating at no load or light load. To overcome these recently starting current being very, high even at no load have used through wavelet analysis [8] produces good results. Motor current during speed and load changing [9], starting vibration transient [10] are also being used through wavelet analysis. But selection of mother wavelet is not an easy task, if not proper, serious error may occur in the results. To overcome these a new methodology is proposed in this paper to extract low frequency below 50 hz based on instantaneous frequency through envelope analysis of motor start-up current using Hilbert transform and higher order DWT at higher level.

2. Theoretical overview

2.1. Instantaneous frequency and Hilbert transform: The concept of instantaneous frequency have introduced for better analysis of transient signal. The instantaneous works on phase variability as defined, $f_i = (1/2\Pi)\, d\Phi/dt$ where Φ is phase. It can be treated like periodic frequency if the signal is represented in the form of AM / FM signals $me^{j\Phi t}$ [11]. This can be done by Hilbert transform of s(t), the original signal[11].The complex form of the signal is known as analytic signal. The unique complex representation of a real signal, s(t) is given by

$$z(t) = s(t) + j[H[s(t)] \tag{2}$$

where $H\left[s(t)\right]$ is the Hilbert transform of s(t). By Hilbert transform, the positive frequencies are shifted in phase by -- *Π /2* whereas negative frequencies are eliminated and the amplitudes of the frequency components doubled. If the signal is of the form of α(t).cos Φ(t) like a real FM signal and its complex analytical signal, z(t) may be given by

$$z(t) = \alpha(t) e^{j\Phi(t)} \tag{3}$$

2.2. Envelope analysis: The envelope of a complex signal, z (t) is defined as

$$E(t) = \left|s(t) + jH\left[s(t)\right]\right|$$

$$\text{Or } E(t) = \alpha(t) \tag{4}$$

That is, the absolute value of the analytic signal defined in equation (3). The envelope signal occupies the low frequency spectral region, the analysis of which gives better detection than the spectrum analysis of the original signal as the power frequency is eliminated from the signal.

2.3. Discrete Wavelet transform (DWT): DWT decomposes a sampled signal s(t) by passing it through HPF(high pass filter) and LPF(low pass filter) into its approximate coefficients a_n and several detail signals d_j . Figure1 shows typical two level wave decomposition. The decomposition can be iterated with successive approximation being decomposed in turn.High pass filter coefficients are called detail coefficient (d_n) and low pass filter coefficients are called approximate coefficients (a_n).Each of the wavelet scales corresponds to a frequency band for sampling frequency 8192 cycles/sec.given in Table 1.

Power detail Density : It is defined as $PDD = d_j \times d_j$ (5)

Power Detail Energy: It is given by $$PDE = \sum_{1}^{N} (d_j \times d_j) \tag{6}$$

where level of decomposition j , containing no. samples N.

Table 1 Spectral Frequency Bands at different decomposition levels

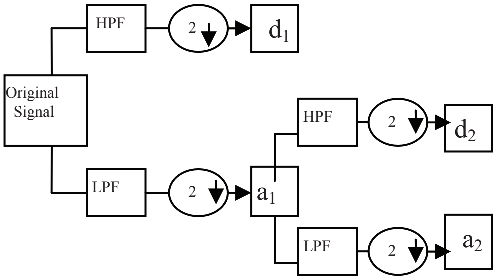

Figure 1: Two Level DWT decomposition

Decomposition Details	Frequency Bands in Hz
Detail Level 1	2048 – 4096
Detail Level 2	1024 – 2048
Detail Level 3	512 – 1024
Detail Level 4	256 – 512
Detail Level 5	128 – 256
Detail Level 6	64 – 128
Detail Level 7	32 – 64
Detail Level 8	16 – 32
Detail Level 9	8 – 16
Detail Level 10	4 – 8

2.4. Proposed Technique: In the present paper, a new technique has been developed to extract low frequency oscillation based on instantaneous frequency below 50 hz from starting current through envelope analysis for detection of present motor fault. The concept of instantaneous frequency has only meaningful application for mono component or signals having narrow range of frequencies. As the starting current being sinusoidal may be written as α (t)cos Φ(t), its complex analytic signal will be be expressed in the same form, z(t). Its argument i.e. the envelope signal E(t)= |z(t)| is required to be separated from the spectrum of the original signal, equal to amplitude α (t) for analysis in the low frequency zone below 50 hz for detection of broken rotor bar belonging to narrow band frequencies makes the method suitable to extract frequencies below 50 hz based on instantaneous frequencies from the envelopes for diagnosis of broken bar fault current. As the supply frequency is completely eliminated from the envelope, the analysis is effective and clean and free from spectral leakage. Higher order wavelet for smoothness though selection of mother wavelet is not at all a problem in this technique is excellent choice to extract low frequency components below 50 hz at higher wavelet level belonging to narrow band frequencies which makes the method suitable for envelope analysis based on instantaneous frequencies for diagnosis of broken bar fault. Simultaneous use of higher order wavelet and Hilbert transform used in the envelope detection, the present method works with higher resolution and higher detectability

3. Experimentation

The two identical motors of same rating -3ph, 1/3HP, 190V, 50Hz, 2980rpm, one healthy , the other with three broken bars intentionally made were supplied from 3ph, 110V, 50Hz. Experiment was carried out on test-rig built by Spectra Quest, USA. The signals ere captured at sampling frequency of 8192 c/s.

4. Discussion of results

Then the signal envelopes were extracted from the captured motor current signatures for both the motors at no load and at a single mass (shown in Figures 2,3,4,5) and decomposed into details and approximate coefficients through DWT using "db10 "of Daubechies family upto wavelet level 10. From the decomposed details at 8th, 9th, 10th levels for both the motors at no-load and at single mass load, PDD curves (in Figures 6,7) are obtained . PDDs at 8th, 9th, 10th levels are processed to get PDE and the mean and standard deviation are estimated. The data analysis is performed on Matlab platform

From the experimental results as given in table2, it is observed that the faulty motor produces higher mean and standard deviation of PDD values of the motor starting current at no-load than the healthy one at all three levels. At single mass load, the mean and standard deviation of PDD for the faulty motor indicates higher values than the healthy one at 9th and 10th level and considerably much higher value (more than 4 times) at 9th level but the values at the 8th level for the faulty motor indicates lower values which do not conform to the expected results. In PDE analysis, the values at no load for the faulty motor are more than 30%- 70% higher with respect to the healthy motor. But at single mass load, the PDE values indicate the same trend like the mean and standard deviation of PDD i.e at the 9th and 10th level, PDE values are higher for the faulty motor with respect to the healthy one, specially at the 9th level, the value is almost 5 times higher, but 8th level indicates lower value. Considering all the values of parameters of PDD and PDE values of motor starting current at no-load and load combinely, 9th level is most sensitive to the broken rotor bar fault and can be applied for diagnosis. The main drawback of this method once the sampling frequency selected, the spectral bands become fixed which means some ranges of frequencies are uncovered. In the present analysis, the range is (32 hz - 50 hz).

Table2 Power Detail Energy in joules and statistical parameters (mean and standard deviation) of Power Detail Density

Motor condition	Load condition	Mean of PDD at Wavelet Level			STD of PDD at Wavelet Level			PDE		
		8	9	10	8	9	10	8	9	10
Healthy	No-load	0.3504	1.101	1.846	0.9324	2.068	1.836	727.4524	2285..5	3832.3
	Single mass load	0.1004	**0.04955**	0.1038	0.8463	**0.3192**	0.5304	2440.1	**1204.2**	2523.2
	No-load	0.6055	1.915	2.378	1.685	3.626	2.868	1272.1	4022.1	4996.4

Faulty	Single mass load	0.09992	**0.242**	0.1748	0.6939	**1.324**	0.7602	2438. 2	**5905.7**	4264.8

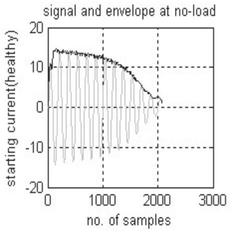

Figure 2

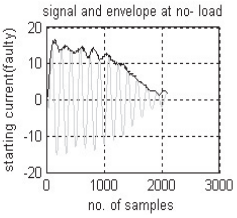

Figure 3

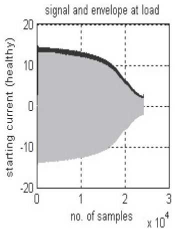

Figure 4

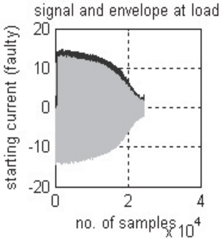

Figure 5

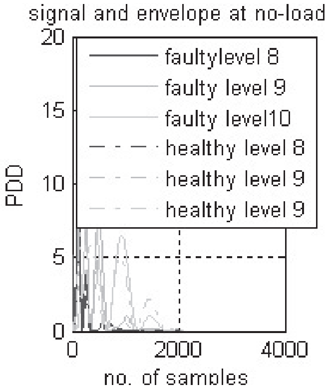

Figure 6

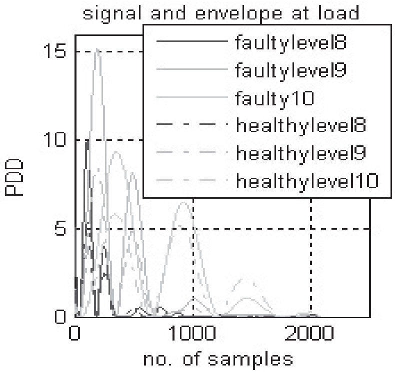

Figure 7

5. Conclusion

Due to Hilbert transform and higher order wavelet, the method works with higher detectability and higher resolution free from spectral leakage to extract low frequency oscillation below 50 hz. As the no. of computation less and power consumption less, no complex software required compared to FFT and other time frequency tools, the method is very suitable for online analysis in the present day industry. The technique may be applied to other faults analysis and low frequency research.

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