WAVELET DECOMPOSITION APPLIED TO SPEED DETECTION OF INDUCTION MACHINE

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ABSTRACT:
By using the Wavelet decomposition in time domain and by the measurements of the stator current one can determine the speed of induction machines. The use of the Wavelet decomposition can eliminate some disadvantages, which are brought in calculations using STFT. It has produced results in shorter time for the same accuracy.

1. INTRODUCTION

The sensorless speed measurements provide the very convenient way of controlling speed and therefore using it in one of control methods for induction machines, such as the field oriented torque control or vector control applied in real time control.

There are used, commonly, several methods for sensorless speed control among which is the most frequent short time Fourier transformation (STFT) [1]. The STFT has several disadvantages. The main being: if one needs high accuracy then there is a big calculation time delay, another is: if one wants short time delay then it is low accurate method. To overcome those problems it has been suggested use of the Parametric spectrum estimation method, like Steiglitz-McBride and MUSIC [2]. Those methods are rather complicated to apply and they are associated with large number of calculations.

The Wavelet decomposition offers the possibility of decomposition of the stator current on several detailed levels in time domain. Detailed level with lower index shows the components at higher frequencies, and vice versa. By an appropriate type of Wavelet and number of levels of decomposition it is possible to select very accurately the rotor slot harmonic of current, and therefore determine the speed of the motor. This method can be applied in very short time delay (1 cycle). When this analysis is used it is desirable not to

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have in the vicinity of the rotor slot harmonics, regarding frequency domain, other dominant harmonics. This simplifies analysis significantly.

2. CALCULATION OF THE SPEED OF INDUCTION MOTOR

For the purpose of control of the induction machine one can determine the speed by using stator current measurements. The method can be applied by calculating decomposition of the stator current and from them calculating the speed of the rotor [3]. Rotor slot and saliency harmonics, which result due to rotor slotting and rotor eccentricity, enable an accurate way for determining rotor speed [4]. The frequency of these harmonics is related to the rotor speed by (1):

$$f_{sh} = \left(\left(kR + n_d \right) \frac{1-s}{p} + n_w \right) \cdot f_1 \tag{1}$$

where f_1 is the supply frequency, k=0,1,2,…, R number of rotor slots, n_d =0, ±1, ±2,.. is order of rotor eccentricity, s per unit slip, p number of pair of poles, and n_w = ±1, ±2, .. is the stator MMF harmonics order.

The calculation is done using the algorithm shown on Fig.1.

The stator's current is recorded by an AD converter. To obtain better accuracy it is required rather high frequency of sampling which is by linear interpolation downsampled to 1024*f_1. Such signal is exposed to Wavelet decomposition in time domain. The most frequently it is used db5 Wavelet where decomposition is done in five or more levels. For the purpose of Wavelet decomposition it is enough to have the analysis of the signal in duration of only one period of supply voltage, what is the major advantage of this method when compared to STFT which requires, at least, 8 period of signal in steady state. Regarding this feature the Wavelet decomposition can be used in the analysis of transitions.

The key factor in the analysis is the localization of the rotor slot harmonics in detailed levels, which are result of Wavelet decomposition. To achieve this without using additional analysis and filters it is desirable not to have in the vicinity of rotor slot harmonics, in frequency domain, other dominant harmonics. In this case the analysis results only in rotor slot harmonics in one of detail levels. The frequency of this harmonic is given by duration of one period of it, or, in order to achieve better accuracy, by several consequent periods of the signal which is recognized in detail level to be rotor slot harmonic. This is the reason why higher frequency of sampling is required. It is noticed that the duration of periods should be determined in the vicinity of the point where the approximation level crosses the zero, rather then maximum or minimum.

3. RESULTS

This method was applied to three phase induction motor 0.5kW, p=2, S=24(number of stator slots), R=22. The decomposition of the signal on details and approximation has been performed by five levels of db5 (Daubechies) Wavelet.

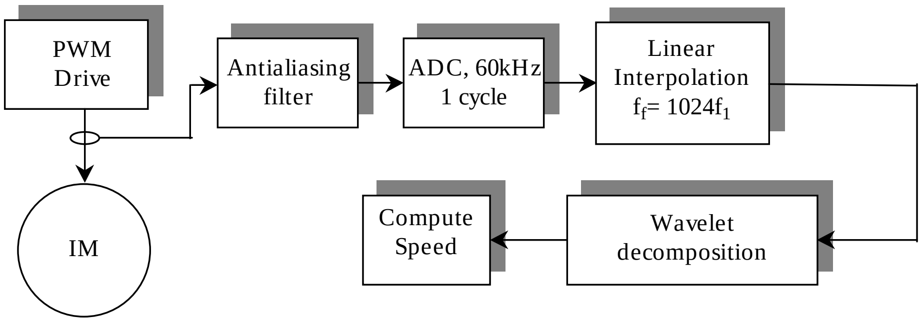

Fig. 1. Algorithm for calculation of speed of the induction machine using Wavelet decomposition

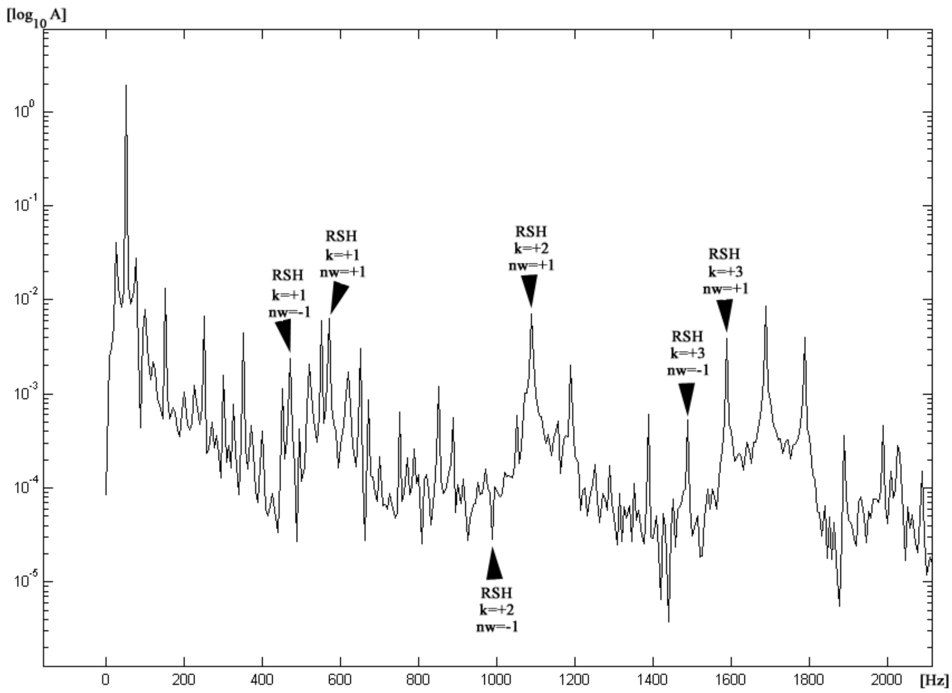

Fig. 2. FFT of the stator current (8 cycles)
RSH – Rotor slot harmonic

It is shown on Fig. 2. the Fourier transform of the stator current waveform where all significant rotor slot harmonics are given. The rotor slot harmonic with parameters k=2 and nw=+1 is dominantly emphasized (Fig. 2.), and there are not in its vicinity others significant harmonics. The Wavelet decomposition in time domain is shown on Fig. 3. The rotor slot frequency is determined by measuring the period of the signal shown as D3.

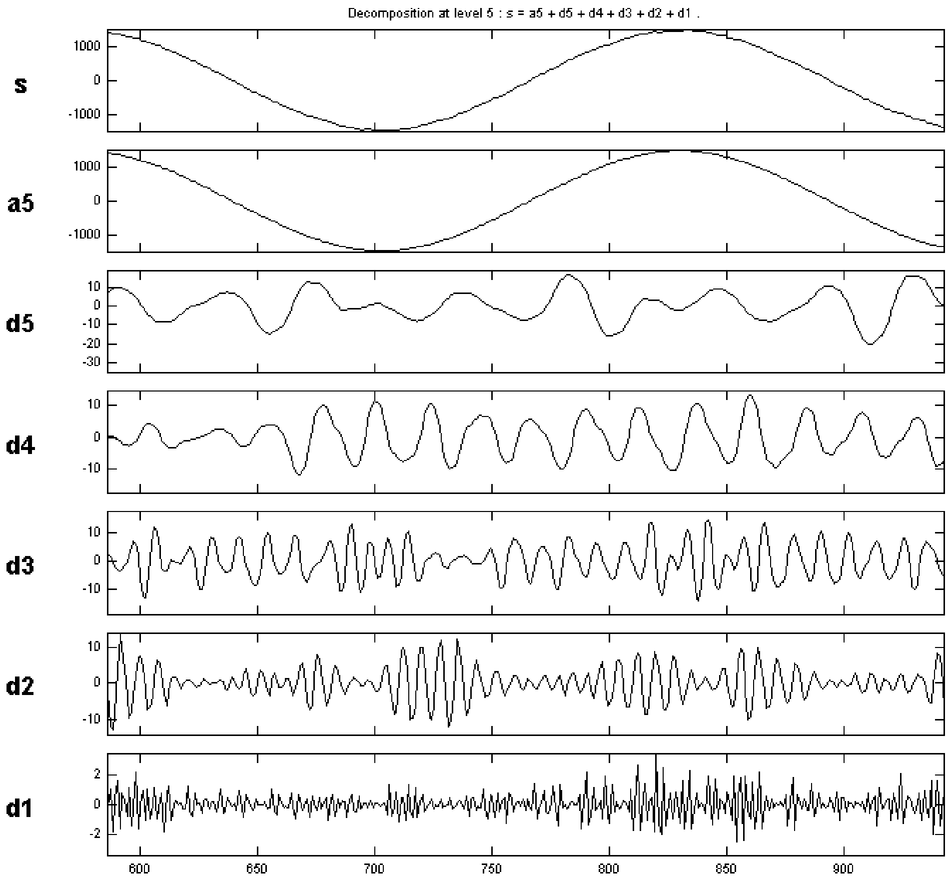

Fig.3. Wavelet decomposition of stator current signal
(s) – stator current waveform
(d3) – rotor slot harmonic (k=2, nw=+1)

Regarding the fact that the examined rotor slot harmonic is alone in frequency domain, estimation of duration of a period and, in consequence, determination of the speed of examined motor is given directly by measurements on D3 detail level window.

4. CONCLUSION

It has been shown that it is possible to obtain very effectively the speed of the induction machine by using Wavelet decomposition. This method produces the same accuracy as the FFT but requires smaller time step (1 cycle instead of 8 cycles). Compared to other methods which produce more accurate results the Wavelet decomposition is much easier to apply and it is very less time consuming, thus enabling very fast speed calculation, which is very important in real time control systems. In particular this method is convenient for speed measurements during transients. Wavelet decomposition is rather easy to apply since it requires convolution of the signal, which is defined as real, and it is numerically straightforward.

One of the disadvantages of this method is requirement for high frequency of sampling ($1024*f_1$ or $2048*f_1$). In the case when the rotor slot harmonic is not alone in frequency domain the additional filtering of the signal is required.

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APPENDIX

A1. MATHEMATICAL BACKGROUND

The Wavelet decomposition produces a family of hierarchically organized decompositions. The selection of a suitable level for the hierarchy depends on the signal and experience. The most frequently the level is chosen based on a desired low-pass cutoff frequency. At each level j, there are build: approximation, *Aj* , at level j, and a deviation signal called the j-level detail, *Dj* . The original signal is considered as the approximation at level 0, denoted by *A*0. The words "approximation" and "detail" are justified by the fact that *A*1 is an approximation of *A*0 taking into account the "low frequencies" of *A*0, whereas the detail *D*1 corresponds to the "high frequency" correction.

The figure 4. graphically represents this hierarchical decomposition. Successive images *A*1, *A*2, *A*3 of given object are built. The images are successive approximations; one detail is the discrepancy between two successive images. For example, image *A*2 is the sum of image *A*4 and intermediate details *D*4, *D*3:

$$\mathrm{A2} = \mathrm{A3} + \mathrm{D3} = \mathrm{A4} + \mathrm{D4} + \mathrm{D3}. \tag{2}$$

A detail *Dj* is than:

$$D_j(t) = \sum_{k \in \mathrm{Z}} C(j,k)\Psi_{j,k}(t), \tag{3}$$

where C(j,k) are Wavelet coefficients which are consequence of Wavelet transformation. $\Psi_{j,k}(x)$ is a family associated with one-dimensional Wavelet function ψ for dyadic scales

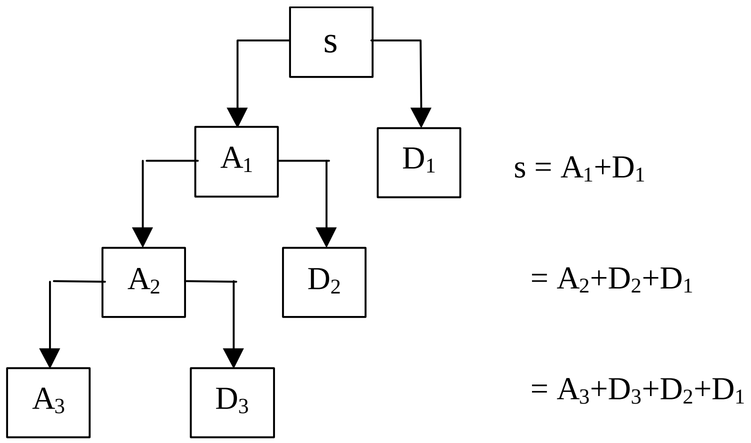

Fig. 4. Wavelet decomposition

$a = 2^j$, $b = k$a.

$\Psi_{j,k}(x)$ is defined by:

$$\Psi_{j,k}(x) = 2^{-\frac{j}{2}} \Psi(2^{-j}x - k), j \in Z, k \in Z \quad (4)$$

It should be noted that $\psi = \psi_{0,0}$.

Dyadic scales $a = 2^j$, $b = ka$ defines frequency and time locality of the particular Wavelet function in the family of Wavelet functions. The $a = 2^j$ gathers or stretches the basic Wavelet function ψ, while $b = ka$ does its time translation.

In the case of continuous time, continuous analysis:

$$C(a,b) = \int_R s(t) \frac{1}{\sqrt{a}} \Psi(\frac{t-b}{a}) dt, a \in \Re^+ - \{0\}, b \in \Re, \quad (5)$$

while in the case of discrete time, discrete analysis:

$$C(a,b) = C(j,k) = \sum_{n \in Z} s(n) g_{j,k}(n), a = 2^j, b = k2^j, j \in N, k \in Z. \quad (6)$$

The function $g_{j,k}$ is defined by:

$$g_{j,k}(n) = 2^{-\frac{j}{2}} g(2^{-j}n - k), n \in Z, \quad (7)$$

where *g(n)* is discrete Wavelet function which is equivalent of Wavelet function ψ.

The signal is the sum of all the details:

$$s = \sum_{j \in Z} D_j . \quad (8)$$

Consider a reference level called J. There are two sorts of details. The first associated with indices $j \le J$ correspond to the scales $a = 2^j \le 2^J$ which are the fine details. The second, which correspond to j>J, are the coarser details. Latter details are grouped in:

$$A_J = \sum_{j>J} D_j, \tag{9}$$

which defines what is called an approximation of the signal s. Thus, there are created the details and approximations which are interconnected. The equality:

$$s = A_J + \sum_{j \le J} D_j \tag{10}$$

signifies that signal s is the sum of its approximation A_J and of its fine details. From the previous formula, it is obvious that the approximations are related to one another by:

$$A_{J-1} = A_J + D_J. \tag{11}$$

A2. EXPERIMENT

The experiment was carried out on the special constructed rig, which enabled generation of the sinusoidal voltage at different frequencies. This was necessary since it was required current waveform which distortion was only due to slot harmonics. Any implication of an inverter was not possible since it produces highly non-sinusoidal current, which would effect the analysis.

The results have been taken for different load conditions, too. The induction motor used in experiment had the following data: 0.5kW, p=2, S=24(number of stator slots), R=22. The stator current was recorded by 12-bit AD converter at the sampling rate of 51.2 kHz.