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CURRENT BASED SPEED DETECTION IN INDUCTION MOTORS BY SPECTRAL POST PROCESSING

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ABSTRACT
Fourier based techniques are utilized widely in motor condition monitoring due to its computational efficiency. Recently, an alternate method, wavelet packet decomposition, has been applied in this area. Although the new method provides better analysis in condition monitoring, the computational complexity of wavelet packet decomposition places a limitation on its use. Rotor speed detection is very important in motor condition monitoring and the latter approach requires additional computational cost for rotor speed detection. In this study, a hybrid method is suggested to provide rotor speed at a very low additional cost in condition monitoring by wavelet packet decomposition.
Keywords: Wavelet packet decomposition, Fourier analysis, motor speed detection, and motor current signature.

1. INTRODUCTION
Fourier based techniques are used widely in applications where rotor speed is determined from motor current data for monitoring and control applications [1-3]. Recently, wavelet packet decomposition (WPD) has also become popular in condition monitoring applications [4-5], but the latter approach is more expensive computationally and requires separate processing for rotor speed detection.
In this study, spectral processing of wavelet packet coefficients (WPCs) [6] is proposed for obtaining rotor speed information at a very minimal additional cost. Since the output of filter banks is down-sampled by two at every level, the number of WPCs becomes very smaller than the original record size after processing through a few levels in WPD.

2. ROTOR SPEED DETECTION BY FOURIER METHODS
All motors have some degree of rotor eccentricity causing rotor speed sidebands in the current spectrum due to rotor eccentricities [1-3]. The resolution in speed depends on the length of the current data. In this project, the current data is captured at 32 points per power system cycle for 256 cycles using the waveform capture capability of SquareD CM4000 Circuit Monitor. The Circuit Monitor has an onboard memory chip that provides storage for captured data. Then, the data is uploaded to a PC via the serial communication port. The frequency resolution in the spectrum will be 0.2344 Hz for current data length of 4.27 seconds. The captured current data and the corresponding spectrum analysis for 0-100 Hz band are shown in figure 1. Here, the power system fundamental frequency is notch filtered in preprocessing and the speed sidebands show up at 30.70 Hz and 89.30 Hz in the motor current spectrum. The rotor speed is determined to be 1758 rpm for a one-hp four pole induction machine operating at system frequency of 60Hz.

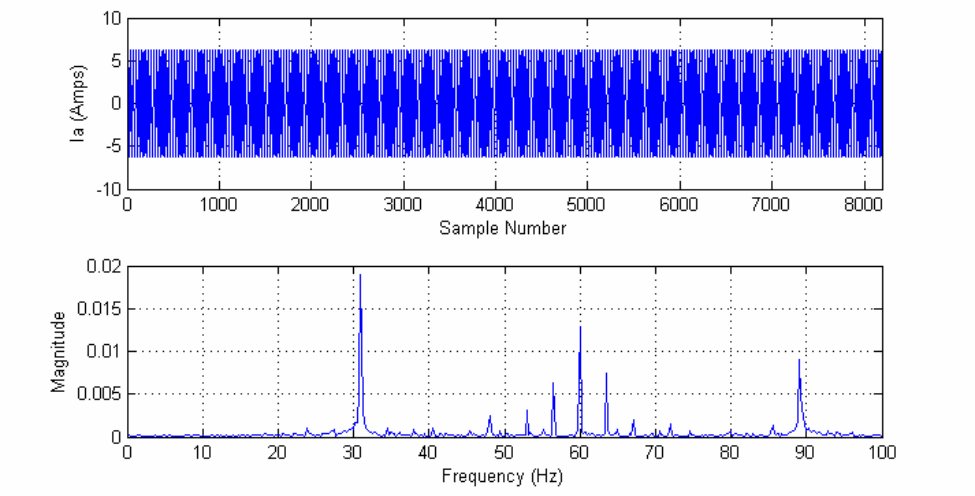


Figure 1. motor current and its spectrum

3. MOTOR SPEED DETECTION BY SPECTRAL PROCESSING OF WPCS

Figure 2 depicts the basic structure of the filter banks employed in the discrete wavelet packet transform where h and g are low pass and high pass half-band filters respectively. Here, the full tree for only two levels is shown.

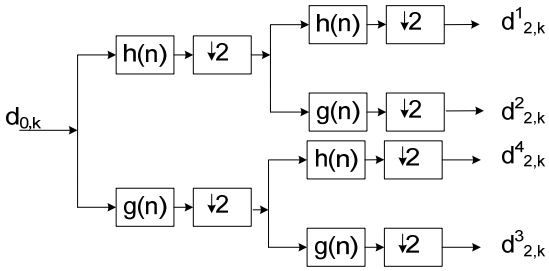


Figure 2. wavelet packet decomposition

It should be noted that, $d^4_{2,k}$ and $d^3_{2,k}$ are in reversed order in the previous figure. This is due to the natural, or Paley, order produced by the algorithm and the order can easily be modified by the algorithm. The wavelet packet coefficients at any level $j+1$, $d^{2p}_{j+1}[k]$ and $d^{2p+1}_{j+1}[k]$, can be obtained from wavelet packet coefficients at level j, $d^p_j[k]$, by using equations 1 and 2.

$$d^{2p}_{j+1}[k] = d^p_j[k] * \bar{h}[2k] \qquad (1)$$

and

$$d^{2p+1}_{j+1}[k] = d^p_j[k] * \bar{g}[2k] \qquad (2)$$

These equations can be used repeatedly to obtain all the wavelet packet coefficients at any node (p,j). Both FIR and IIR filters can be selected for the filter banks employed in WPD. Usually, FIR filters are selected for applications requiring reconstruction whereas IIR filters provide better frequency roll-off characteristics at lower computational cots. The computational complexity of various filter banks can be compared by looking at the number of multiplications required for a full decomposition. The number of multiplications required to fully decompose motor current data of 4096 points into seven levels with commonly used FIR and IIR filters are given in Table 1.

Table 1. Computational complexities of various FIR and IIR filters in WPD

Filter Type	# of coefs.	# of filters	# of muls.
Vaidyanathan FIR	24	2	1,376,256
Daubechies FIR (db9)	18	2	1,032,192
All-pass implementation of Butterworth IIR (L=6)	3	2	229,376
All-pass implementation of elliptic IIR (L=3)	3 and 2 (at each stage)	2	143,360

All-pass implementation of elliptic IIR filters requires the fewest multiplications [7,8], therefore it was chosen for the filter bank structure. The fast Fourier transform requires 24,576 multiplications for the same decomposition. Although, the Fourier based methods require far fewer multiplications than WPD, the ladder approach gives better results in non-stationary signal analysis which is very common in motor operation. WPCs are depicted in the upper whereas their spectral analysis is depicted in the lower part of figure 3.

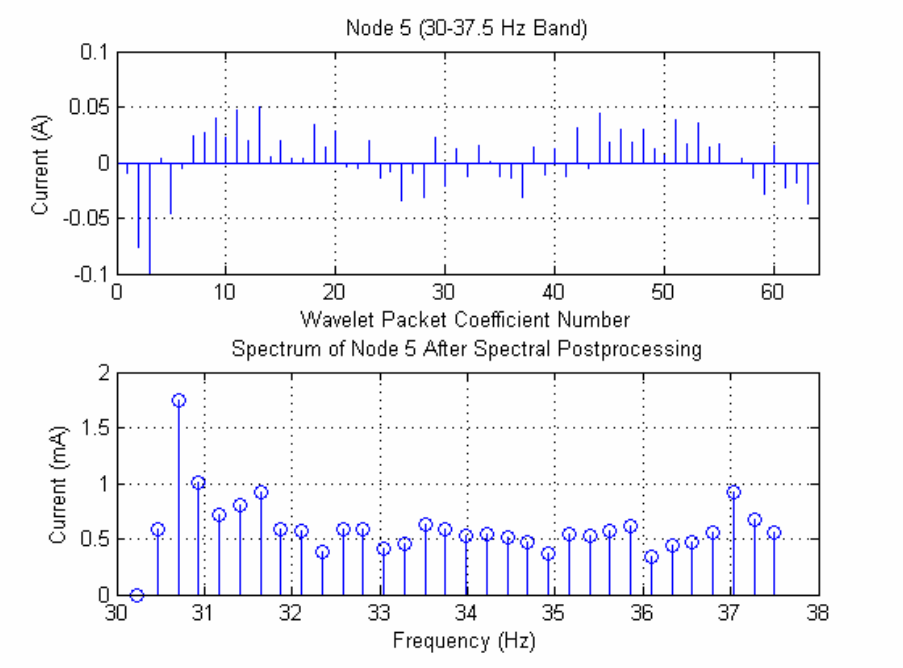


Figure 3. spectral processing of WPCs

There are 64 WPCs for each band after WPD of the original data in seven levels. The spectral analysis of WPCs shows that the rotor speed is determined to be 1758 rpm by this hybrid method too. In order to obtain the speed from these 64 WPCs, we need to have 192 more multiplications which is very small compared to 24,576 multiplications required for the original data length of 4096 points.

4. CONCLUSION

The fast Fourier transform is used widely in determining rotor speed from motor current data. Most of the time, the speed information is needed for condition monitoring applications in which WPD is proved to be more helpful under non-stationary conditions. The second approach is computationally

more expensive and it does not readily provide the speed information. In this study, spectral processing was proposed for obtaining rotor speed at minimal additional cost.
The rotor speed was determined by both spectral analysis of motor current data and spectral analysis of WPCs. In both cases, the same results were obtained. As a result, the proposed method can be employed in condition monitoring applications where WPD is used as the signal processing tool.

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