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MOTOR SPEED DETECTION VIA SPECTRAL POST PROCESSING OF WAVELET PACKET COEFFICIENTS

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ABSTRACT
This study deals with speed detection of induction motors by spectral post processing of wavelet packet decomposed motor current. The motor current is decomposed into wavelet packet coefficients first. Then, the fast Fourier transform is applied to the wavelet packet coefficients to get better resolution at minimal additional computational complexity. Finally, the resultant spectrum is analyzed for motor speed detection.
Key Words: Wavelet Packet Decomposition, Fast Fourier Transform, Motor Speed Detection.

1. INTRODUCTION
Induction motors are used widely by the manufacturing industry. The speed detection is very important for both control and monitoring of induction motors. The Fourier based methods are utilized widely for power quality and motor condition monitoring applications. The speed can be detected from motor line current [1]. In such analysis, long data records are required to achieve necessary spectral resolution. Wavelet packet decomposition is another widely used technique that was introduced more recently. Many power quality measurement and condition monitoring devices employ fast wavelet transform algorithms [2-7]. However, wavelet based techniques do not provide enough resolution for speed detection. In this study, a hybrid approach is proposed in which the motor current is decomposed into wavelet packets before post spectral processing is applied for obtaining higher resolution [8]. Since the fast wavelet algorithms use downsampling at each level, applying fast Fourier transform to wavelet packet coefficients at the last level provides further resolution at minimal computational cost.

2. WAVELET PACKET DECOMPOSITION
Wavelet packet transform is used widely in power quality and condition monitoring applications. The basic structure of the filter banks employed in the discrete wavelet packet transform is depicted in figure 1. Here, the full tree for only two levels is shown where h and g are low-pass and high-pass half-band filters respectively.

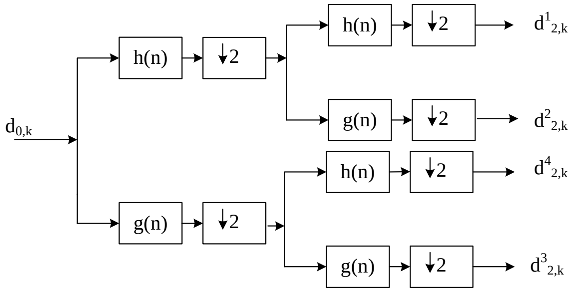

Figure 1. Wavelet packet decomposition

The wavelet coefficients at any level j+1 can be found from coefficients at level j using equations 1 and 2.

$$d_{j+1}^{2p}[k] = d_j^p[k] * \bar{h}[2k] \tag{1}$$

and

$$d_{j+1}^{2p+1}[k] = d_j^p[k] * \bar{g}[2k] \tag{2}$$

3. SPECTRAL POST PROCESSING

In both equations 1 and 2, data is down-sampled after the filtering operations. Down-sampling discrete data in the time domain can be shown by

$$y[k] = x[2k] \tag{3}$$

taking the discrete Fourier transform of down-sampled signal

$$Y(\omega) = \frac{1}{2}\left(X(\frac{\omega}{2}) + X(\frac{\omega}{2} + \pi) \right) \tag{4}$$

The second term is the aliased term introduced by the down-sampling operation. A filter bank composed of a high-pass and a low-pass half-band filter is utilized in wavelet packet decomposition. Outputs of both filters are downsampled by two as shown in figure 1. Down-sampling the output of the low-pass filter will have no effect on the Fourier transform if the frequencies in the lower half of the signal bandwidth are admitted and frequencies in the upper half are suppressed. On the other hand, applying the Fourier transform to the down-sampled output of high-pass filter, will alias all frequency components present into the lower half of the band spectrum. There is folding effect at mid-band and the aliased frequencies can easily be identified if near brick-wall filtering is used in the decomposition. The folding effect is utilized in obtaining further resolution with minimal computational effort in this study.

4. TESTING

The test system consists of a four-pole, one hp induction motor (US Motors Frame 143T), a Magtrol model HD-805 hysteresis dynamometer as the load, and a SquareD CM4000 Circuit Monitor for capturing motor current data. The captured current data is depicted in figure 2. Here, the circuit monitor is set to sample line current at 32 points per cycle for a record length of 256 cycles.

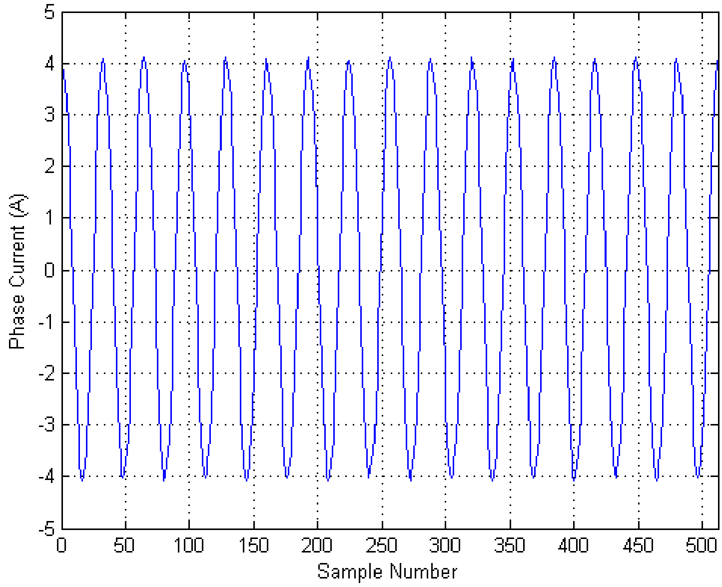

Figure 2. Captured line current

The data is decomposed into wavelet packet coefficients after processing filter banks at eight levels and separating data into 7.5 Hz wide frequency bands. Then, the fast Fourier transform is applied to the wavelet packet coefficients associated with 30-37.5 Hz band. The speed related ripple frequency shows up in this band. Wavelet packet coefficients and spectrum after post processing is shown in figure 3.

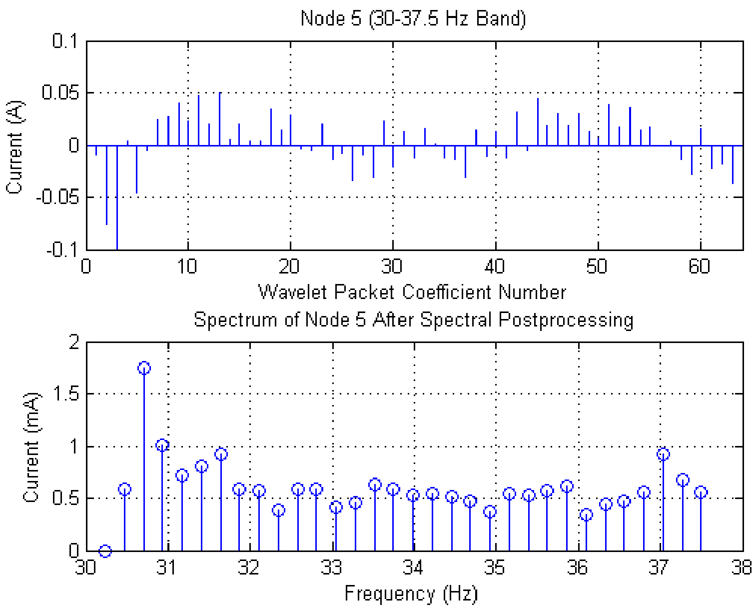

Figure 3. Results for node 5

Third component in the lower chart is significantly higher than other components. This is used to detect the speed of the motor. Rotor eccentricity is utilized in speed detection. An eccentric rotor creates a point of minimum air gap that rotates with the rotor at one times the rotational frequency. Current spectrum component due to dynamic rotor eccentricity, f_{RE}, can be calculated by the following equation.

$$f_{RE} = f_e\left[k\left(\frac{1-s}{p/2}\right)\pm 1\right] \tag{5}$$

where

k ≡ Harmonic index (k= 1,2,3,...)
s ≡ Per unit slip
p ≡ Number of fundamental pole pairs
f_e ≡ Supply frequency

According to figure 3, the motor speed is 1758 rpm. The speed resolution for this process is 14 rpm. The resolution can be increased either by extending the data length or applying interpolation techniques to get closer results to actual speed of the motor.

5. CONCLUSION

In this work, discrete wavelet packet decomposition of motor line current with spectral post processing was proposed for detecting speed of an induction motor. The frequency resolution was 7.5 Hz when only discrete wavelet packet decomposition was used which is too low for speed detection. Post spectral processing improved frequency resolution to 0.2344 Hz at very little additional computational effort. The corresponding speed resolution is 14 rpm and it can easily be increased either by extending the data length or applying interpolation techniques to get closer results to actual speed of the motor.

6. REFERENCES

[1] K.D. Hurst and T.G. Habetler, "Sensorless speed measurement using current harmonic spectral estimation in induction machine drives," IEEE Trans. Pow. Electron., vol. 11, no. 1, pp. 66-73, Jan. 1996.
[2] Z. Ye, B. Wu, and A. R. Sadeghian, "Current signature analysis of induction motor mechanical faults by wavelet packet decomposition," IEEE Trans. Ind. Electron., vol. 50, no. 6, pp. 1217-28, Dec. 2003.
[3] L. Eren and M.J. Devaney, "Bearing damage detection via wavelet packet decomposition of the stator current," IEEE Trans. Instrum. Meas., vol. 53, pp. 431- 6, Apr. 2004.
[4] W. Yoon and M.J. Devaney, "Reactive power measurement using the wavelet transform," IEEE Trans. Instrum. Meas, vol. 49, no 2, pp. 579-84, Apr. 2000.
[5] E.Y. Hamid and Z.I. Kawasaki, "Wavelet packet transform for rms values and power measurements," IEEE Power Engineering Review, vol. 21, no 9, pp. 49-51, Sept. 2001.
[6] L. Eren, M. Unal, and M. J. Devaney, "Harmonic analysis via wavelet packet decomposition using special elliptic half-band filters," IEEE Trans. Instrum. Meas., vol. 56, no 6, pp. 2289-93, Dec. 2007.
[7] W. Yoon and M.J. Devaney, "Power measurement using the wavelet transform," IEEE Trans. Instrum. Meas, vol. 47, no 5, pp. 1205-10, Oct. 1998.
[8] L. Eren, "Enhanced feature detection in bearing health diagnosis with spectral post processing," International Review of Electrical Engineering (IREE), vol. 4 no. 2, pp. 260-268, Apr. 2009.