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A Wavelet based multiresolution analysis for real time condition monitoring of AC machine using vibration analysis

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Abstract-Wavelet is a powerful tool used for non stationary signal analysis. It does not change the time information content present in the signal hence it provides a time-frequency representation of the signal. Using the wavelet technique, transients can be decomposed into series of wavelet components, in which each is a time-domain signal that covers a specific frequency band. Disturbances of small intervals are amplified frequency band. In this paper a multi-resolution based pattern recognition technique is used for vibration analysis of angle grinder machine by which different frequencies are analyzed with different resolutions. This method is more reliable as compared to other FFT based techniquesrelative to the rest of the signal when projected to similar size wavelet bases and, thus, they can be easily detected in the corresponding

Index Terms- Fault diagnosis, wavelet transform, multi resolution analysis, pattern recognition, wavelet density estimation.

1 Introduction

Condition monitoring is the process for monitoring any parameter of condition in machinery, such that a significant change is indicative of a developing failure. The use of condition monitoring allows maintenance to be scheduled, or other necessary actions to be taken to avoid the consequences of failure, before the failure occurs [1]. Nevertheless, a deviation from a reference value must occur to identify impeding damages in the machinery. Condition monitoring for any machine is much more cost effective than allowing the machinery to fail. The prime aim of vibration monitoring is the detection of changes in the vibration condition of the machine under investigation during its operation.

In industry machines are expected to run continuously with their full capacity in order to meet the production needs. Any defects in the machinery must be detected and should be analyzed at the early stage to avoid its failure. In this case planned shutdown can be arranged to diagnose the causes of the problem and to make further corrections. In opposite to this condition, the unscheduled shut down of the machinery & equipment can cause enormous economic losses and may result high damage of the machine. So condition monitoring of various machines is gaining importance in every industry since it keeps the plant at healthy condition for maximum production, detecting and diagnosing the fault at very early stage to avoid serious accidents and machine damage and to run the plant economically [2].Most of the defects occurred in the machines give rise to a distinct vibration signature and hence mostly faults can be identified using vibration signature analysis techniques. A similar attempt have been tried out here for the conditioning monitoring of AC machine using wavelet technique for its proper and economical functioning[3]. An AC machine is a handheld power tool used for cutting, grinding and polishing. Angle grinders may be used both for removing excess material from a piece or simply cutting into a piece.AC machines are widely used in metalworking and construction, as well as in emergency rescues. They are commonly found in workshops, service garages and auto body repairs.

1.1 From Fourier Analysis to Wavelet Analysis

Drawbacks of signal processing techniques used in power quality disturbances:

i) RMS is major tool used in signal processing techniques. The RMS of signal is not an analysis technique but it gives some basic information about an electrical system. The main disadvantages of this algorithm is its dependence on size of sample window[6].As a result of small window RMS parameter becomes less relevant and loses meaning of mean value of power.

ii) Another most widely used tool in signal processing is Fourier analysis. It helps in analysis of harmonics and essential tool for filter design. The DFT and FFT are essential tools for estimation of fundamental amplitude of signal. The DFT importance in area of frequency (spectrum) analysis as it takes a discrete signal in time domain and transforms that signal into the discrete frequency domain representation. A FFT used for transformation of signal from time domain to frequency domain. Speed is main advantage of this technique and also high speed calculations.

iii) In time frequency signal processing, a filter banks is special quadric time frequency distortion (TFD) that represents signal in joint time frequency domain. This technique used for estimation of specific sub-band components.

iv) Another special type of filter is Kalman Filter .Their solutions are based on set of state space equations. These are used for real time tracking harmonics as proposed in [8], frequency estimation under distorted signal [9], estimating voltage and current parameters on power system protection and parameter of transient [10].

v) In 1994, use of wavelets was proposed which led to study of non stationary harmonic distortion in power systems. This technique decomposes signals in different frequency subbands and characteristics can be studied separately.

vi) The STFT mainly used in power quality analysis and called

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as sliding window version of FFT. The advantage of STFT is its ability to give the harmonic content of signal at every time period specified by defined window.

2 Wavelet Transformation Technique

The wavelet transform is representation of signal as sum of wavelets at different location and scales. The main advantage of wavelet transform is its varying length window. The wavelet transform can be classified in three different ways. The continous wavelet Transform possesses ability to construct a time-frequency representation of signal that offers very good time and frequency realization. The second type of transform known as wavelet series which maps function of continous variables into sequence of coefficients. The third is Discrete wavelet in which wavelets discretely sampled and has advantage of temporal resolution as it captures both frequency and location information.

2.1 Why Discrete Wavelet Transforms

The continous wavelet transform was developed to overcome resolution problem to short time Fourier transform. It is correlation between wavelets at different scales and signal with scale being used as measure of similarity.DWT are applied to discrete data sets and produce discrete outputs. The DWT is special case of wavelet transform that provides a compact representation of signal in time and frequency that can be computed efficiently. When compared to Fourier transform, wavelet can obtain both time and frequency information of signals while frequency information obtained by Fourier transform [3, 4, 16, 18, and 19]. The signal can be represented in terms of both the scaling and wavelet functions as follows:

$$f(t) = \sum_n Cj\,(n)\Phi(t-n) + \sum_n \sum_{J=0}^{J-1} dj\,(n)_2^{2j}\psi(2^j t - n) \quad (1)$$

Where **cj** is the J level scaling coefficient,
dj is the j level wavelet coefficient,
j**(t)** is the scaling function,
y**(t)** is wavelet function,
J is the highest level of wavelet transform,
t is time.
For practical applications and for efficiency reasons one prefers continuously differentiable function with compact support as mother wavelet.
Wavelet theory can be expressed by continous wavelet transformation as,

$$CWTx(a,b)=W_x(a,b) = \int_{-\infty}^{\infty} x(t)\psi_{a,b}(t)dt \quad (2)$$

Where Ψ_a, a (scale) and b (translation) are real numbers.
The discretization of this equation necessary for practical application.
For Discrete time system,

$$DWT_\psi x(m,n)= \int_{-\infty}^{\infty} x(t)\psi_{m,n}(t)dt \quad (3)$$

$$\psi_{m,n}(t) = a_0^{\frac{-m}{2}}\psi\left(\frac{t-n\,b_0 a_0^m}{a_0^m}\right) \quad (4)$$

Where a = a_0^m and b = n$b_0 a_0^m$

The DWT analysis can be performed using fast pyramidal algorithm related to multirate filter banks.

3 DWT ALGORITHM

A multiresolution analysis is design method of most of the practically relevant discrete wavelet transform. A low pass approximation and high pass details can be obtained from original signal .The original signal divided into different scales of resolution whereas in Fourier transform it is divided in different frequencies. A low pass filter removes high frequency componentsand high pass filter helps for picking high frequency components [3, 4, 16, 18, and 19].
The synthesized signal is finally decomposed into subbands of continous wavelets where each band represents part of original signal at particular frequency.
Following steps are taken to identify time interval of disturbances of wavelet:

a) Actual data signal is generated,
b) Application of different wavelet transformation having suitable mother wavelet.
c) Identification of disturbance intervals with help of wavelet coefficients.

4 CHOICE OF ANALYSIS MOTHER WAVELET

Various power quality disturbances for small scale signal decomposition can be detected by use of choice of analysis of mother wavelet. Daub 4 and Daub 6 wavelets are useful for fast and short transient disturbances. Daub 8 and 10 are suitable for slow and long transient disturbances [3, 4, 16, 18, and 19]. At scale 1, mother wavelet localized in time and oscillates more rapidly in short spam of time. As wavelet reaches higher scale analysing wavelets become less localized in time and oscillations, so as a result of high scale signal decomposition, fast and short transient disturbances detected st lower scales and for high scales, slow and long transient disturbances will be detected.
Both time domain & frequency domain methods can be used to analyze vibration signals. The time domain refers to a display or analysis of the vibration data as a function of time. The frequency domain approach allows both the amplitude & phase spectrum to be an identified and are more useful for vibration analysis. The Fourier transform is a frequency domain approach which converts a continuous time signal into frequency domain. Fourier representation X (f) which is calculated by the Fourier transforms integral shown by:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-i2\pi ft}\,dt \quad (5)$$

The disadvantage of frequency-domain analysis approach is that a significant amount of information (transients, non repetitive signal components) may be lost during the transformation process. This information is non retrievable unless a permanent record of the raw vibration signal has been made. The problem of Fourier transform is overcome up to some extent using Short Term Fourier Transform. STFT is simply the result of multiplying the time series by a short time window and performing a discrete Fourier transform. Mathematically for a signal, it is written as

$$\text{STFT}\{x(t)\} \equiv X(\tau,\omega) = \int_{-\infty}^{\infty} x(t)\omega(t-\tau)e^{-j\omega t}\,dt \quad (6)$$

For discrete signals, this transform is known as Short Term Discrete Fourier Transform (STDFT) expressed mathematically with signal $x[n]$& window $\omega[n]$ as

$$\text{STFT}\{x[n]\} \equiv X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]\omega[n-m]\,e^{-j\omega n} \quad (7)$$

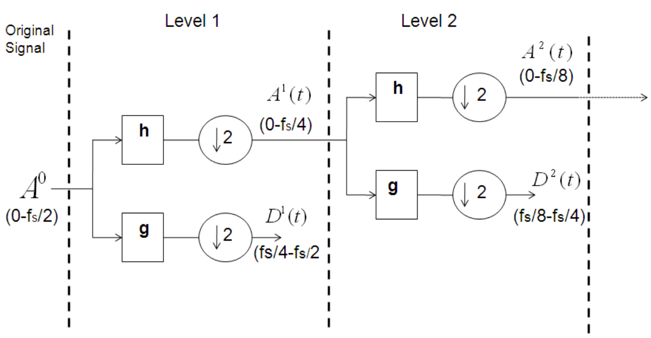

Fig.1 Multi-resolution wavelet decomposition.

Application of STFT have been used to for analyzing different vibration signals for different application but having problem that time resolution is same for all spectral components. This problem is overcome by using the wavelet transform [4]. It is a technique which allows the time-frequency place to be divided in a more flexible way such that a smaller time is user for higher frequencies & larger time is used for lower frequencies. It is calculated by convolving the wavelet with the original signal, multiply the shifted wavelet with the original signal, then sum the result to produce a single value [5].
The continuous wavelet transform is defined as the convolution between the original signal s (t) and a wavelet $\Psi_{a,b}$ (t).

$$W_{\Psi}(a,b) = \int_{-\infty}^{+\infty} S(t)\,\overline{\Psi}_{ab}\,(t)dt \quad (8)$$

$$\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} s(t)\varphi(\tfrac{t-b}{a})dt \quad (9)$$

Where s(t) is the input signal; 'a' is the scaling factor; 'b' is the translation parameter; and Ψ(t) is called mother wavelet. The wavelet function is given by

$$\Psi_{a,b} = \frac{1}{\sqrt{a}}\,\Psi\left(\frac{t-b}{a}\right) \quad (10)$$

The Discrete Wavelet Transform (DWT) coefficients are usually sampled from the CWT on a dyadic grid parameters of translation b = n*2^m and scale a = 2^m and is defined as,

$$\Psi_{m,n\,(t)} = \frac{1}{\sqrt{2^m}}\,\Psi\left(\frac{t-n2^m}{2^m}\right) \quad (11)$$

It is not strictly a time-frequency representation but rather a time-scale representation of the signal. WT can give a time-frequency analysis if the centre frequency of the wavelet is estimated for each scale [6].

5 Proposed Data Acquisition System for Signal Acquisition

The very first step of vibration monitoring of any equipment or machine is the acquisition of the vibration signal. This system uses Muratha piezoelectric shock & vibration sensor (model no.PKS1-4A1) for measuring angle grinder vibration signals which is mounted on the surface of the AC machine. Vibration signals are amplified using pre-amplifier circuit & fed to PC using its audio port. Finally the vibration signal uses MATLAB environment for further processing using wavelet based multi resolution technique

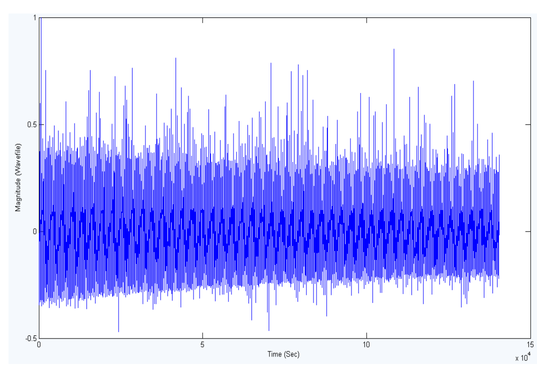

Fig.2. Vibration Signature of Angle Grinder machine

6 PROPOSED NEW METHOD USING MRA & DENSITY ESTIMATION

The multi-resolution analysis algorithm decomposes a signal into scales with different time and frequency resolution [7]. The fundamental concept involved in MRA is to find the average features and the details of the signal via scalar products with scaling signals and wavelets.MRA is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at low frequencies[16]. The algorithm of wavelet signal decomposition is illustrated in Fig 1 where down sampling operation is performed. In Fig 1, h represents low pass decomposition filter, g is the high pass decomposition filter. A^1 (t), A^2 (t) are approximation coefficient of original signal at level 1, 2 and D^1 (t), D^2 (t) are the detailed coefficients at levels 1 & 2.wavelet Filter Banks are used to represent the vibration signal in the next lower scale [17, 18].

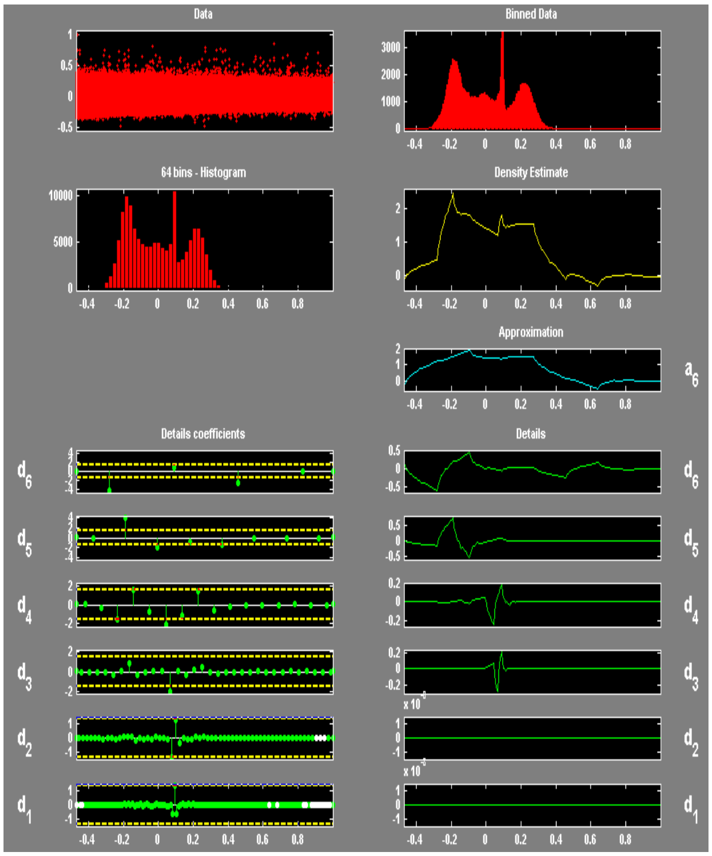

Fig.3. Decomposition upto six level

$$V_j = \underset{k}{Span}\left\{2^{j/2}\phi\left(2^j t-k\right)\right\}$$

$$V_j = \underset{k}{Span}\left\{2^{j/2}\phi\left(2^j t-k\right)\right\}$$

$$f(t)\in V_{j+1} \Rightarrow f(t)=\sum_k s_{j+1}(k)2^{(j+1)/2}\phi\left(2^{j+1}(t-k)\right) \quad (12)$$

The decomposition of signal is V_{j+1} which is sum of two

seuences with $d_j(k)$.

$$f(t)=\sum_k s_j(k)2^{j/2}\phi(2^j t-k)+\sum_k d_j(k)2^{j/2}\psi(2^j t-k)$$

$$V_j = \underset{k}{Span}\left\{2^{j/2}\phi\left(2^j t-k\right)\right\}$$

Where

$$S_j(k) = \sum_{m=2k}^{2k+N-1} h(m-2k)S_{j+1}(m)$$

$$d_j(k) = \sum_{m=2k}^{2k+N-1} g(m-2k)S_{j+1}(m)$$

The sum of number of coefficients in sequence $\{s_j(k)\}$ and $\{d_j(k)\}$ is almost equal to the number coefficients in the sequence $\{s_{j+1}(k)\}$ and no information is lost in the splitting of frequency bands of t

7 CONCLUSIONS

Six levels of decomposition have been selected in this paper to estimate density and detail coefficient of AC machine. This wavelet based decomposition technique identifies the vibration fluctuation due to overloading on single phase fault condition, more easily and efficient way. An attempt has been carried to provide the necessary information of abnormal condition of an AC machine .The implementation technique can process vibration data with low consumption cost and in reliable manner decomposed to other signal processing techniques.

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