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Harmonic Estimation Using Discrete Wavelet Transform

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ABSTRACT—The radical development in the area of power semiconductor switching devices have paved the way for wide use of power electronics based nonlinear loads from industries to the households. In the era of power semiconductor based appliances, defilement in power supply waveform due to harmonics is critical from power quality and reliability point of view. An accurate estimation of harmonics is the basic requirement in the field of harmonic analysis. In this paper, an effective signal processing technique, Discrete Wavelet Transform (DWT) is proposed for the estimation of harmonics in a power system, which is created due to nonlinear loads present. The proposed method is examined with simulated signals of an AC Motor Drive. The method based on Wavelet Transform overcomes the shortcomings of conventional Fast Fourier Transform (FFT) in harmonic estimation.

INDEX TERMS—AC Motor Drive, Discrete Wavelet Transform (DWT), Fast Fourier Transform (FFT), Harmonic Estimation, Power Quality

I. INTRODUCTION

The emphasis on overall power system efficiency in dispersed generation and deregulated electricity market, the quality of power is the increasing concern for both electric utilities and end users of electric power. The increasing use of power semiconductor devices based nonlinear loads such as rectifiers, personal or notebook computers, laser printers, fax machines, dimmers, fluorescent lighting with electronic ballast, stereos, adjustable speed drives, arc furnaces, uninterrupted power supplies, switched-mode power supply (SMPS) equipment, has developed a significant problem of power supply waveform distortion. While there are a few cases where the distortion is random, most distortion is periodic, or an integer multiple of the power system fundamental frequency. This has given rise to the widespread use of the term harmonics to describe distortion of the waveform.

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate. Harmonics create numerous problems in the generating and load equipment. Harmonic currents produced by nonlinear loads are injected back into the supply systems. These currents can interact adversely with power system equipment, such as capacitors, transformers, and motors, causing additional losses, overheating, and overloading. These harmonic currents can also cause interference with telecommunication lines and errors in power metering. In addition, harmonics propagate over the system and as a consequence, even linear loads draw harmonic currents from distorted supply. The lower harmonic currents produce less of an impact on other power users sharing the same power lines of the harmonic generating power system. IEEE Standard 519-1992 represents a consensus of guidelines and recommended practices by the utilities and their customers in minimizing and controlling the impact of harmonics generated by nonlinear loads.

An accurate estimation of harmonics is required in designing harmonic filters, and for other harmonic pertained issues. The Fourier transform consents a very convenient assessment of magnitude and phase information. It is an efficient algorithm for spectral analysis, which requires low computation time; nevertheless, it suffers shortcomings resulting in inaccuracies. Recent literature [3]-[5] employs countermeasures, such as interpolation, windowing, and harmonic grouping, in order to avoid pitfalls of fast Fourier transform. But those measures come at the expense of additional computational burden.

This paper proposes a method grounded on Wavelet Transform. The Discrete Wavelet Transform (DFT) is accounted as a well suited execution for harmonic group estimation in accordance with IEC Standard 61000-4-7 [2]. It is a signal decomposition technique, which is useful in separating frequency components. The simulated signals are used to validate the proposed wavelet transform.

II. DISCRETE WAVELET TRANSFORM

A wavelet is a waveform of efficaciously limited duration that has an average value of zero. Wavelet transform is adequate to provide the time and frequency information simultaneously, thus yielding a better time-frequency representation of the signal than any other existing transforms. In wavelet analysis, approximations and details are the terms used. The discrete wavelet transform can be defined as a mathematical tool in which the original signal is passed through two complementary filters and comes forth as two signals known as approximations and details. The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. The wavelet transform uses short windows at high frequencies and long windows at low frequencies. This results in multi resolution analysis by which the signal is analyzed with different resolutions at different frequencies.

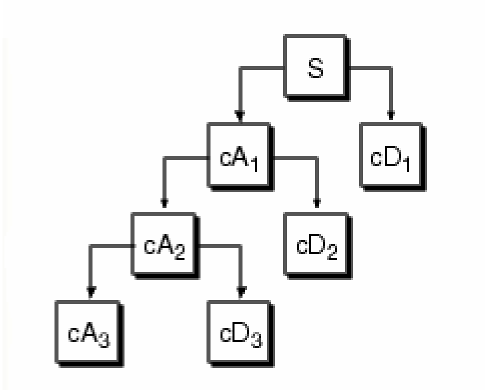

Fig. 1. Wavelet Decomposition

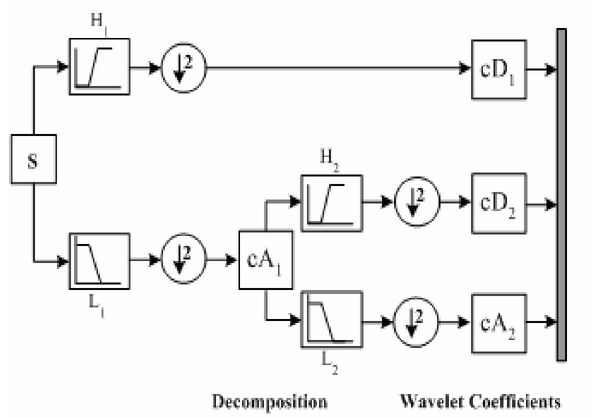

Fig. 2. The process of wavelet transforms producing DWT coefficients

The wavelet analysis is performed because the coefficients hence received have heaps of cognized uses, de-noising and compression being front most amidst them.

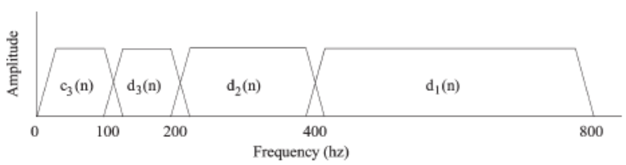

Fig. 3. Frequency bands of the three-level decomposition tree

The approximation and detail coefficients at scale j are written as CA_j and CD_j, to detect the order of harmonics. The sampling frequency selected is 3.2 kHz or 64f1. In this paper, the fundamental frequency is 50Hz and have used 5 level of Wavelet Transform, thus the output receives the sub-band as follows:

- CD1 : 16f1 ~ 32f1 ;
- CD2 : 8f1 ~ 16f1 ;
- CD3 : 4f1 ~ 8f1 ;
- CD4 : 2f1 ~ 4f1 ;
- CD5 : 1f1 ~ 2f1 ;
- CA5 : 0f1 ~ 1f1 ;

III. PROBLEM FORMULATION

A Fourier series represents a distorted periodic signal as the sum of sinusoids as

$$x_i = \sum_{h \in H} A_h \sin(2\pi f_h t + \theta_h)$$

where, t is the time

H is the set of frequency components present in the distorted signal

A_h is the amplitude of the h^{th} component

f_h is the frequency of the h^{th} component

θ_h is the phase angle of the h^{th} component

The wavelet transform of a signal s is the category *C(a,b)* which reckons on two indices a and b. The wavelet decomposition comprises of computing a "resemblance index" between the signal and the wavelet located at position b and of scale a. The indexes *C(a,b)* are called coefficients.

The Discrete Wavelet Transform (DWT) coefficient is defined as follows:

$$C(a,b) = \int_{-\infty}^{\infty} s(t)\psi_{a,b}\,dt$$

Where, $\psi_{a,b}(t) = \psi((t-b)/a)/\sqrt{a}$ is a scaled and shifted version of the mother wavelet $\psi(t)$

IV. SIMULATION RESULTS

To obtain a signal which includes harmonics and inter-harmonics, an AC Drive is simulated using MATLAB/SIMULINK. The voltage and current signal from the simulated model is used to carry on with harmonic analysis. Fig. 4 and Fig. 5 shows the voltage and current waveform of the simulated model. Fig. 6 and Fig.7 shows harmonic spectrum of voltage and current waveform. The harmonic amplitude estimation of voltage and current signal using fast Fourier transform is given in Table I and Table II.

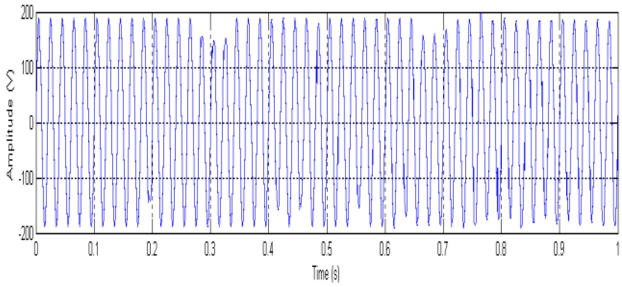

Fig. 4. Simulated voltage waveform of AC Motor Drive

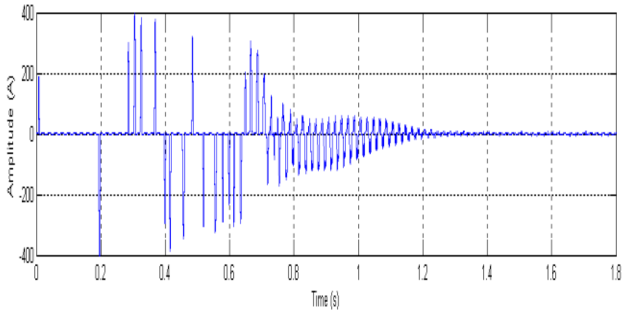

Fig. 5. Simulated current waveform of AC Motor Drive

The fast Fourier transform of the voltage and current signal provides the frequency information.

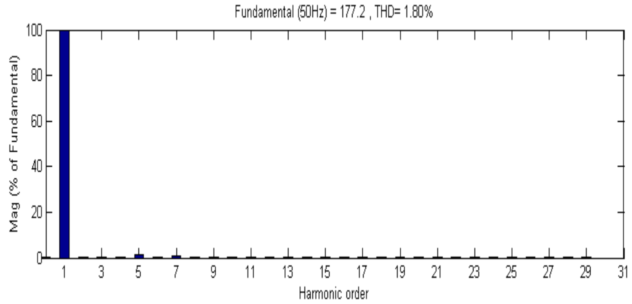

Fig. 6. Harmonic Spectrum of voltage waveform

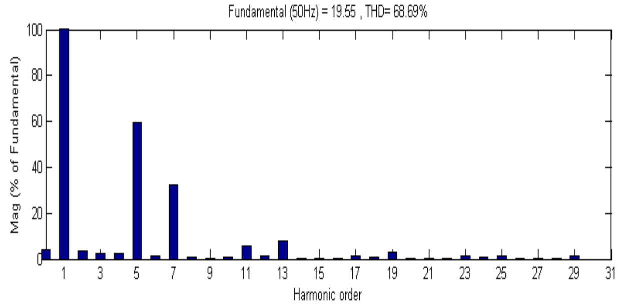

Fig. 7. Harmonic Spectrum of current waveform

Thus, the harmonics and their respective magnitude present in the voltage and current waveform can be observed from the above shown fig. It is understood that fifth and seventh order harmonics are dominant which is because of six step pulse used for triggering the semiconductor switches.

The following table provides the harmonic voltage and harmonic current amplitude estimated using conventional fast Fourier Transform. The values indicate the percentage of magnitude to the root mean square value of the voltage and current.

TABLE I
Harmonic voltage amplitude estimation of AC Motor Drive using FFT

Harmonic Order	Frequency(Hz)	Magnitude (%)
1	50	100.00
3	150	0.16
5	250	1.11
7	350	0.95
9	450	0.09
11	500	0.30

TABLE II
Harmonic current amplitude estimation of AC Motor Drive using FFT

Harmonic Order	Frequency(Hz)	Magnitude (%)
1	50	100.00
3	150	2.24
5	250	59.35
7	350	32.36
9	450	0.49
11	500	5.45

The decomposition property of discrete wavelet transform is utilized to carry out the harmonic analysis of simulated voltage and current waveform as shown in fig. 8 and fig. 9.

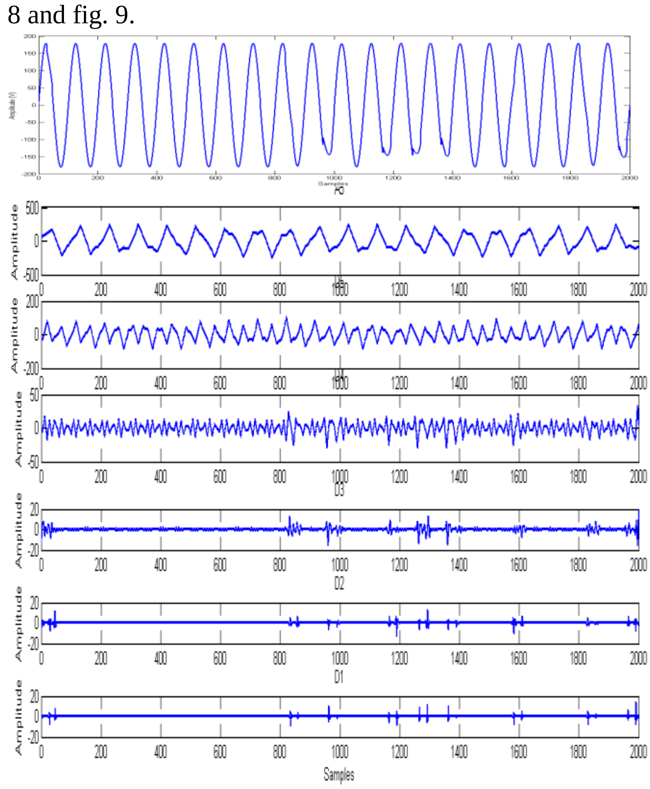

Fig. 8. Wavelet analysis of simulated voltage signal using

DWT

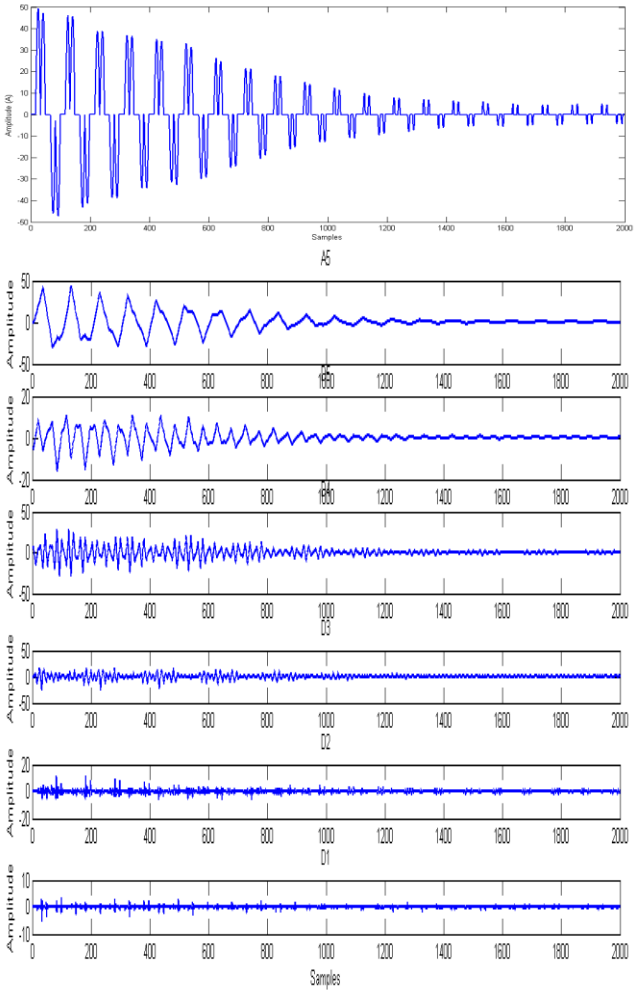

Fig. 9. Wavelet analysis of simulated current signal using DWT

The discrete wavelet transform is performed on supply voltage waveform. Using this signal processing technique, time and frequency domain of the signal can be analyzed.

As per the concept of wavelet transform, the decomposition of signal in various sub-bands is shown in fig. 8 and fig. 9. The sub-bands give the detail of harmonics frequency present in the waveform, thereby, the magnitudes of those frequencies can also be obtained. Moreover, in many applications, where the time information of the event is essential, wavelet transform is handy.

TABLE III
Harmonic voltage amplitude using wavelet Db3

Sub-band	Peak amplitude (Volt) using Db3
CA5	168.763
CD5	75.5561
CD4	17.7134
CD3	2.1590
CD2	0.3570
CD1	0.0850

TABLE IV
Harmonic current amplitude using wavelet Db3

Sub-band	Peak amplitude (Ampere) using Db3
CA5	42.160
CD5	8.696
CD4	7.357
CD3	5.330
CD2	0.337
CD1	0.556

V. CONCLUSION

This paper presents the harmonic amplitude assessment of voltage and current signal of simulated AC Motor Drive. The estimation of harmonics in the power system forms the basis in the field of harmonic analysis. The accuracy and computational complexity are two main features that determine the effectiveness of any harmonic estimation technique. The conventional fast Fourier transform is simple and accurate in the absence of frequency deviation and interharmonics. The signal processing technique, wavelet transform, overcomes the shortcomings of conventional method used for harmonic analysis.

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