Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-1 (2017) 13569–13574

Harmonic Fault Diagnosis in Power Quality System Using Harmonic Wavelet

Mojtaba Kordestani[1], Ali Akbar Safavi[2] and Mehrdad Saif[3]

***Abstract*— The increasing use of non-linear loads such as power electronics, converters, arc furnaces, transformers, fluorescent and high intensity discharge lights have caused harmonics distortion in power quality (PQ) systems. On the other hand, harmonics have numerous effects on electrical systems. For examples, they can be troublesome to communication systems, they increase heating in the transformers and motors, and consequently decrease their life cycle. The first step to address these issues is to diagnose harmonic faults in power distribution systems. This paper introduces a new method for detecting harmonic faults using harmonic wavelets. For this purpose, harmonic wavelet transform (HWT) is used to decompose the faulty signal at different levels. Then, the energies of the decomposition levels based on parseval's theorem are computed. Finally, the faulty signal is reconstructed with harmonics wavelets. Simulation results show that the suggested fault detection and diagnosis (FDD) system can successfully identify the maximum harmonic in the faulty signal and the amount of harmonics in the faulty signal compared to fundamental signal.**

I. INTRODUCTION

Nowadays, new equipment have been designed to work with high power quality. These devices are sensitive to disturbances which may cause failures in their systems [1]. These requirements imposed by advance technologies and competition between power suppliers require steps to deal with power quality problems [2]. The first step to address these problems is fault detection and diagnosis in power distribution system.

Faults in power quality systems are defined as deviations of voltage or current waveform from their ideal sinusoidal forms [3]. IEEE standard 1159 introduces different faults in power quality system. Many faults based on this standard may occur in electricity distribution systems. The most common faults are sags, swells, harmonics, and transient oscillations.

Harmonics as a common fault is considered in[1–4]. Harmonics increases the currents in the electricity distribution systems and consequently can result in overheating in electromotor, cause communication problems, and so on. For these reasons, IEEE standard 519 introduces practices and requirements for harmonics control in electric power systems. This standard suggests limits on harmonics distortion for both customers and power suppliers. In order to apply IEEE standard 519, harmonics faults in power quality systems need to be detected. Unfortunately, processing a large amount of data is time consuming and it could increase the error of systems [2], [4]. Therefore automatic fault detection and diagnosis (FDD) is often used in power quality systems.

Signal processing is widely considered in the field of power quality to diagnose different faults. It consists of different methods like Fourier transform (FT), wavelet transform (WT) and S-transform (ST) [5], [6]. FT is the most popular method in signal processing, which normally decomposes the signal into frequency components. However, it is more suitable for detecting stationary signals. This method may have some difficulties for processing non-stationary signals, so that some researchers apply a fixed window to focus on certain period of time which is known as a short time Fourier transform (STFT). Although this method can deal with smooth time varying signal, but it fails in addressing complicated signals with uncertainty [7] due to the limitation of fixed window. Wavelet transform (WT) as a famous method in signal processing assumes a short window for high frequency components and long window for low frequency components [8] which makes it suitable to apply to non-stationary signals [2], [6], [8–12]. The most important benefit of WT is to use the time and frequency information together [14], [15]. Therefore it is known as a time-frequency representation of the signal [16], [17].S-transform (ST) as a new tool can be formulated by phase correction of WT [17] and it has the ability to diagnose faults at the present of noise [1]. ST is considered in the field of power quality [17–21].

This paper presents a new idea for analyzing harmonics fault in power quality system via harmonics wavelet transform introduced by D. E. Newland[22]. For this purpose, the faulty signal is decomposed by Harmonic wavelets at different harmonic levels and the energy of each level is computed by parseval's theorem. Then, the faulty signal is reconstructed by the harmonic wavelets and the amount of harmonics in the faulty signal are determined with respect to the computed energies.

The main novelty of the paper is in the way that it is designed. An analytical method is introduced to compute

[1]Mojtaba Kordestani, Member, IEEE, is with the Department of Electrical and Computer Engineering, University of Windsor,401 Sunset Avenue, Windsor, O. N., N9B 3P4, Canada. kordest@uwindsor.ca

[2]Ali Akbar Safavi is with the Department of Electrical and Computer Engineering, University of Shiraz, Namazi Square, Shiraz, IRAN. safavi@shirazu.ac.ir

[3]Mehrdad Saif, Senior Member, IEEE, is with the Department of Electrical and Computer Engineering, University of Windsor,401 Sunset Avenue, Windsor, O. N., N9B 3P4, Canada. msaif@ uwindsor.ca

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.2370

harmonics in the faulty signal based on multi resolution analysis. This method reveals the amount of harmonics in the faulty signal and estimates the maximum harmonic in it. Simulation results show the capability of the proposed method.

The organization of the remainder of this paper is as follows. Section II presents harmonics faults in electricity distribution system. Section III illustrates the basic theory of harmonics wavelets. Then, the suggested method and simulation tests are introduced in Section IV. Finally, a summary of results is given in Section V.

II. Harmonics fault description in power quality

Harmonics fault is the most common fault in power distribution system. In harmonics distortion, the faulty signal is made by summation of the waveform with the fundamental frequency and several waveforms with integer multiple of the fundamental frequency. In the most cases, harmonics fault contains harmonic 3,5,7,9,11. Bigger harmonics have very small magnitudes and thus they can be neglected. Nevertheless, IEEE standard 1159 considers all harmonics smaller than 100. An example of this fault is modelled as follows:

$$y(t) = A(\sum_{i=1}^{2n-1} a_{2i-1} sin((2i-1)wt)) \\ 0 < a_i < .9, n = 6, w = \frac{2\pi}{T} \quad (1)$$

III. The basic theory of the harmonics wavelets

This section illustrates harmonics wavelet (HW) [22]. For this purpose, harmonics scaling functions and wavelets are briefly described [22]. Then, an algorithm for training harmonics wavelet coefficients are presented. Finally, the energy of signal at different decomposed is obtained.

A. Harmonics wavelets and harmonics scaling functions

In some engineering problems, it is desired to have a wavelet, which is confined to frequency band so that it is compact in both frequency and time domains. As a result, the signal of detail at each resolution is proper to its frequency band and it can be interpreted as its frequency content. First, this subsection presents harmonics wavelets. Then harmonics scaling functions are illustrated. To obtain harmonics wavelets , a real function $w_e(t)$ whose Fourier transform is defined by (2) can be considered. Figure 1 shows function $W_e(w)$.

$$W_e(w) = \begin{cases} \frac{1}{4\pi}, & \text{for } -4\pi \le w \le -2\pi \text{ and } 2\pi \le w \le 4\pi \\ 0, & \text{elsewhere} \end{cases} \quad (2)$$

$w_e(t)$ can be computed by using the inverse Fourier transform as follows:

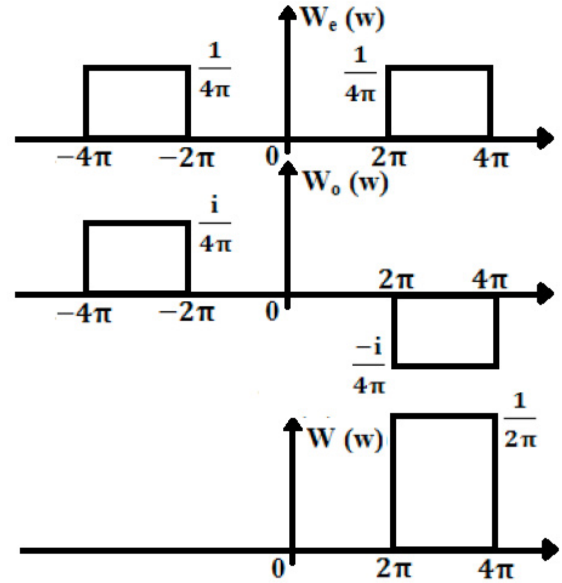

Fig. 1: The Fourier transform for the even, the odd and the complex harmonic wavelet

$$w_e(t) = \int_{-\infty}^{\infty} \mathrm{W}_e(w) exp(iwt)\,\mathrm{d}w = \frac{\sin(4\pi t) - \sin(2\pi t)}{2\pi t} \quad (3)$$

Notice that $w_e(t)$ is an even function.

Similarly, an odd function is obtained as follows:

$$W_o(w) = \begin{cases} \frac{i}{4\pi}, & \text{for } -4\pi \le w \le -2\pi \\ \frac{-i}{4\pi}, & \text{for } 2\pi \le w \le 4\pi \\ 0, & \text{elsewhere} \end{cases} \quad (4)$$

Figure 1 shows function $W_o(w)$. The inverse function is obtained as follows:

$$w_o(t) = \int_{-\infty}^{\infty} \mathrm{W}_o(w) exp(iwt)\,\mathrm{d}w = -\frac{\cos(4\pi t) - \cos(2\pi t)}{2\pi t} \quad (5)$$

Then, a complex function is defined by using $W_e(w)$ and $W_o(w)$ in (6). This function is shown in Fig. 1.

$$W(w) = W_e(w) + iW_o(w) = \begin{cases} \frac{1}{2\pi}, & \text{for } 2\pi \le w \le 4\pi \\ 0, & \text{elsewhere} \end{cases} \quad (6)$$

Similarly, $w(t)$ is computed by combining $w_e(t)$ and $w_o(t)$.

$$w(t) = w_e(t) + iw_o(t) = \frac{exp(i4\pi t) - exp(i2\pi t)}{i2\pi t} \quad (7)$$

Like other wavelets, a family of wavelets can be obtained by changing t to $2^j t - k$ where j and k are dilation and translation, respectively. j and k are integers. Consider $W(w)$ is Fourier transform of $w(t)$ and $V(w)$ is the Fourier