Electrical Power and Energy Systems 46 (2013) 184–197

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An image processing based method for power quality event identification

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ARTICLE INFO

Article history:
Received 22 June 2010
Received in revised form 27 August 2012
Accepted 12 October 2012
Available online 23 November 2012

Keywords:
Power quality
Image processing
Grayscale patterns
Binary images
Disturbance classification

ABSTRACT

This paper presents a novel technique to visualize and detect various power quality disturbance events. It is based on the image processing methods known as grayscale images and binary images. Gray image created from recorded disturbance voltage waveform is first represented as a transverse wave having compressions and rarefactions. Then using image enhancement techniques, the unique features of the disturbance waveform are visualized. Furthermore, the patterns obtained for a pure sine signal and the signal with disturbances are compared for identification of the signal with disturbance. The decision regarding the disturbance type is made using binary image analysis techniques. Finally, to exhibit the novelty of the proposed method, a comparison is made with a conventional image processing based power quality event detection method. In addition, evaluation studies for verifying the accuracy of the method are presented.

1. Introduction

Due to the stringent demands from the microelectronics industry nowadays, the need for improved power quality (PQ) is also increasing. Poor PQ could cause failure or malfunction of certain equipment and processes. Hence, to guarantee high quality of power and to identify PQ problems, a large number of smart power quality meters have been used in electric power systems and industrial premises. These devices capture and store a huge number of the PQ disturbance events every day. However, sophisticated software and algorithms are required to analyze the captured data. In the past, PQ data was analyzed manually, which is very time consuming and also requires special expertise.

Many automatic PQ disturbance identification methods have been proposed in the last few years. Some of the earliest methods that were employed in the characterization of PQ events are based on root mean square (rms), fast Fourier transform and short time Fourier transform (STFT) [1,2]. These methods are useful in providing information for signals that are stationary. However, most of the PQ data captured are non-stationary and hence the techniques cannot properly track the signal dynamics.

The alternative algorithm of STFT is the wavelet transform. This technique has the capability in extracting information from non-stationary signals. In [3–8] the authors utilize wavelet transform to extract the unique features for fast-changing signals such as switching transients and impulses. Even though the wavelets provide a variable window for low and high frequency currents and voltage waveforms, the performance of the one dimensional wavelet transform cannot capture some waveform variations which do not exhibit abrupt waveform discontinuities such as voltage sag [7]. To tackle this problem, two dimensional discrete wavelet transform (2D-DWT) was introduced in [7,8] by separating the two dimensional cyclo-stationary disturbance event in different wavelet sub-spaces. However, it is well known that all the wavelet based methods get affected because of the effect of the noises [9,10]. To improve the performance of the wavelet, an alternative technique called the S-Transform was developed. The S-transform is equivalent to phase corrected continuous wavelet transform. It is fully convertible from the time domain to the two dimensional frequency translation domain, and to the familiar Fourier frequency domain. Researchers [11–14] have utilized S-transform to extract features such as amplitude factor, frequency factor, etc., from the PQ disturbance signals. In [15], the power signal disturbances in time–time transformation (TT-transform) are derived from the S-transform. TT-transform is the two dimensional time–time representation of a one dimensional time series based upon the S-transform. TT-transform helps in the interpretation of the S-transform.

Based on the features extracted from the aforementioned signal processing techniques, a variety of methods has been adopted for the decision-making stage of automatic classification of PQ disturbances. The authors in [16–18] have utilized the Support Vector Machines (SVMs) to classify the disturbance types of PQ. Similar to SVM, artificial neural network (ANN) approaches have found applications in predicting the type of PQ disturbance [19]. Fuzzy and Rule-based expert system has also been employed for the decision-making step in the process of classifying PQ disturbance types [13,14,20,21,22].

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http://dx.doi.org/10.1016/j.ijepes.2012.10.049

In this paper, a novel method for visualizing and classifying the different types of PQ disturbances is proposed. The proposed method is based on the image processing methods known as grayscale images and binary images. Gray image created from recorded disturbance voltage waveform is first represented as a transverse wave having compressions and rarefactions. During a disturbance such as a transient, the gray patterns of these images reveal the information about the type disturbance, as will be shown in the paper. A brief overview on the conventional 2D-DWT method to represent PQ disturbances is given first [7]. 2D-DWT has been used to compare with the proposed method.

2. Conventional 2D-DWT power quality detection

Two dimensional discrete wavelet transform (2D-DWT) PQ detection method is an image processing-based PQ event detection introduced by Dogan and Omer to solve the limitations of one dimensional DWT in PQ disturbance classification [7,8] and data compression. The method starts by dividing the voltage or current time series into a two dimensional matrix whose rows represent individual cycles of the event waveform. This representation, as an image is beneficial in power quality disturbance detection. It produces visible short discontinuity at the beginning and at the end of the disturbance.

To analyze the PQ event in the two dimensional version called the image, 2D-DWT is applied to decompose the image into corresponding sub-spaces with their relative DWT coefficients. By implementing a high and low pass filter bank, these DWT coefficients provide approximation, horizontal, vertical and diagonal details of the image respectively. When single level decomposition is applied, the obtained four sub-spaces are reduced images in both dimensions by two with respect to the original image. It is noteworthy to mention that horizontal sub-space image contains the necessary discriminating features even if the waveform distortion is smooth, which is usually the case for sags and swells. Moreover, other detail sub-spaces, also contain band-pass information which indicates sharp waveform distortions. The structure of disturbances in different sub-spaces provides discriminating criteria for event identification. Finally, to convert the image information contained in separate sub-spaces into feature data, inverse DWT is applied by suppressing approximate sub-space image. Then this feature image is raster scanned and threshold to get a one dimensional feature waveform. Fig. 1 shows the sub-space images and feature waveform when applied to a pure signal using Daubechies-2. No variations are observed in any sub-spaces, and therefore the joint feature waveform as shown in Fig. 1e, do not detect any disturbance. More details of this method can be found in [7,8].

3. Proposed concept for PQ events classification

Image processing techniques have been effectively applied in many areas, including medicine, radar, sonar, robotics, material science, and indentation to name a few. It addresses binary and grayscale images, as well as color and 3 dimensional imagery.

A grayscale image is a data whose values represent intensities within some range. Generally, the intensity 0 represents black and the intensity 256 represents white. Each element of the image data corresponds to one pixel of the image.

For PQ disturbance visualization and detection, an image can be created by converting the recorded single phase voltage information from the PQ monitor for each time step by using the following transformation function [23]:

$$f : \Re^1 \rightarrow [0, 256]^1 \tag{1}$$

The transformation function shown in (1) involves a two-step procedure. First, the voltage values are normalized and shifted in the positive direction to make them bounded between 0 and 256. Fig. 2 shows grayscale image obtained for a pure voltage waveform.

As seen in Fig. 2, a grayscale image file consists of pixels on 2 dimensional (2D) space. The 2D coordinates of one pixel is composed by treating *x*-axis as time and *y*-axis as the pixel intensity. This transformation causes the time varying sinusoidal waveform to appear somewhat like a longitudinal wave with compressions and rarefactions. The compressions can be thought of high intensity regions and the low intensity regions as the rarefactions, as shown in Fig. 2. Observe that the transition in gray intensity throughout the image is regular and smooth. This is a unique

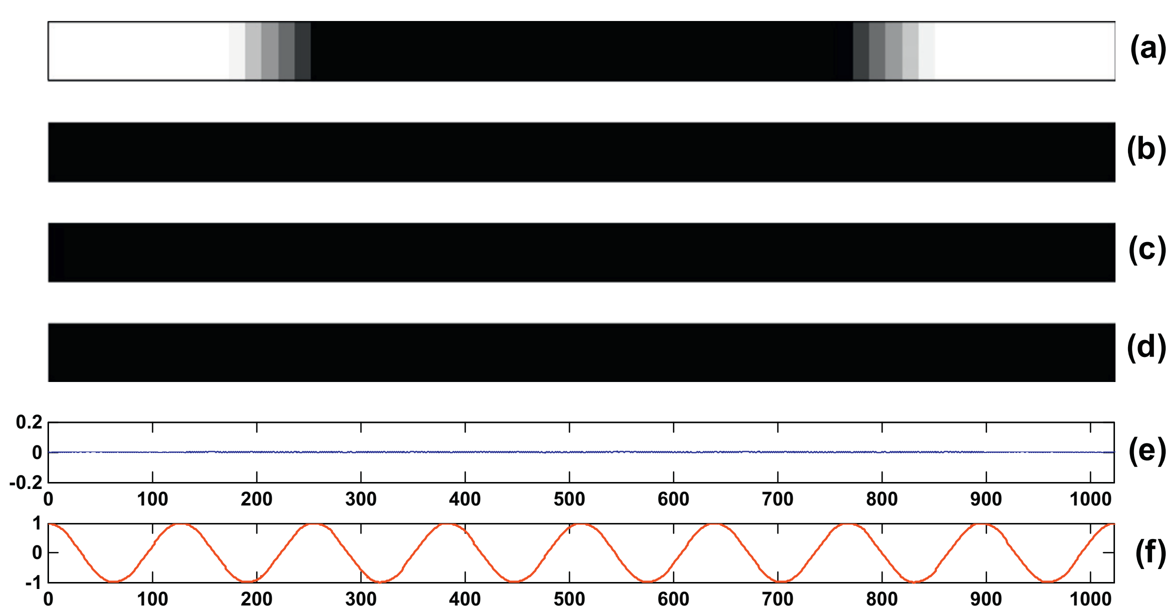

Fig. 1. 2D cyclo-stationary sub-space images for a pure signal: (a) approximation, (b) horizontal details, (c) vertical details, (d) diagonal details, (e) 1D feature waveform after inverse DWT and (f) scaled pure signal.