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A real-time method for time–frequency detection of transient disturbances in voltage supply systems

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ABSTRACT

This paper presents a new method for real-time detection, extraction and analysis of transient disturbances in low-voltage supply systems. The algorithm developed is based on the sliding window method and applies the discrete wavelet transform to a difference signal computed in the time domain, comparing each voltage sample with its corresponding sample in the previous period. In the case that the difference signal surpasses a defined threshold, the algorithm proposed computes the energy of the different frequency bands of the difference signal corresponding to one fundamental period, detecting a transient disturbance in the frequency domain within the next period of the input signal when a specific threshold is exceeded. Other voltage events, such as short duration root-mean-square variations can also be detected using the method proposed. The results obtained demonstrate the good performance of the method.

1. Introduction

IEC Standard 61000-4-30 [1] and IEEE Standard 1159 [2] define a transient as "pertaining to or designating a phenomenon or a quantity that varies between two consecutive steady stages during a time interval that is short compared to the time scale of interest". According to Ref. [2], in a broader sense, transient disturbances can be classified into two categories: impulsive and oscillatory. An impulsive transient is a sudden, non-power frequency change from the nominal condition of voltage, current or both, that is unidirectional in polarity (either positive or negative). Impulsive transients are normally characterized by their rise and decay times, and can also be described by their spectral content. The precise definition of these magnitudes can be seen in IEEE Standard C62.41-1991 [3]. The most common cause of impulsive transients is lighting.

An oscillatory transient is a sudden, non-power frequency change in the steady-state condition of voltage, current or both, that includes both positive and negative polarity values. Oscillatory transients are described by magnitude, duration and spectral content. These disturbances are normally produced by switching in the distribution system, such as capacitor bank energization or switching of end-user equipment.

Transient disturbances are one of the most dangerous power quality disturbances because of their effect on equipment. Because of its short duration, normally less than one fundamental period, and the high-frequency components involved they are difficult to detect, requiring high sampling rates and real-time operation.

The development of real-time methods and instruments for the detection and analysis of transient disturbances is at present a major concern in power quality analysis in order to assess the quality of voltage supply and to prevent the harmful effects on equipment. The purpose of this paper is to present a new and more exact time–frequency method for on-line and real-time detection, extraction and analysis of transient disturbances in low-voltage supply systems.

The paper is organized as follows: Section 2 reviews the different methods proposed for detection of transient disturbances, Section 3 presents a full description of the new method proposed, Section 4 studies the performance of the method in the detection of different transient disturbances, Section 5 describes the implementation of the method and some experimental results and finally, and Section 6 presents the conclusion.

2. Detection of transient disturbances

There is no standard method defined for detection and analysis of transient disturbances, as is the case of other power quality phenomena, such as harmonic distortion, voltage dips or flicker. There are different methods proposed in the literature that can be applied to this end, although none of them is dominant. Standard IEC 61000-4-7 and Refs. [4,5] report some of the most common methods applied. They can be grouped as time-domain and frequency-domain methods. The time-domain methods are the comparative method, the envelope method, the sliding window

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method, the dv/dt method and the rms method. In the comparative method the transient is detected when a fixed absolute threshold is exceeded. The envelop method is similar to the comparative method, but after removing the fundamental component of the signal. In the sliding window method the instantaneous values are compared to the corresponding values in the previous cycle, directly or after removing the fundamental component. In the dv/dt method a transient disturbance is detected when a fixed absolute value of dv/dt is exceeded, in the rms method the rms value is computed for intervals less than one fundamental period and compared to a threshold.

Frequency-domain methods are based on the used of fast Fourier transform (FFT), wavelets, S-transform or others. The use of wavelets allows the decomposition of a signal into components as a function of time and frequency, providing a more precise time location of a transient than other frequency-domain methods.

Different instruments and methodologies have been proposed in the technical literature for detection and analysis of transient disturbances in voltage supply systems [6–24]. Ref. [6] presents a real-time DSP-based instrument that uses the sliding window method without removing the change in fundamental component from the disturbance signal. The beginning of the disturbance is detected when the difference signal exceeds a given threshold and ends when it surpasses another threshold. The selection of these thresholds is the critical point in this method.

Refs. [7] and [8] present a DSP-based equipment for real-time detection of transients. The system operates in the time domain computing an index using the voltage samples for different segments of the signal in an observation interval. The disturbance is detected if the index of at least one segment in each observation interval exceeds a given threshold. The method is sensitive to noise, even-order harmonic distortion and interharmonics, and could fail in the detection of low magnitude short duration transient disturbances. This method cannot extract the disturbance signal without the fundamental component as is required in [2] for analysis of the transient disturbance.

Papers [9,10] propose a simple detection algorithm based on the sliding window method, using a notch filter to avoid the effect of the fundamental component in the disturbance signal. The filtered disturbance signal is compared with a given threshold for detection of a transient disturbance. The performance of the notch filter, that could affect both the magnitude and the duration of the transient, and the selection of the detection threshold are the critical points in this method.

Time–frequency methods such as wavelets [11–22] or a combination of wavelets and Fourier analysis have also been proposed for detection and analysis of transient disturbances [23]. Refs. [11] and [12] were the first in proposing wavelet transform for analysis of transient disturbances. In those references a visual inspection of the time–frequency plane was used for detection and analysis of a transient in a disturbance record.

Refs. [13,14] use the deviation of the energy of the wavelet coefficients at the different resolution levels with respect to a standard signal for classification and quantification of short duration events in distribution systems. In Ref. [15] the discrete wavelet transform is applied to an error signal without the fundamental component obtained using an adaptive filter. The energy of the different scales relative to the error signal is used to identify the disturbance. This error signal contains the harmonic distortion and the noise present in the input signal, limiting its performance.

The difference in the energy distribution between the disturbance signal and a pure sinusoidal signal with the nominal voltage is used in Refs. [16–20] for automatic classification of power system disturbances. This method also has a limited performance because the error signal contains part of the fundamental component, the harmonic components and the noise in the input signal. All these components superimposed onto the disturbance signal, can make the transient disturbance undetectable. Another problem related to the use of this method is the strict synchronization requirement to obtain the difference signal.

The difference of energies is also used in Ref. [21], but using the de-noised distorted signal caused by the power quality event as a reference signal. This method uses previously obtained disturbance records and is not valid for real-time applications.

Finally, Ref. [22] presents an instrument for detection of transient disturbances and voltage notching using wavelets. The instrument detects a transient when the reconstructed voltage samples in the different frequency bands obtained using 10-cycle records of the input signal, surpass a specific threshold.

Most of the wavelet-based detection methods proposed use disturbance records previously recorded by power quality monitoring instruments and do not allow the on-line, real-time detection of transient disturbances. Another practical problem related to the use of wavelets for detection of transient disturbances is the effect of noise in the wavelet transform coefficients, mainly in the case of slow and small transients or in the case of the detection of transients in highly distorted signals. The use of a difference voltage signal instead of the actual voltage waveform, as is proposed in this paper, considerably reduces the effect of noise on the detection capabilities of wavelet transform as will be shown in the next sections of this paper.

In general, the time-domain methods are faster and easy to implement than the frequency-domain methods but they present worse detection performance than the frequency-domain methods.

Once the transient disturbance has been detected it can be characterized and classified using parameters such as: the peak magnitude, the overshoot voltage, the rate of rise of the leading edge, the frequency parameters, the duration, damping or the frequency of occurrence, if the transient is continuous (every cycle, such as voltage notches) or it is a single-shot (unpredictable) transient [1]. According to Ref. [2], it is also important to indicate the magnitude of the transient with and without the fundamental component.

3. Detection algorithm

The time–frequency detection method proposed processes the input signal continuously, period by period, on-line and in real-tine, detecting a transient disturbance in the previous period of the signal while it is simultaneously acquired the actual period.

The sliding window method is used in the time-domain for extraction of the disturbance. Each sample of voltage waveform is compared with the corresponding sample in the previous period stored in memory as the reference signal. If the difference signal exceeds a defined threshold (the capture threshold) then it is decomposed into different frequency bands applying the discrete wavelet transform (DWT), and computing the energy of the output bands. Finally, a transient is detected within the next period of the input signal if any of the components of the vector of energies surpasses a given threshold (the detection threshold).

Fig. 1 shows the block diagram of the method proposed. In the initialization block the reference signal is obtained as proposed in Ref. [6]. The first fundamental cycle acquired is stored in memory. If no transient disturbance is detected in the next fundamental cycle, the reference signal is suitably obtained, otherwise, at least one of the two cycles contains a transient, so the two cycles are discarded and a new cycle is obtained until a suitable initialization cycle is found.

In the extraction of the transient block each sample of the actual period of voltage waveform $u(t)$ is compared with the