Electric Power Systems Research 114 (2014) 110–117

Contents lists available at ScienceDirect

Electric Power Systems Research

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

A novel algorithm for voltage transient detection and isolation for power quality monitoring

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ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form 11 April 2014
Accepted 12 April 2014
Available online 10 May 2014

Keywords:
Electric power quality
Detection and isolation of disturbances
Voltage transients
Notches and impulsive transients
Time domain algorithm
Isolation from steady state disturbances

ABSTRACT

Usually the measurement instruments dedicated to power quality assessment contain a transient detection stage that is activated only when it is necessary. However, it is common that such stage does not have the same sampling time than the stage devoted to measurements in steady state such as power factor, harmonic content or RMS values.

In this paper, the authors describe a simple algorithm that can detect and isolate notches and impulsive transients from other voltage disturbances with the same sampling time used for measurements in steady state. The merit of this approach is that, if the proposed algorithm is set up in a power quality analyzer (PQA), this device will be able to record all kind of disturbances, the steady state ones using the classical algorithms programmed in the PQA and the transient ones by the approach addressed in this paper, the same sampling time considered for all of them, without substantial increase of the computational effort.

The method was implemented in a prototype, and laboratory and industry results are shown. Additionally, operative limitations of the method are discussed.

1. Introduction

The importance of power quality assessment has been growing lately, mainly due to the associated cost of poor electrical power quality, over all in industrial applications. This reason has created multiple standards and recommendations related with this topic [1–3] and, consequently, the technological development of several types of Power Quality Analyzers (PQA) [4–6].

The detection of voltage transients with duration lower than a half cycle has special interest because of its complexity to detect them and their consequences in power quality of electrical networks [7]. However, usually the PQA requires activating a special stage dedicated to voltage transients, with a different sampling time as compared with steady state measurements and as a consequence, both stages cannot be carried out simultaneously.

There are several works in the literature that deal with the power quality monitoring problem using different and elegant viewpoints. For example, in [8] the authors propose the use of a method based on the least square minimization of the residual signal given by a short Fourier filter with two adaptive coefficients; this method is simple, but the accuracy of the method is dependent on these coefficients. Methods based on wavelet and fast Fourier transform (FFT) generate information of the measured signals in time–frequency and frequency–amplitude, respectively, even in combination with expert systems [9] and [10]. Such methods are able to detect transients; however they fail if transient is very short. Additionally, in order to detect all kind of transients, wavelet transform requires high decomposition levels [11], [7]; even the simplest wavelet requires defining design parameters intuitively [12]. Other proposed techniques dedicated to the classification of the disturbances are based on complex methods, which increase computational effort [13–15].

However, the complexity of the method and its impact in the computational effort is a critical consideration for PQA manufacturers. In [16] and [17], the authors carry out a wide study of methods and algorithms and their impact in hardware showing the importance of simplicity in the algorithm formulation. In other previous works research is done to obtain an optimal feature selection for power quality disturbance classification by using a probabilistic neural network combined with a global optimization algorithm with an adaptive neural network to gradually remove redundant and irrelevant features in noisy environments [18]. This method has good performance for classification but its complexity is high for a PQA. Other methods for classification are shown in [19].

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http://dx.doi.org/10.1016/j.epsr.2014.04.009
0378-7796/

Reference [20] proposes an algorithm for real-time detection of transients. It relies on a simple and robust algorithm. The drawback of this algorithm occurs when noise appears, since a considerable development is performed (high computational effort) to discriminate it. The authors of this work do not mention if the algorithm can be used in a PQA. Reference [21] proposes a simple method for transient detection, but this is dependent on the use of a digital filter which requires to be tuned.

This paper discusses an algorithm with the ability to diagnose voltage transients from steady state disturbances with the same sampling time. The authors present a voltage transient detection and isolation algorithm based on arithmetic operations [22]. In this work authors highlight normal operative limitations and include laboratory and industrial experimental results. This algorithm was designed considering the following assumptions: (a) simplicity of the algorithm, (b) time–frequency transformations are avoided, (c) the algorithm does not depend on selection of constants or parameters or adaptations and (d) the algorithm is able to detect and isolate voltage transients from other disturbances with the same sampling time.

In terms of classification, in this paper the two disturbances under analysis are: (1) impulsive transient is a sudden, nonpowered frequency change from the nominal condition of voltage, that is unidirectional in polarity (primarily either positive or negative) and (2) notching has attributes that could be considered both, transient and harmonic distortion; the frequency components associated with notching can be quite high and may not be readily characterized with measurement equipment normally used for harmonic analysis [1]. In this paper, impulsive transient and notching are treated as transients. The proposed algorithm in this paper diagnoses such phenomena considering typical sampling times used by commercial PQA with basic computing and low cost operations versus wavelets, FFT, etc. [7,10,19].

This paper is organized as follows: in Section 2 the proposed algorithm with its three stages is explained in detail, these stages give accurate results. In Section 3, simulations illustrate the algorithm benefits and demonstrate the effectiveness of the method, even in extreme situations. In Section 4 experimental results validate the method considering the same situations in the previous section, and measurements of power quality obtained by the authors in a Mexican Copper mine are used to show the effectiveness of the algorithm. In Section 5 authors give general conclusions about the performance of the algorithm and the application in a PQA for power quality monitoring.

2. Detection and isolation algorithm

According to specialized literature, authors consider that detection and isolation algorithm is required to be fast, robust and simple, preferably without tuning any parameter and regardless of the user. In this section the proposed algorithm is described in detail. This algorithm works in time domain being its main operation a subtraction. Besides it allows an easy way to be programmed in a simple digital board.

To explain the algorithm it is required to divide it into three stages: the first one shows how the detection is performed, the second one explains how the isolation is carried out and the last one deals with the algorithm limitations taking into account operative considerations.

2.1. Detection stage

Let $f_i(t)$ be an ideal continuous function in time domain representing a voltage signal, defined as

$$f_i(t) = V_p \mathrm{sen}(\omega t) \tag{1}$$

where V_p is the peak voltage, $\omega = 2\pi f$, f is the frequency and t is time.

Now, it is considered a non-ideal voltage signal (e.g. a real voltage measured of electrical network), as follows

$$f_r(t) = f_i(t) + f_h(t) \tag{2}$$

where $f_h(t)$ is considered as some periodic or aperiodic disturbance on the voltage signal such as harmonic disturbance, sags, swells, impulsive transients, notches, noise or a combination of them.

In the discrete case, (1) and (2) are defined as follows

$$f_i[n] = f_i(nT) \tag{3}$$

$$f_r[n] = f_r(nT) \tag{4}$$

where t is discretized as nT, T is the sampling time and n is the current sample.

The main idea behind the proposed methodology is to know how far the real signal (4) is from the ideal signal (3); namely, how the real signal is disturbed. For this situation, the following procedure is proposed

$$V_f[n] = f_r[n] - f_i[n] \tag{5}$$

then:

$$V_f[n] = f_h[n] \tag{6}$$

$V_f[n]$ in (6) indicates the remaining voltage which can be positive or negative. The next conditions define if the voltage is positive or negative. Condition one (C1) is considered as follows

> if $|f_i[n]| > |f_r[n]|$ then $V_f[n]$ is negative,
> this is, $V_f[n] = -|f_h[n]|$
> Missing voltage is indicated.

In the opposite case, the condition two (C2) is considered as follows

> if $|f_i[n]| < |f_r[n]|$ then $V_f[n]$ is positive,
> this is, $V_f[n] = |f_h[n]|$
> Excess voltage is indicated.

However, the algorithm requires a threshold since, as a first approach, the threshold was selected considering the steady state values given by the ITIC curve depicted in Fig. 1. This curve provides the voltage susceptibility levels for electronic devices [23].

The upper threshold is defined as "*upper_limit*" and the lower threshold as "*lower_limit*" and their values are given as a percentage of the peak value V_p. Then, the condition three (C3) is defined as follows

At this point, if $V_f[n]$ is not within the established threshold given by C3, then data processing and the detection of the event begin. Additionally, in the detection stage the following relationship between the upper and lower thresholds is

The purpose of the minus sign is to find out if a noth or an impulsive is present.

In the implementation, the steady state disturbances can be detected as a transient (e.g. harmonic voltage of a certain value). In order to avoid this problem, the method must be provided with isolation capability as follows.