Available online at www.sciencedirect.com

ScienceDirect

Electric Power Systems Research 78 (2008) 618–625

ELECTRIC POWER SYSTEMS RESEARCH

www.elsevier.com/locate/epsr

An extended Kalman filtering approach for detection and analysis of voltage dips in power systems

E. Pérez, J. Barros *

Department of Electronics and Computers, University of Cantabria, Avenida de los Castros, Santander 39005, Spain

Received 3 August 2006; received in revised form 26 March 2007; accepted 9 May 2007
Available online 21 June 2007

Abstract

This paper proposes a new method based on the use of an extended Kalman filter for the detection and analysis of voltage dips in power systems. The paper describes the model used to enable the most accurate representation of the system and the selection of the parameters to ensure optimal filter performance. The results obtained using this method are presented both for simulated and for real voltage dips and are compared with the results obtained using the rms method proposed in the power quality standards in order to demonstrate the improved performance of this new method in the estimation of the time instant of the beginning and end of a voltage dip as well as in the estimation of the magnitude and phase angle of voltage supply during the event.

Keywords: Kalman filtering; Power quality; Voltage dips

1. Introduction

Voltage dips are one of the most important power quality disturbances in power systems because of their frequency of occurrence and the sensitivity of electrical and electronic equipment to short voltage variation. The development of new methods for detection and analysis of voltage dips is of utmost importance to know the characteristics of the power system itself and to design strategies for protection of sensitive equipment in order to avoid the economic impact that voltage dips could have in industrial and commercial distribution systems.

IEC Standard 61000-4-30 defines the $U_{\mathrm{rms}(1/2)}$ magnitude as the basic measurement for detection and evaluation of voltage dips. This magnitude is defined as "the rms voltage measured over 1 cycle, commencing at a fundamental zero crossing, and refreshed each half-cycle" [1].

According to this standard a voltage dip is characterized by a pair of values: the residual voltage or the depth and the duration. The residual voltage is the lowest $U_{\mathrm{rms}(1/2)}$ value measured during the dip, and the depth is defined as the difference between the reference voltage and the residual voltage (generally expressed as a percentage of the reference voltage). A voltage dip begins when the $U_{\mathrm{rms}(1/2)}$ magnitude goes below the dip threshold, 0.9 p.u. of the declared or nominal voltage according to European Standard EN50160 [2], and ends when the $U_{\mathrm{rms}(1/2)}$ magnitude is equal to or above the dip threshold plus the hysteresis voltage. The duration of a voltage dip is defined as the time difference between the beginning and the end of the voltage dip.

The $U_{\mathrm{rms}(1/2)}$ method is simple and easy to implement, but shows a limited performance in the detection and in the estimation of magnitude and duration, mainly for short duration and less severe voltage dips [3]. Using the $U_{\mathrm{rms}(1/2)}$ value, the magnitude of a voltage dip is exactly computed only when the duration of the voltage dip is greater than the sampling window used. Furthermore, because the $U_{\mathrm{rms}(1/2)}$ value is computed each half-cycle of the fundamental component, the duration of a voltage dip is given in integer multiples of half-cycles and thus, depending on the point-on-the-wave where the voltage dip begins and on its magnitude, the error in the duration could be very important, especially for short duration and low magnitude voltage dips.

Other signal processing tools have been proposed in the literature for the detection and estimation of voltage dips. The short time Fourier transform, wavelet analysis and Kalman filtering are the most important alternative methods for detection

* Corresponding author. Tel.: +34 942201355; fax: +34 942201303.
E-mail address: barrosj@unican.es (J. Barros).

0378-7796/$ – see front matter
doi:10.1016/j.epsr.2007.05.006

and analysis of voltage events. An interesting review of different signal processing methods for power quality disturbance characterization and classification can be seen in ref. [4] and a comparative study of the performance of the methods previously referred to is reported in ref. [5].

Wavelets are a signal-processing tool especially devoted to the analysis of non-stationary signals and they have been successfully applied for the detection and analysis of power quality disturbances in power systems [6–12]. Using wavelet analysis a signal can be studied with different time-frequency resolutions. Short time intervals are provided for the high-frequency components of the signal whereas long-time intervals are provided for the low-frequency components.

The time locating properties of the coefficients of the high-frequency decomposition of the wavelet analysis (detail coefficients) can be used for locating the beginning and the end of a voltage dip. These coefficients present a high variation in magnitude associated to the transitions of a voltage dip but they are insensitive to a steady-state signal. The key factor in the use of these coefficients is the selection of the mother wavelet function and the adequate detection threshold to discriminate a voltage dip against other high-frequency disturbance in voltage waveform. Refs. [12,13] present a study of the performance of different wavelet functions for detection of voltage dips and the selection of the voltage dip detection threshold.

The extreme sensitivity of these coefficients to any high-frequency noise in voltage supply could make this method useless for an automated on-line system for detection of voltage dips. Ref. [19] shows how the high-frequency noise that normally accompanies voltage dips could produce false voltage dip detection using the peak values of the detail coefficients of the high-frequency scale of wavelet analysis. Another effect that could produce false detections using wavelet analysis is observed in the case of multi-step voltage dips. In this case, the new transitions in voltage waveform are also detected using the detail coefficients producing uncertainty in the detection of the beginning or the end of the voltage dip. As an example, Fig. 1 represents the waveform of a two-step voltage dip detected in the low-voltage distribution system of our building and Fig. 2 shows

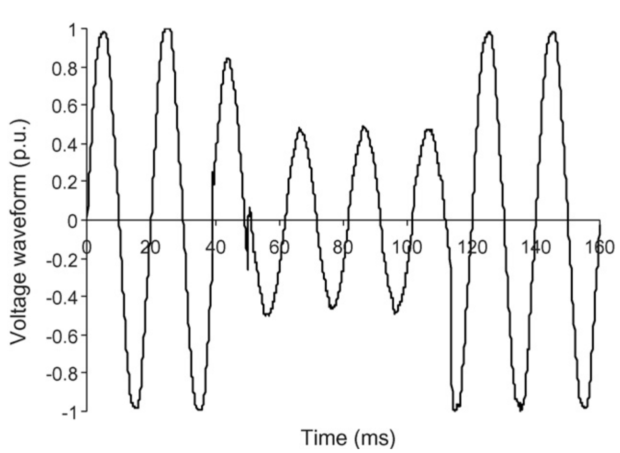

Fig. 1. Voltage waveform of a voltage dip measured in a low-voltage distribution network.

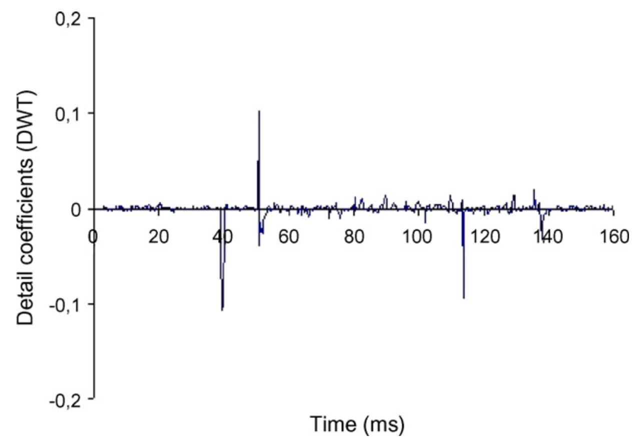

Fig. 2. Time evolution of the detail coefficients of the high-frequency scale of the discrete wavelet analysis for the voltage dip of Fig. 1.

the time evolution of the detail coefficients of the high-frequency scale of the discrete wavelet analysis using Daubechies with six-coefficients as the mother wavelet function. The high-frequency noise and the transitions in voltage waveform produce peak values of the detail coefficients over the voltage dip detection threshold making the detection and characterization of voltage dip very difficult.

On the other hand, the detection properties of Kalman filtering and its accuracy in the estimation of the magnitude and duration of voltage dips depend on the model of the system used and on the specific characteristics of the voltage dip (magnitude, duration and point-on-the-wave of the beginning). An important advantage of Kalman filtering over the rms method is that it gives information about the magnitude and phase-angle jump associated with the voltage dip and also about the point-on-the-wave where it begins. Refs. [14–19] discuss the Kalman filtering modelling issues and compare the performance of Kalman filters of different order in the detection and analysis of voltage dips. Ref. [18] reports the results of several months monitoring of voltage events in a low-voltage distribution system using a three-phase Kalman filter for real-time detection and analysis of voltage events.

One of the most critical issues related with the use of Kalman filters is the adequate selection of the noise covariance matrixes Q and R. These error covariance matrixes act as tuning parameters to balance the dynamic response of the filter against the sensitivity to noise. The theoretical values of Q and R can be computed mathematically, but in many cases and especially for non-linear systems, these theoretical values do not produce the most accurate results. It has been demonstrated that the filter response depends more on the Q/R ratio than on the values of Q and R [20].

Another important aspect to be considered in the use of Kalman filtering is how the filter responds to abrupt changes, as is the case in a voltage dip, which can make the filter to lose the ability to track these changes. Different solutions have been proposed to compensate for this problem. Liu [21] proposes resetting the error covariance matrix P to a predefined level just after detection of abrupt change of the state variables, to increase the sensitivity of the Kalman filter. On the other hand, refs. [22,23] propose the use of two values of the noise covariance