Measurement 90 (2016) 372–381

Contents lists available at ScienceDirect

Measurement

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

An implementation of a Power System Smart Waveform Recorder using FPGA and ARM cores

E.B. Kapisch [a], L.R.M. Silva [a,*], C.H.N. Martins [a], A.S. Barbosa [a], L.M.A. Filho [a], C.A. Duque [a], A.E. Tavil [b], L.A.R. de Souza [b]

[a] PSCOPE Signal Processing and Computational Intelligence for Power Systems, Electrical Engineering Program, Federal University of Juiz de Fora, Juiz de Fora, MG 36.036-900, Brazil
[b] KRON Medidores Eletrônicos, São Paulo, SP 04.760-020, Brazil

ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form 21 March 2016
Accepted 26 April 2016
Available online 4 May 2016

Keywords:
Detector
Compressor
Power Quality
Wavelet
FPGA
Embedded Processor

ABSTRACT

In this paper, the design and the prototype implementation of a Power Quality (PQ) disturbance detector and compressor are described. This instrument, named Power System Smart Waveform Recorder (PSSWR), is able to acquire the samples of the Electric Power System (EPS) signals and process them in order to detect, compress and store the disturbances waveforms into an SD card, from which it can be reconstructed and analyzed offline with a suitable computer application. The prototype uses, among other devices, Field Programmable Gate Array (FPGA) and ARM platforms to work with the EPS signals in a smart way. The PSSWR is able to detect and record either the waveform of the well-known PQ disturbance as well the new PQ disturbances not yet observed in EPS, thanks to the Novelty Detection concept. This characteristic is important in the new context of smart grids where hidden disturbances can be detected by the methodology.

1. Introduction

Nowadays there is a growing concern about Power Quality (PQ) problems. These problems are due to the massive use of non-linear loads and electronic-based equipment in residences, commercial centers, and industrial plants, and the proliferation of distributed generation in the Electric Power System (EPS). Therefore, the monitoring of EPS in real-time, along with off-line analysis using both centralized and decentralized schemes, has grown in importance [1].

In several applications the continuous data acquisition and storage are necessary. This is sustained by the fact that the post-processing of this data can uncover information not previously observed, allowing system enhancement, troubleshoot, algorithm optimization, among others. For example, high frequency disturbances like transient oscillations or switching processes are only visible in the full waveform, the signature hidden in raw data can be used to predict the breaking of cables, etc. Although aggregation is useful for data reduction and comparison, deep data analysis should be enabled considering full observation possibilities [2].

However, continuous raw data recordings of electrical signal is not a simple task due the large amount of data to be recorded and later transferred. Besides, few commercial types of equipment are currently available aiming at recording continuous raw data at high sampling rate [3]. Most of the conventional recorders are application oriented and are used only for acquiring either a short-term of failure signal or disturbance signal [4,5]. A thorough survey of the leading manufacturers of PQ analyzers was made. Nine of the top brands were examined, totaling 27 devices. From the investigation of their manuals and data sheets, it was observed that all of them are able to record the PQ parameters (data) for a long period of time. Depending on the aggregation time, some equipment are able to record over than a year of PQ parameters. Nevertheless, only two of them are able to save waveform recordings for a long period. The one described in [6] was used in this paper for a comparison purpose, because it is able to recording about 1 year of gapless waveform using a compression technique.

The system described in this paper, named Power System Smart Waveform Recorder (PSSWR), is able to reconstruct the entire waveform signal, acquired at a high sample rate. However, a continuous raw data recording is not employed. Instead, only samples around the detected electrical disturbance are packed, compressed and recorded for offline reconstruction of the whole signal. Apart those samples, an information about the frequency estimation of each cycle of the signal is also recorded. These informations are used to produce a smooth signal between two disturbances, recovering the entire electrical signal at any time, either when the frequency is time varying.

* Corresponding author.
E-mail address: leandro.manso@ufjf.edu.br (L.R.M. Silva).

http://dx.doi.org/10.1016/j.measurement.2016.04.062
0263-2241/

To further reduce the amount of data to be stored or transmitted, a compression algorithm is added to the system. The compression consists in eliminating the redundant information present in the signal. In general it is done trough a transform. The Discrete Wavelet Transform (DWT) [7–9] has been extensively used to this purpose due to its ability to sparse the signal.

The PSSWR has three levels of compression: (i) the novelty detection, (ii) wavelet decomposition and (iii) bit coding. These three levels allow the optimization of memory space. It ensures that long periods of measurement can be saved in a memory card.

Section 2 of this paper presents a description of the adopted methodology, showing the online compression scheme and the offline reconstruction system. In Section 3, the real time implementation of the PSSWR is shown, covering the role played by FPGA and ARM devices on the system. In Section 4, a prototype developed is shown. Some results and comments about the tests realized with the prototype of the PSSWR are presented in Section 5. Finally, some general conclusions are stated in Section 6.

2. Proposed methodology

The proposed methodology is based on the fact that only the novelties present in the signal must be saved [10]. In this way, the signal is divided in frames that contain four cycles of the fundamental component and the main objective is to identify which ones are novelty frames (frames that present some difference compared to a reference one) to be saved. Furthermore, two other stages of compression are performed: the novelty frame is compressed by a wavelet transform followed by a modified Lempel–Ziv coding algorithm that does a lossless compression.

2.1. Compression system – online

The compression system is composed by five main blocks as shown in Fig. 1: (a) the novelty Detector; (b) the Frequency Estimation; (c) the Wavelet Compression; (d) the Builder and (e) the Coding.

As mentioned above, knowing which frame is different from the reference one is the core of this system. The parameter chosen to make this decision is the energy of the signal at each frame. Before the energy calculation, the signal passes through a high-pass filter with cutoff frequency of 720 Hz in order to suppress detections due to fundamental frequency variations. Then, the energy of each frame is calculated in the output of this filter and subtracted from the energy of the reference frame. If this value is higher than a threshold, a novelty is detected.

The frequency estimation is necessary in the reconstruction algorithm since only the novelty frames are stored and the entire signal may be desired to be reconstructed. The non-novelty frames are then reconstructed based on the shape of the reference frame (the last frame of novelty) and on the averaged frequencies. The frequency estimation algorithm is the PLL (Phased Locked Loop) presented in [11,12]. The frequency is estimated instantaneously and averaged each cycle. Thus, four frequency values are stored for each frame. It is worth to mention that slow frequency variation does not trigger the novelty detector, however rapid or abrupt changes in the frequency estimation do.

When a novelty is detected, the corresponding frame of the signal must be stored. However, instead of storing the points themselves, a wavelet compression is performed in order to eliminates the redundant signal information. The filters of the wavelet were obtained from a Daubechies 3 (db3) mother wavelet and a decomposition in three levels was adopted, as shown in Fig. 2.

In this figure $v[n]$ is the signal to be decomposed, H_d and L_d are the highpass and lowpass filter respectively, CD_1, CD_2 and CD_3 are the detail coefficients and CA_3 is the approximation coefficient. The decomposition is performed in parallel with the other processes and a threshold is applied to the detail coefficients aiming at eliminating the low energy information. If they are lower than this threshold they are replaced with zero. The approximation coefficients are all remained since the processed signals have more information in the lower frequencies.

The information from the novelty detector, frequency estimation and wavelet compression is packed by a block called Builder that, according to the result of the novelty detector builds the file structure as follows:

- If the current frame is of novelty and the previous one is not: write the ‘1’ flag followed by the four frequency values and the wavelet coefficients.
- If the current frame is a novelty and the previous too: writes the ‘2’ flag followed by the four frequencies and the wavelet coefficients.
- If the current frame is not of novelty and the previous is of novelty: writes the ‘3’ flag followed by the four frequencies and one cycle of wavelet coefficients.

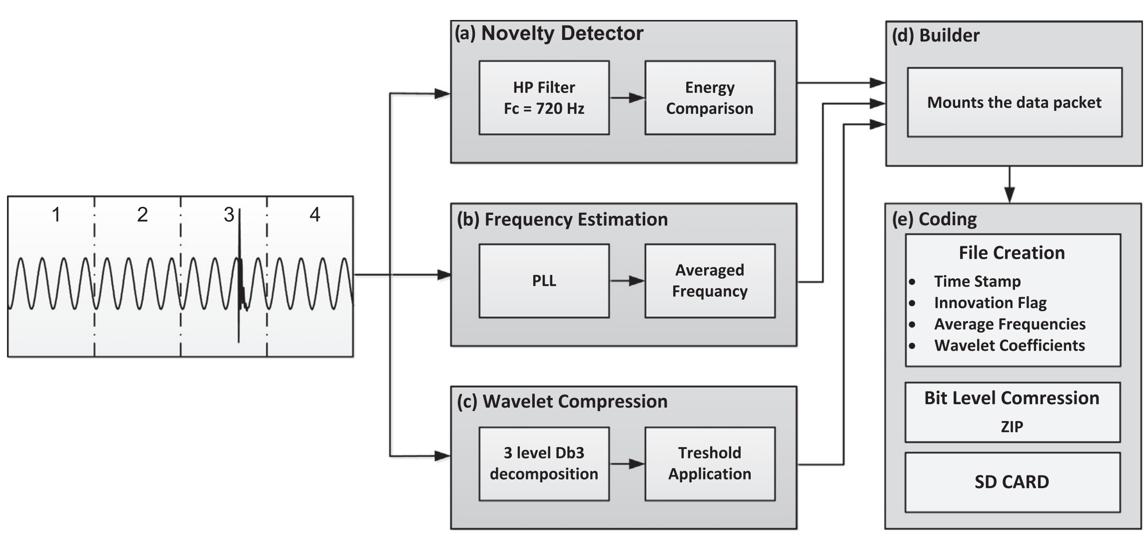

Fig. 1. Block diagram of the proposed methodology.