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Harmonic and interharmonic measurements through a compressed sampling approach

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ABSTRACT

The paper deals with the distributed monitoring of harmonic and interharmonic pollution in electrical power delivery systems. In order to measure the disturbances and to identify the sources in a wide grid, a distributed measurement system with hundreds of measurement nodes has to be adopted. With the aim of obtaining the reduction of realization costs, the authors propose an innovative distributed architecture, based on cost-effective nodes, that takes advantage from the compressive sampling strategy. Differently from traditional approach, the network nodes will be only mandated to acquire and to digitize the line voltage directly in a compressed form, whereas a central measurement unit will receive data from all nodes deployed in the grid and will perform the successive signal reconstruction, making possible the use of low-performance hardware to realize them. The assessment of the compliance of the proposed measurement technique with the current power quality standards turns out to be mandatory, thus verifying the absence of artifacts introduced by the adopted compressed sampling approach.

1. Introduction

In recent years significant change in the power grid for the distribution of electrical energy have been observed. Thanks to liberalization of the electrical market and the incentives offered to the production of energy from renewable sources, the number of medium and small producers has increased [1]. Moreover, with the development of communication technology, the transmission grid has been increasingly equipped with automated devices capable of monitoring and transmitting some information about the grid and, in some cases, to control the actuation devices connected to the grid itself [2]. In this scenario, the term smart grid was born, used to describe a power grid that can cleverly manage itself, performing the appropriate actions due to events occurring on the grid [3]. With the evolution of the smart grid, Power Quality (PQ) issues became even more important; assessing the quality of electrical power delivered to customers connected to the grid should be advisable to prevent harmful fault on their equipment. Recently, the increasing use of electronic devices and the large use of renewable energy sources in the transmission grid are leading to the generation of harmonic and interharmonic disturbances [4]. Consequently, in order to evaluate the power quality in a grid, the capability of measuring the amplitude of harmonic and interharmonic disturbances and the identification of the sources of disturbances is becoming very relevant [5–7].

The measurement system of the grid electrical quality has to be distributed, with the measurement nodes that locally acquire the signals, process the sample in order to calculate the quantities of interest, and send them back to a central collecting and processing unit.

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As it can be expected, the number of measurement nodes increases according to the extension of the monitored grid. Even though the cost of the single nodes should not be excessive (ranging from 10 k€ for high performance meter down to few hundreds of euro for devices not compliant with the current measurement standards), deploying thousands of such devices turns rapidly to be very expensive.

To overcome the considered limitation, the authors suggest the possibility to move toward a different approach for monitoring grid deployed on wide geographical areas, exploiting the advantages of an innovative measurement approach: the Compressed Sampling (CS) [8]. CS is a signal processing technique for efficiently acquiring and reconstructing a signal from far fewer samples than those required by the Shannon–Nyquist sampling theorem [9]. In particular, the proposed architecture consists of low cost nodes (*in the following referred as Sampling Node*), mandated only to acquire and digitize a limited number of input signal samples and transmit them to a central measurement unit, saving, thus, the costs related to large memory supports and expensive digital processing units. Once the samples have been received, the central unit recovers the signal spectrum thanks to CS-based algorithm and carries out the desired measurements.

In their previous experience [10–12], the authors verified the capability of CS-based acquisition approach of correctly measuring the root-mean-square amplitude of voltage waveforms. In the following, the attention is focused on harmonic and interharmonic voltage pollution. By means of numerical and experimental tests, authors verified that the sampling node based on CS approach is compliant with the current standard [13–17].

2. The proposed approach

The traditional sampling protocol, based on the well-known Shannon–Nyquist theorem, requires that the input signal has to be sampled at a sampling rate at least twice its maximum frequency:

$$f_S = 2 \cdot f_{MAX} \quad (1)$$

Thus, in order to perform a proper sampling, without artifacts introduced by aliasing effects, the maximum frequency of the input signal has to be known, and an A/D converter with maximum sample rate greater than the maximum frequency of the input signal has to be adopted.

On the contrary, Eq. (A.9) in Appendix A, combined with an incoherent sampling, provides the acquisition constraints for a CS-based sampling approach [18]. In particular, Eq. (A.9) defines the minimum number of samples M, which have to be acquired to assure a reliable reconstruction of $\boldsymbol{x}$, according to the coherence μ, the sparsity S, and the number N of points to be reconstructed. As it can be observed, the only required information about the input signal is the sparsity S, i.e. the maximum number of harmonic and interharmonic components, independently on their frequency [19]. With reference to the measurement approach proposed in this paper, the Discrete Fourier Transform (DFT) has been selected as orthonormal basis Ψ and the complex spectrum $\boldsymbol{s}$ as sparse representation of $\boldsymbol{x}$. This choice allows computing magnitude spectrum of $\boldsymbol{x}$, directly from the reduced number of measurements $\boldsymbol{y}$, by solving the problem (A.7).

A traditional measurement instrument compliant with IEC 61000-4-30 standard for the distributed power quality monitoring is shown in Fig. 1a [20–22]. After a necessary synchronization pre-processing, the acquisition is performed at a sample rate according to sampling approach based on the Nyquist–Shannon theorem. Thus, in order to measure harmonics up to the 100th order, a suitable A/D converter has to be adopted. For each acquisition of 10/12 periods of the input signal, the measurement instrument determines the amplitude of harmonic and interharmonic components by means of a DFT-based algorithm [23]. For long time analysis, this approach requires large memory depth, which notably increases the cost of each

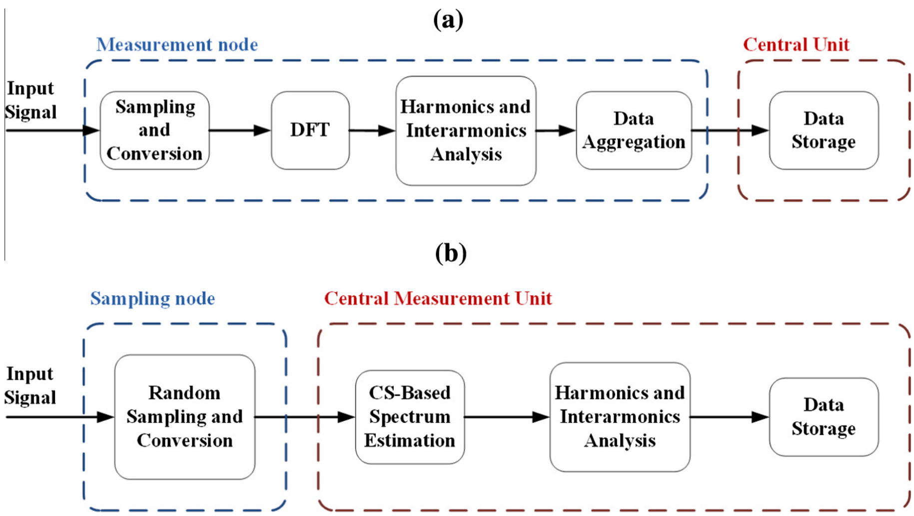

Fig. 1. (a) Typical architecture for PQ monitoring. (b) Proposed architecture based on CS approach.