

Measurement of power quality indices using advanced spectrum estimation methods

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Introduction

The quality of voltage waveforms is nowadays an issue of the utmost importance for power utilities, electric energy consumers and also for the manufactures of electric and electronic equipment. The proliferation of nonlinear loads connected to contemporary power systems has triggered a growing concern with power quality issues. The inherent operation characteristics of these loads leads to deterioration in supply quality as discontinuities and nonstationarities are introduced to the system. On one hand, these loads may be highly sensitive to the quality of its power source [2]. The voltage waveform is expected to be a pure sinusoidal with a given frequency and amplitude. Spectrum analysis of power-line frequency-distorted sinusoids is an up-to-date problem, closely connected to the power quality measurement. The estimation of the interharmonics is very important for control and protection tasks.

To control power quality problems, standards have been established worldwide identifying the various aspects of the problem and defining the acceptable limits of many of its known measures [3] [2] [4]. However, they generally refer to periodic signals which allow an "exact" definition of harmonic components and require only a numerical value to characterize them. When the spectral components are time-varying in amplitude and/or in frequency (as in case of non-stationary signals), a misleading use of the term harmonic can arise and several numerical values are needed to characterize the time-varying nature of each spectral component of the signal.

The IEC Standard drafts 61000-4-7 and 61000-4-30 deal with signals which are time-varying. They, for practical purpose, define the harmonic (interharmonic) frequency as an integer (not integer) multiple of the fundamental frequency.

There are many different approaches for measuring harmonics, like FFT, application of adaptive filters, artificial neural networks, SVD, higher-order spectra, etc [7] [4] [5].

In this paper the characteristics of power system signal components are estimated using Short-Time Fourier Transform (STFT - for comparison with more advanced methods), the Prony model, ESPRIT and root-Music methods.

Prony method is a technique for modeling sampled data as a linear combination of exponentials and has a close relationship to the least squares linear prediction algorithms used for AR and ARMA parameter estimation. Recent methods of spectrum estimation are based on the linear algebraic concepts of subspaces and so have been called "subspace methods" [7]. The model of the signal in this case is a sum of sinusoids in the background of noise of a known covariance function.

Most of the power quality indices used are based on the individual harmonic components of current and voltage waveforms. Conventionality, the Fourier transform

technique (FFT) is utilized to extract the spectrum of power system waveforms. To ensure the accuracy of FFT, the analyzed waveform must be periodic and stationary, the Nyquist criterion must be satisfied, and the sampling interval must be an exact integer multiple of the waveform fundamental period [2].

The proposed use of advanced spectrum estimation methods instead of FFT when calculating power quality indices overcomes the shortcomings of FFT and leads to more accurate results even for highly distorted and non-stationary waveforms.

Proposed Approach

Investigated waveforms are typical for dc arc furnace plant which consists of a dc arc connected to a medium voltage ac busbar with two parallel thyristor rectifiers that are fed by transformer secondary winding. The Prony, ESPRIT and root-Music methods (for description of methods see [6] and [7]) are compared with STFT on the basis of the values of the IEC harmonic and interharmonic subgroups. The IEC Standard drafts 61000-4-7 and 61000-4-30 with reference to a DFT with 5 Hz resolution of frequency (200 ms of window width) - introduce the concept of harmonic and interharmonic groupings and characterize the waveform distortions with the amplitudes of these groupings.

Fig. 1 shows an example of two harmonic subgroups ($n = 7$ and $n = 8$) and of one interharmonic subgroup ($n = 7.5$). The amplitudes of the harmonic and interharmonic subgroups $C_{n-200-ms}$ and $C_{n+0.5-200-ms}$ can be evaluated, respectively, as:

$$C_{n-200-ms}^2 = \sum_{k=-1}^1 C_{10n+k}^2 \quad C_{n+0.5-200-ms}^2 = \sum_{k=-2}^8 C_{10n+k}^2 \quad (1)$$

where C_{10n+k} are the spectral components (RMS value) of the DFT output.

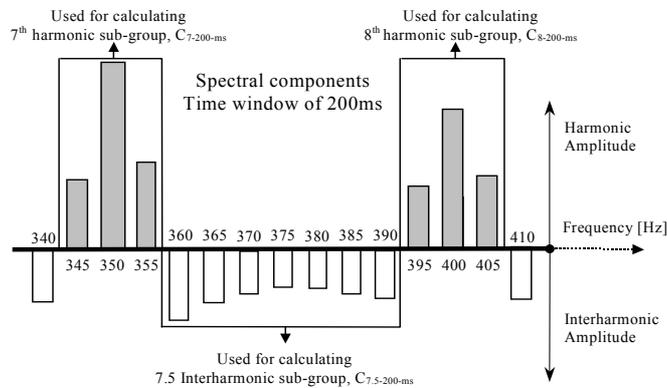


Fig. 1. IEC grouping of spectral components for harmonics \uparrow and for interharmonics \downarrow .

The progressive average has been calculated by averaging values obtained with successive 200 ms-groups with the following expression:

$$C_{1.5-mean}(k) = \sqrt{\frac{1}{k} \sum_{i=1}^k C_{1.5-(200-ms)_i}^2}, \quad k = 1, \dots, 15 \quad (2)$$

In order to compare the different processing techniques, a reference technique is adopted. We assumed as reference the technique proposed in [8], named as "Ideal IEC", based on the extension of IEC grouping to high resolution spectral analysis performed on $T_W = 3$ s, that is the whole interval of very short time measurements.

The same definition and the same filters have been used to apply the Prony method, the rootMusic method, the ESPRIT method and the STFT method for the evaluation of the *IEC harmonic and interharmonic subgroups* and for the calculation of the *progressive average of the subgroup amplitudes*.

Results

The following figures report some results of the evaluation of the progressive average defined in (2) referred to different harmonic and interharmonic subgroups by applying the aforementioned methods to the voltage and current waveforms recorded at MV busbar of the dc arc furnace.

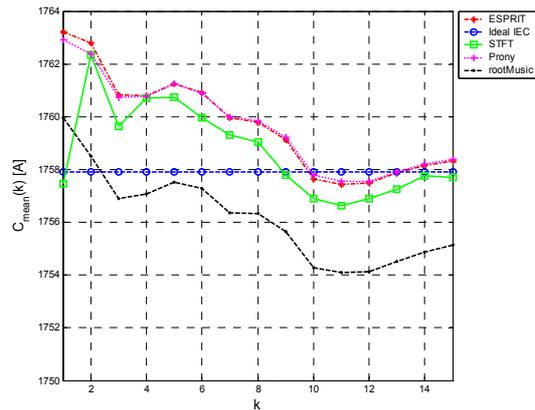
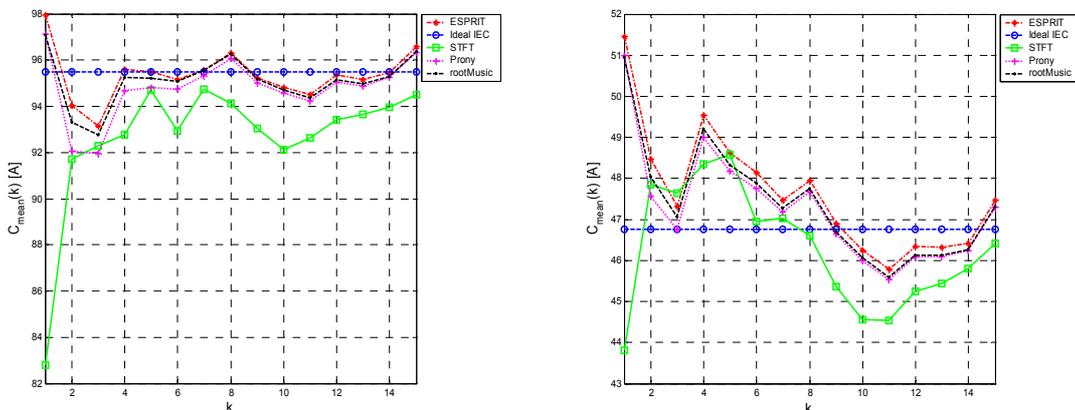


Fig. 2. Current waveform: progressive average of the first harmonic subgroup.

From the analysis of Figs. 2 and 3 it can be observed that the results obtained by using the DFT algorithm furnish an underestimation of the progressive average referred to the IEC harmonic subgroups and an overestimation of the progressive average referred to the IEC interharmonic subgroups. These results can be explained by taking into account the problem of spectral leakage present in the DFT based algorithms; this problem leads to dispersion of a part of the fundamental subgroup energy content to the contiguous interharmonic subgroups.

With reference to the other methods, the Fig. 2 shows that the root Music method gives an underestimation of the progressive average related to the first harmonic group. On the other hand, generally, Prony, root Music and ESPRIT methods show the same behaviour.



(a)

(b)

Fig. 3. Current waveform: progressive average of the 11th (a) and 13th (b) harmonic subgroups.

The high resolution methods furnish results closer to the “Ideal IEC” than the ones obtained with STFT for the evaluation of the progressive average related to the higher harmonic subgroups, as shown in Fig. 3.

In the final version of the paper, more detailed results will be shown, with quantitative comparison of different methods.

The novelty of the proposed approach lies in replacing FFT with advanced spectrum estimation methods, which gives more accurate results, when analysing strongly distorted waveforms with non-stationary behaviour. There are other approaches in the literature aiming at substitute the FFT using e.g. wavelets, windowing techniques, filters to avoid or diminish inherent drawbacks of FFT (mentioned above), although the approach presented in this paper is, to the best of our knowledge, original, presents significant advantages and is tested for important, real-life problems.

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