INTRODUCTION
The quality of voltage waveforms is nowadays an issue of the utmost importance for power utilities, electric energy consumers and also for the manufacturers of electric and electronic equipment. The proliferation of nonlinear loads connected to power systems has triggered a growing concern with power quality issues. The inherent operation characteristics of these loads deteriorate the quality of the delivered energy, and increase the energy losses as well as decrease the reliability of a power system.

Methods of power quality assessment in power systems are almost exclusively based on Fourier Transform. Parametric spectral methods, such as ESPRIT or MUSIC do not suffer from inherent limitations of resolution or dependence of estimation error on the window length (phase dependence of the estimation error) of FFT.

The author argues that the use of high-resolution spectrum estimation methods instead of Fourier-based techniques can improve the accuracy of measurement of spectral parameters of distorted waveforms encountered in power systems, in particular the estimation of the power quality indices.

PARAMETRIC METHODS
The ESPRIT and the root-Music spectrum estimation methods are based on the linear algebraic concepts of subspaces and so have been called “subspace methods” — the model of the signal in this case is a sum of sinusoids in the background of noise of a known covariance function.

MUSIC
The MUSIC method assumes the model of the signal as:

\[ x = \sum_{l=1}^{N} \alpha_l y_l + n = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} \alpha_1 & \cdots & \alpha_N \end{bmatrix}^T + n \]

The autocorrelation matrix of the signal is estimated from signal samples as:

\[ R = \sum_{l=1}^{N} E\{x(t)x(t)^H\} \]

The smallest eigenvalues of the correlation matrix (matrix dimension N+p+1) correspond to the noise subspace and p largest (all greater than the noise variance) correspond to the signal subspace.

The matrix of noise eigenvectors of the above matrix is used to compute the projection matrix for the noise subspace:

\[ P = E_nE_n^H \]

The polynomial has p double roots lying on the unit circle which angular positions correspond to the frequencies of the signal components.

Powers of each component can be estimated from the eigenvalues and eigenvectors of the correlation matrix, using the relations:

\[ \sum_{l=1}^{N} \alpha_l^2 = \lambda_i \] and solving for \( \alpha \cdot \) components’ powers.

ESPRIT
The original ESPRIT algorithm is based on naturally existing shift invariance between the discrete time series, which leads to rotational invariance between the corresponding signal subspaces.

Eigenvectors \( \mathbf{E} \) of the autocorrelation matrix of the signal define two subspaces (signal and noise subspaces) by using two selector matrices:

\[ \mathbf{S} = \mathbf{E} \mathbf{S}_n = \mathbf{E} \mathbf{S}_n \]

TLS (total least-squares) approach assumes that both estimated matrices can contain errors and finds the matrix as minimization of the Frobenius norm of the error matrix.

RESULTS of accuracy comparison

Several indices are in common use for the characterization of waveform distortions. However, they generally refer to periodic signals which allow an “exact” definition of harmonic components and deliver only one 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 wrong 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.

Experimental setup and results

The waveforms obtained from a power supply of a typical for dc arc furnace plant are analyzed. The IEC groups and subgroups are estimated by using DFT and the results are compared to those obtained with subspace methods: the ESPRIT and the root-MUSIC.

In order to compare the different processing techniques, a reference technique is adopted: “Ideal IEC”, where the respective harmonic groupings are computed on the whole interval of 3 cycles.