Advanced Spectrum Estimation Methods for Signal Analysis In Power Electronics

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Introduction

- Modern frequency power converters generate a wide spectrum of harmonic components
- this may strongly deteriorate the quality of the delivered energy, increase the energy losses as well as decrease the reliability of the power system.
- The estimation of the signal parameters is important for control and protection tasks. Most of commonly used approaches for measuring harmonics, like FFT, application of adaptive filters, artificial neural networks, operate adequately only in the narrow range of frequencies and at moderate noise levels.

Introduction..

Authors propose the use of modern parametric methods, based on:

- signal model consisting of sum of exponential functions - Prony
- linear algebraic concepts of subspaces – Min-Norm

Prony method

- Model of the signal as a sum of exponential components

$$y[n] = \sum_{k=1}^{p} A_k e^{(\alpha_k + j\omega_k)(n-1)T_p + j\psi_k}$$

- estimation problem bases on the minimization of the squared error

$$E = \sum_{n=p+1}^{N} \left| e[n] \right|^2$$

- Prony polynomial

$$y[n] = \sum_{k=1}^{p} h_k z_k^{n-1}$$

$$F(z) = \prod_{k=1}^{p} (z - z_k) = \\ = (z - z_1)(z - z_2)\ldots(z - z_p)$$

$$\sum_{m=0}^{p} a[m] x[n-m] = e[n]$$

Min-Norm Method

- The correlation matrix of the signal vector $\mathbf{s}_i = \begin{bmatrix} 1 & e^{j\omega_i} & \cdots & e^{j(N-1)\omega_i} \end{bmatrix}^T$ is $\mathbf{R}_x = \sum_{i=1}^{M} \mathrm{E}\{A_i A_i^*\} \mathbf{s}_i \mathbf{s}_i^T + \sigma_0^2 \mathbf{I}$
- N-M smallest eigenvalues of the correlation matrix (matrix dimension $N>M+1$) correspond to the noise subspace and M largest correspond to the signal subspace.
- We define the matrices of eigenvectors:

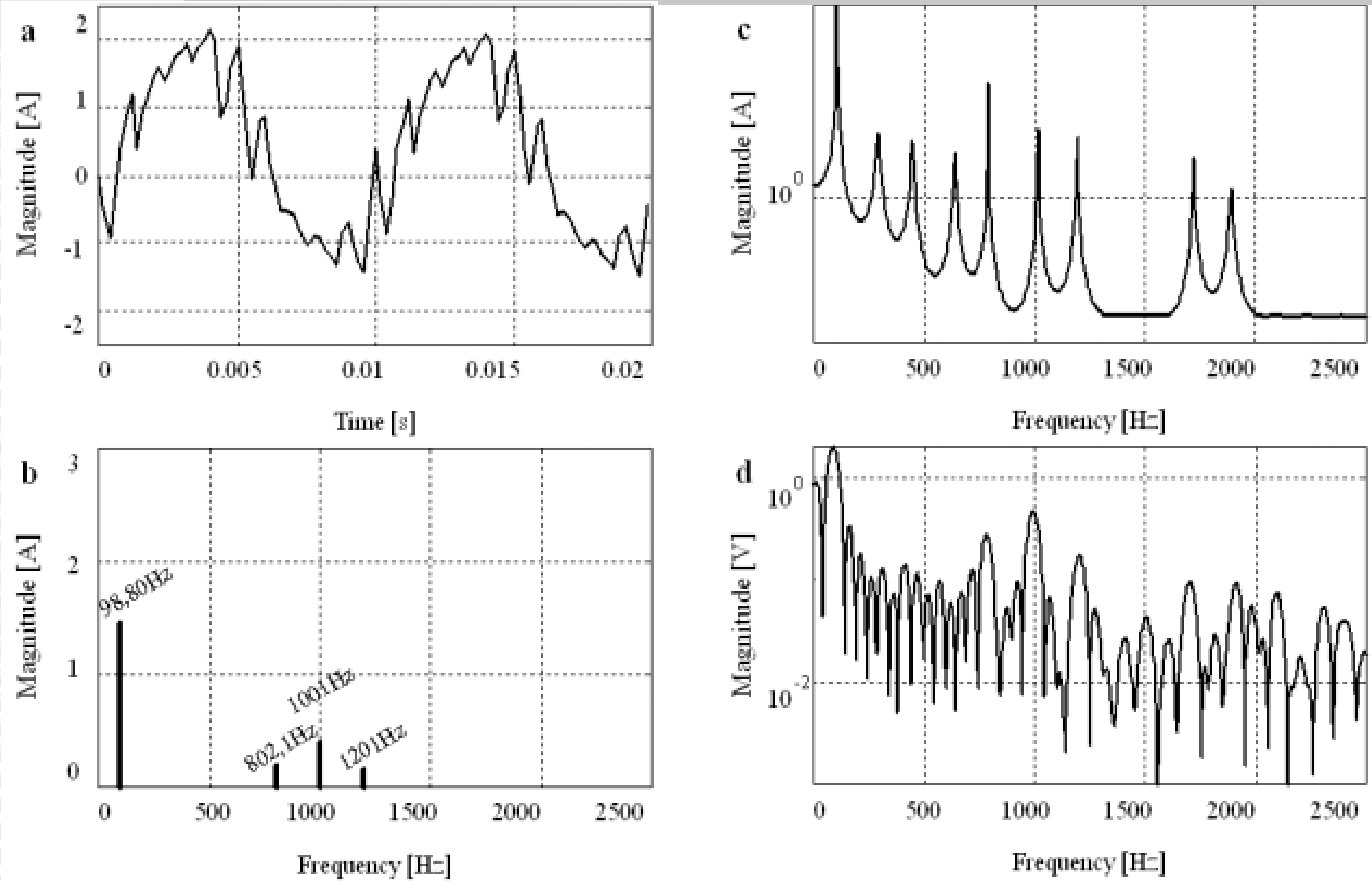
$$\mathbf{E}_{signal} = \begin{bmatrix} \mathbf{e}_1 & \mathbf{e}_2 & \cdots & \mathbf{e}_M \end{bmatrix} \qquad \mathbf{E}_{noise} = \begin{bmatrix} \mathbf{e}_{M+1} & \mathbf{e}_{M+2} & \cdots & \mathbf{e}_N \end{bmatrix}$$

- Min-norm method uses one vector $\mathbf{d}$ belonging to the noise subspace which has minimum Euclidean norm and his first element equal to one.

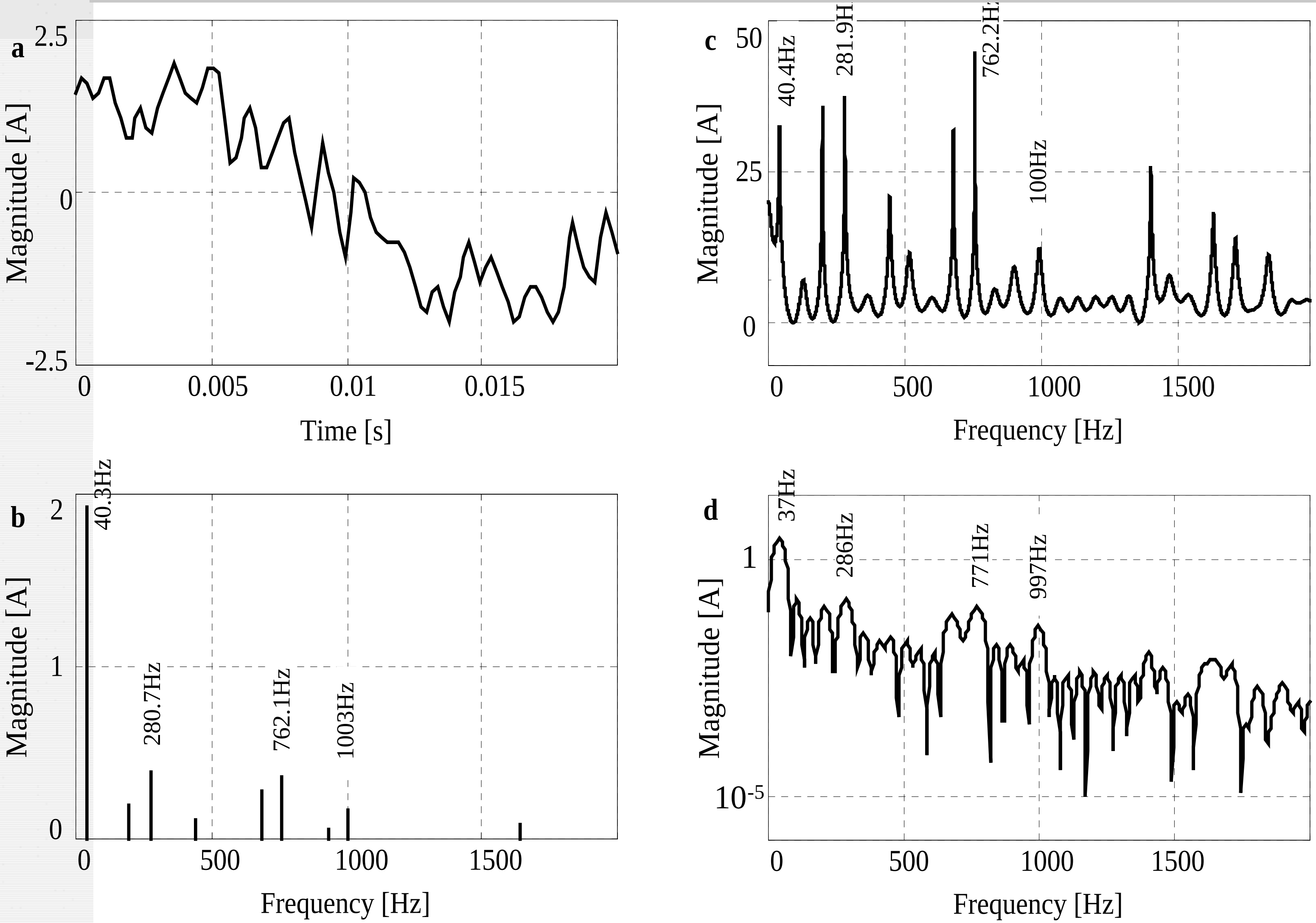
$$\mathbf{d} = \frac{1}{\mathbf{c}^{*T}\mathbf{c}} \mathbf{E}_{noise} \mathbf{c} = \begin{bmatrix} 1 \\ \left(\mathbf{E}'_{noise} \mathbf{c}\right) / \left(\mathbf{c}^{*T}\mathbf{c}\right) \end{bmatrix}$$

- Pseudospectrum defined with the help of $\mathbf{d}$ is $\hat{P}\left(e^{j\omega}\right) = \frac{1}{\left|\mathbf{w}^{*T}\mathbf{d}\right|^2} = \frac{1}{\mathbf{w}^{*T}\mathbf{d}\mathbf{d}^{*T}\mathbf{w}}$
- and it exhibits sharp peaks at the signal frequencies where $\mathbf{w}=\mathbf{s}_i$.

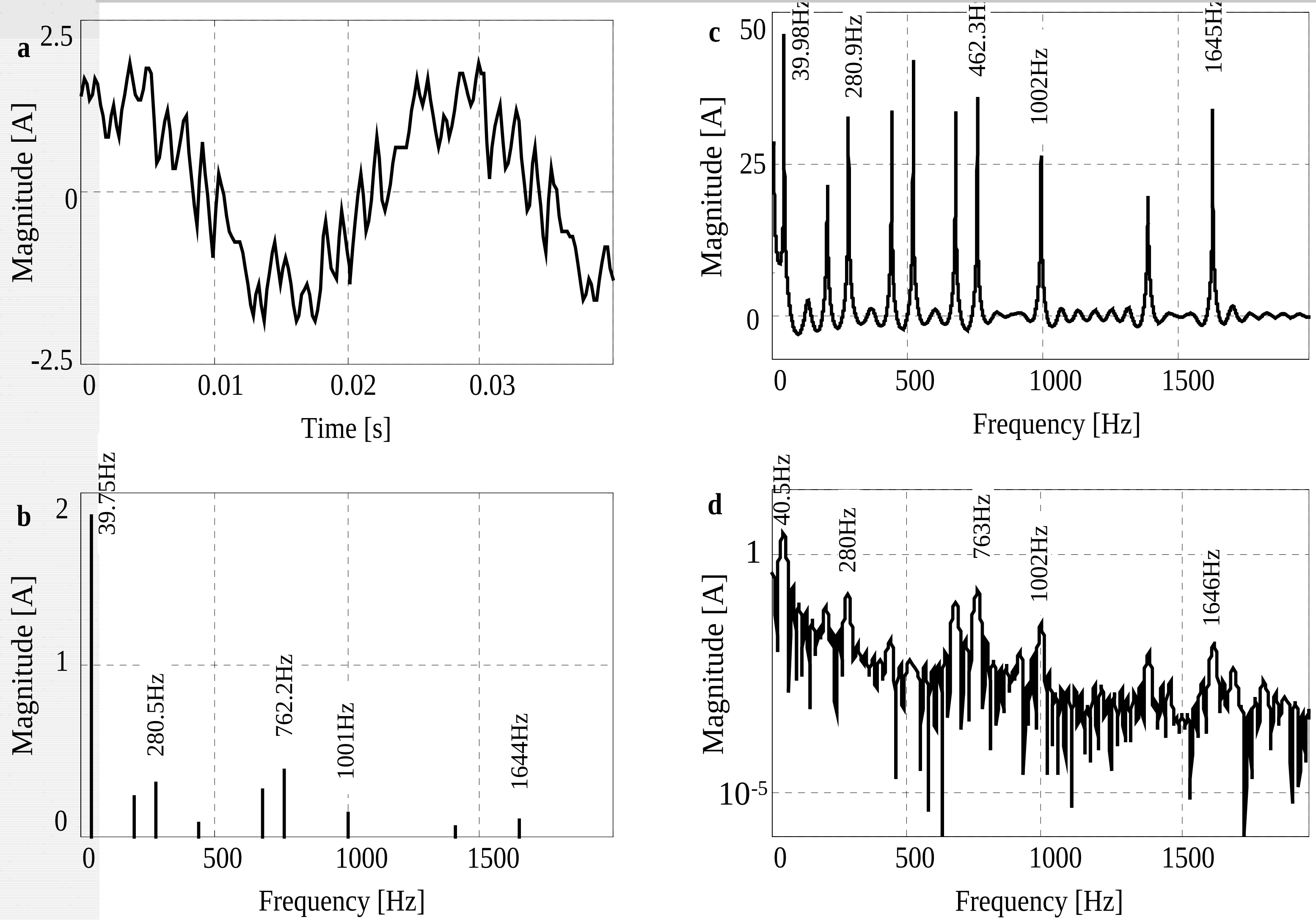
Simulation of Frequency Converter



Industrial Frequency Converter I



Industrial Frequency Converter II



CONCLUSIONS

- High-resolution spectrum estimation method, such as min-norm could be effectively used for parameter estimation of distorted signals.
- The Prony method could be applied for estimation of the frequencies, amplitudes and initial phase of signal components.
- The accuracy of the estimation depends on the signal distortion, the sampling window and on number of samples taken into the estimation process.
- Unfortunately, the computational effort of the high-resolution methods is significantly higher than FFT processing.
- The proposed methods were investigated under different conditions and found to be variable and efficient tools for detection of all higher harmonics existing in a signal. They also make it possible the estimation of interharmonics