Power Quality in Wind Power Systems

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Abstract. Wind power generation systems influence power quality in a specific way making important the need for detailed and accurate evaluation of disturbances caused by wind generators. Wind power system can cause sub- and interharmonic components to appear in the spectrum of voltages and currents.

The paper shows different aspects of spectrum estimation in power systems, including the doubly fed induction generator (DFIG) connected to low voltage distribution grid. Harmonic distortions caused by wind generator under various operational conditions regarding wind speed, active and reactive power are shown and discussed. Advanced spectral methods (like ESPRIT) are applied to overcome the drawbacks of Fourier-based techniques.

Key words

power quality, subharmonics, interharmonics, parametric spectral estimation.

1. Introduction

Wind generation is one of the most mature and cost effective resources among different renewable energy technologies [1].

There exist various design concepts of wind generators which allow fulfillment of regulatory requirements [4], concerning grid stability. One of the most efficient designs is the doubly fed induction generator DFIG [10], which allows the regulation of reactive power and the adjustment of angular velocity to maximize the output power efficiency. These generators can also support the system during voltage sags.

However, the drawbacks of converter-based systems are harmonic distortions injected into the system [1].

The paper is devoted to the evaluation of harmonic distortion in various operation conditions of the wind generation units.

Parametric spectral estimation ESPRIT algorithm [4] is applied to extract information on harmonics parameters. It is assumed that those advanced methods could give more detailed information, then traditional FFT.

The interest was focused on the harmonics generated by DFIG. Due to restrictions imposed by utilities on wind park operators it is difficult to run such research activity on real object within widespread range of parameters changes in acceptably short time.

In the first part, the physical, grid connected model consisting of induction generator, direct converter, DC machine and control unit is introduced. In the second part of the paper, the ESPRIT algorithms are presented. The measurement procedure and assessment of grid parameters follow. Current measurements and harmonics estimation results are finally presented and discussed.

2. ESPRIT Algorithm

ESPRIT algorithm [4] belongs to the subspace parametric spectrum estimation methods. It allows determining the parameters of harmonic components with high accuracy.

Furthermore, the results of spectral estimation do not depend, to large extent, on the length of the analysis window. Extensive investigations shown in [6] confirm the suitability of this algorithm to provide reliable estimates. Parametric algorithm show very high accuracy in frequency estimation independently of the window length and also relatively high accuracy in amplitude estimation, without the de-synchronization effects.

3. Model of wind generator

Simplified model of DFIG was used. The rotor of induction machine is connected to the grid with a back-to-back voltage source converter which controls the excitation system. This most significant feature enables sub synchronous and super synchronous operation speeds in generator mode and adjustable reactive power generation.

The wind turbine was modeled with a separately excited 30 kW DC machine. Torque and angular velocity could be set in a controlled manner in accordance to speed-torque characteristic of a real three blade rotor adapted for steady state operation of the 5 kW DFIG model. The generator in Fig. 1 is a 5 kW, two pole pairs slip ring induction machine with synchronous speed of 1500 rpm.

4. Results of Analysis and Discussion

A. Sub-synchronous Mode

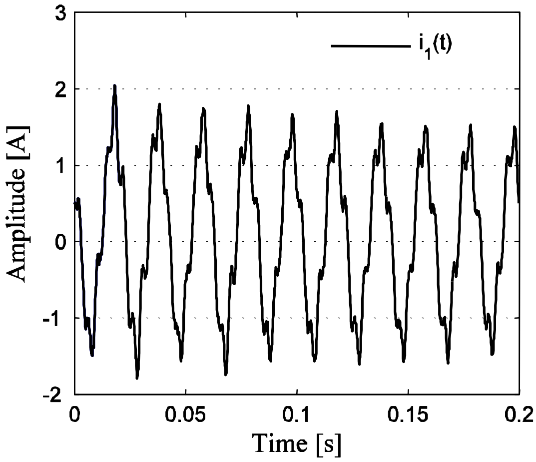

Fig. 2. Measured current in phase one in sub-synchronous mode.

Spectral components were obtained using a windowed signal with the length adapted to ten periods of fundamental 50 Hz component.

TABLE I. - Spectral components estimated using the ESPRIT algorithm in sub-synchronous mode

Frequency [Hz]	Amplitude [A]
16.20	0.21
49.98	1.56
150.64	0.11
249.49	0.30
349.26	0.06
525.41	0.04

ESPRIT algorithm allows detecting one subharmonic component, impossible to detect using the Fourier spectrum (Fig. 3), because of the lack of synchronization with fundamental component, which causes an important leakage effect. Parametric spectral estimation does not suffer from many shortcomings, typical for Fourier-based techniques. Moreover, in addition to third, fifth and seventh harmonic it shows the presence of one interharmonic component, clearly visible also in the Fourier spectrum.

B. Super-synchronous Mode

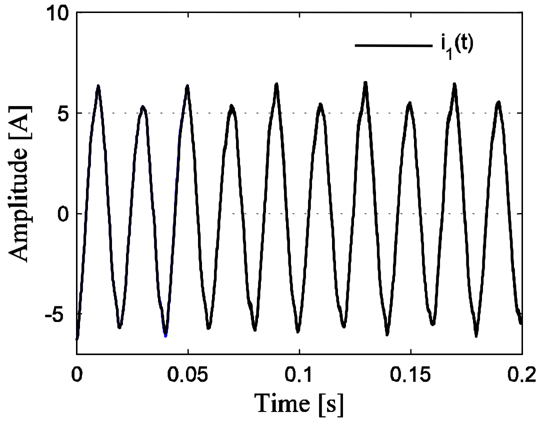

Fig. 5. Measured current in phase one in super-synchronous mode.

TABLE II. - Spectral components estimated using the ESPRIT algorithm in super-synchronous mode

Frequency [Hz]	Amplitude [A]
49.95	5.52
102.79	0.20
149.99	0.18
252.20	0.16
300.10	0.09
351.42	0.10
400.01	0.05
412.20	0.43
598.07	0.05

In this case, the current spectrum contains in general less harmonic distortion than in the sub-synchronous mode, which makes the correct spectrum estimation even more difficult (due to “masking” effect which affects more the Fourier-based methods). Beside the expected odd harmonic components, also even harmonic components are present in the current spectrum, as well as interharmonic component. Detection and resolution capabilities of ESPRIT method clearly outperform the Fourier-based classical method.

Parametric spectral estimation ESPRIT method, accurately and reliably showed high content of interharmonics in the current waveforms, justifying their usefulness as a tool for spectral analysis of distorted electric signals in wind power generators.

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