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Measurements of harmonic emission versus active power from wind turbines

Kai Yang[a,*], Math H.J. Bollen[a,b], E.O. Anders Larsson[a], Mats Wahlberg[a,c]

[a] Electric Power Engineering, Luleå University of Technology, 931 87 Skellefteå, Sweden
[b] STRI AB, 771 80 Ludvika, Sweden
[c] Skellefteå Kraft AB, 931 80 Skellefteå, Sweden

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ABSTRACT

This paper presents harmonic measurements from three individual wind turbines (2 and 2.5 MW size). Both harmonics and interharmonics have been evaluated, especially with reference to variations in the active-power production. The overall spectra reveal that emission components may occur at any frequency and not only at odd harmonics. Interharmonics and even harmonics emitted from wind turbines are relatively high. Individual frequency components depend on the power production in different ways: characteristic harmonics are independent of power; interharmonics show a strong correlation with power; other harmonic and interharmonic components present various patterns. It is concluded that the power production is not the only factor determining the current emission of a wind energy conversion system.

1. Introduction

Modern wind turbines are commonly equipped with power electronics, either with reduced-capacity power converters or full-capacity power converters. Doubly-fed induction wind generators equipped with reduced-capacity power converters are referred to as type-3, and the wind turbines with full-capacity power converters as type-4 [1,2].

The use of power electronics produces waveform distortions [3–7]. A waveform conversion from AC to DC, and then from DC to AC is utilized in the schema of a power converter. The switching of converter involves waveform distortions in the output power [4,8].

The potential consequences of high voltage and current distortion are discussed in various textbooks [9–11]. Waveform distortion is however well regulated in most countries, through compulsory or voluntary limits. The main concern for wind park owners and network operators is to keep distortion levels below those limits.

There are various power conversion schemes part of wind energy conversion systems [5,8]. The output waveforms with distortions are determined by the switching schemes. To smooth the generated harmonics, harmonic filters are used in the wind energy conversion system [6,8]. The output distortions are thus dependent on the detailed configuration of the wind turbines.

The standard IEC 61400-21 [12] recommends measurement and assessment of power quality characteristic of grid-connected wind turbines with the measurement method specified in IEC 61000-4-7 [13]. IEC 61400-21 recommends that values of the individual current components (harmonics, interharmonics and higher frequency components) and total harmonic current distortion are measured within the active power bins 0, 10, 20, . . ., 100% of wind turbine rated power. The highest value for each power bin is reported. From a standardization viewpoint there are reasons for selecting one single value, the maximum value in this case. However, to quantify the turbine emission, this is only of use when there are limited variations of the emission within one power bin.

A study based on IEC 61400-21 has been performed on five wind turbines [14]. The current total harmonic distortion is found independent on the output power. Also the fifth harmonic is shown to be independent of the active power for the five wind turbines. The interharmonics and other harmonics have not been presented in reference [14].

A number of 600 kW squirrel-cage induction generator wind turbines have been tested according to IEC 61400-21 and IEC 61000-4-7 on the medium voltage level [15]. The paper presents an exponentially decreasing of current THD (in percent of fundamental current) with power output; the low order harmonics 3, 5

* Corresponding author. Tel.: +46 736158980.
E-mail addresses: kai.yang@ltu.se, epiphany_edwen@hotmail.com (K. Yang).

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and 7 (the dominant ones in THD) are presented without obvious trend with power output.

The aim of this paper is to verify the findings from earlier papers about the relation between active power production and harmonic emission and to extend the study to other harmonics and interharmonics. For this, detailed measurements have been performed on three modern wind turbines, with rating 2 or 2.5 MW. Especially the significant levels of interharmonics present in wind power installations, which is much different from conventional installations, has been studied. The risk of the interharmonics and high order harmonics exceeding the limit has been also studied in this paper.

Section 2 describes the measurement setup used to obtain the emission data from the three turbines. Section 3 presents the analysis of wind turbine spectra, whereas Section 4 studies the relation between the emission and the active-power production. And the paper is concluded in Section 5.

2. Measurement procedure

2.1. Measured objects

Three wind turbines, from different manufacturers and different wind parks, have been measured. All three are 3-blade rotor with horizontal axis, and upwind pitch turbine.

Turbine I: This is a type-3 wind turbine with a rated power 2.5 MW. It is equipped with a six-pole doubly-fed asynchronous generator (DFIG). A partial rated converter is installed, and designed as a DC voltage link converter with IGBT technology. The rotor outputs a pulse-width modulated (PWM) voltage, while the stator outputs 3 × 660 V/50 Hz voltage. The wind turbine is connected to the collection grid through one medium-voltage (MV) transformer, which is housed in a separate transformer station beside the turbine foundation. There are totally 14 such wind turbines within the wind park.

Turbine II: The second wind turbine is also a DFIG type (type-3), whereas the rated power is 2 MW. The turbine contains a four-pole doubly-fed asynchronous generator with wound rotor, and a partial rated converter. The output voltage is 690 V, and connected to the collection grid through a medium voltage transformer (installed inside the nacelle). There are 5 such turbines in the park.

Turbine III: The third wind turbine is type-4, with full-power converter. The rated power is 2 MW. The turbine is designed based on a gearless drive with synchronous generator. Power is fed into the grid via a full rated converter, a grid side filter and a turbine transformer to the medium voltage level. The inverters are self commutated and pulse the installed IGBTs with variable switching frequency [16].

2.2. Measurement setup

Measurements of the above three wind turbines have been performed at the MV side of the turbine transformers (Fig. 1). Both voltage and current have been monitored and recorded using a standard power quality monitor Dranetz-BMI Power Xplorer PX5. Details at the measuring point are listed in Table 1.

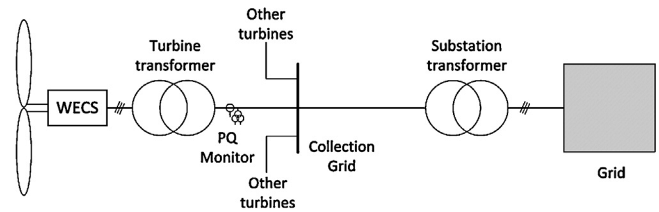

Fig. 1. Power quality monitor position of an individual wind turbine measurement within a wind park.

2.3. Measurement parameters

The three-phase voltage and current waveforms were recorded by the monitor through the conventional voltage and current transformers at medium voltage, with a sufficient accuracy for the frequency range up to few kHz [17,18].

The waveform was continuously acquired with a sampling frequency of 256 times the power-system frequency (approximately 12.8 kHz) by the power quality monitor. The Discrete Fourier Transform has been applied using a rectangular window of 10 cycles, which results in a 5 Hz frequency resolution. According to IEC 61000-4-7 [13], the harmonic and interharmonic groups and subgroups are obtained.

Harmonic subgroups $G_{sg,n}$ and interharmonic subgroups $G_{isg,n}$ at order n are grouped as (for a 50 Hz system):

$$G_{sg,n}{}^2 = \sum_{i=-1}^{1} C_{k+1}{}^2 \quad (1)$$

$$G_{isg,n}{}^2 = \sum_{i=2}^{8} C_{k+i}{}^2 \quad (2)$$

where the harmonic subgroup $G_{sg,n}$ is derived from the 3 Discrete Fourier Transform (DFT) components $C_{k-1}, \ldots, C_{k+1}$ and the interharmonic subgroup $G_{isg,n}$ is from the 7 DFT components $C_{k+2}, \ldots, C_{k+8}$, due to the 5 Hz resolution spectrum of 10 cycles of sampled waveforms.

The harmonic and interharmonic subgroups, over each 10-cycle window, are next aggregated into 10-min values. The 10-min value is the RMS over all 10-cycle values within those 10 min. Details are found in the standard, IEC 61000-4-30.

The grouping and aggregation according to the standard methods take place in the monitor. The user has only access to the grouped and aggregated 10-min values. To allow more detailed analysis, a 10-cycle snapshot of the voltage waveform, with a sample frequency of 12.8 kHz, is obtained every 10 min. The analysis presented in this paper is partly based on the aggregated harmonic and interharmonic subgroups and partly on the 200-ms snapshots.

2.4. Measurement accuracy

The average spectra, especially for Turbine I, show a broadband spectrum as in Fig. 3 (will be shown later). This spectrum originally raised the suspicion of being due to quantization noise. The spectra

Table 1
Measured objectives details (measure point current and voltage in nominal).

Turbine no.	Generator type	Turbine type	Measure point		Measure duration
			Current	Voltage	
Turbine I	Asynchronous double-fed	Type-3	66 A	22 kV	11 days
Turbine II	Asynchronous double-fed	Type-3	36 A	32 kV	8 days
Turbine III	SYNC-RT	Type-4	116 A	10 kV	13 days