WIND ENERGY CONVERTERS AND SOME ASPECTS OF POWER QUALITY

R. E. Hanitsch*, D. Schulz

Institute of Energy and Automation Technology, TU Berlin
Faculty of Electrical Engineering and Computer Science
Einsteinufer 11, D-10587 Berlin
Tel: +49.30.31422403, Fax: +49.30.31421133
Rolf.Hanitsch@iee.tu-berlin.de, Detlef.Schulz@iee.tu-berlin.de

Abstract

With the introduction of the "renewable energy law" in Germany, the wide use of wind energy is encouraged. Aspects of the achievements are presented and the problem of power quality is treated in greater detail.

Keywords: Wind energy; power quality; total harmonic distortion; flicker; power factor

1. INTRODUCTION

With the focus on grid connected wind energy converters and putting together on- and offshore systems the development for the installed power until 2010 could be the following:

Germany	13,000 MW
Europe (Rest)	47,000 MW
World (Rest)	50,000 MW
Total	**110,000 MW**

So each year, depending on the capacities, about 12,000 MW have to be installed.

The wind turbines developed rapidly from the early 500 kW system with a rotor diameter of 40 m via 1.5 MW system with a rotor diameter of 70 m to the 2.5 MW system with a rotor diameter of 80 m. A 4.5 MW prototype has a rotor diameter of 110 m. The large systems in the MW range operate with a rotor speed between 12 and 25 rpm under pitch control. Blade tip velocities are therefore in the range between 60 m/s and 80 m/s. Only few systems operate with 90 m/s. The specific installed capacity can be 300 W/m² up to 500 W/m².

TECHNICAL PARAMETERS

The progress of wind energy utilisation around Europe in recent years has been consistently impressive. Installations of wind energy converters become more and more powerful. With the growing unit power up to 4.5 MW the influence on the grid parameters cannot be ignored [1, 2, 3].

* corresponding author

In co-operation with a wind park operator we investigated selected power quality parameters of a number of variable-speed wind energy converters (WEC's) with a nominal power of 1.5 MW and 1.8 MW. Measurements were done at the low- and medium voltage level. Synchronous and doubly-fed asynchronous generator types were in the focus of the experimental work.

All the energy sources which are connected to the grid form two clusters:

I) stochastic sources

- wind energy converters
- photovoltaic generators
- small hydro systems

II) deterministic sources

- conventional power plants
- pumped hydro plants
- fuel cells
- batteries (electro-chemical).

This mixture of stochastic and deterministic energy sources creates a number of problems e.g.: grid stability, operation of grid, voltage regulation and reactive power compensation, protection and harmonics and power quality [4, 5, 6, 7].

Purpose of the work was to find out the level of harmonics of voltage and current on the grid's low- and medium voltage level, total power factor λ, power factor of the fundamental and flicker. In detail harmonics, interharmonics, subharmonics, voltage deviations and transients were studied. Special measurement devices were used with data storage over 8 or 16 periods as required by the standards, e.g. IEC 1000-4-7 (1991).

This approach guarantees comparable results of the calculated spectra of power analysers. In standards, such as IEC 61000-3-4, IEC 61000-3-2 relevant parameter for the evaluation of the harmonic contents are given:

- Total Harmonic Distortion (THD) of current and voltage

$$\mathrm{THD(I)} = \frac{\sqrt{\sum_{n=2}^{40} I_n^2}}{I_1} \tag{1}$$

- Partial Weighted Harmonic Distortion (PWHD) of current and voltage

$$\mathrm{PWHD(I)} = \frac{\sqrt{\sum_{n=14}^{40} n I_n^2}}{I_1} \tag{2}$$

- Standards were supplemented with a selfdefined parameter called "Total Harmonic Distortion with interharmonics THDz(I)".

$$\mathrm{THDz(I)} = \frac{\sqrt{\sum_{n=1}^{400}\left(I_{n\cdot 0,125}\right)^2 - I_1^2}}{I_1} \tag{3}$$

This parameter offers the possibility to evaluate the total content of harmonics and interharmonics because in the standards only upper limits for the interharmonics are mentioned.

Measurements were practised over some weeks in order to cover the full power range of the WEC's. The four channel power analyser used works with a sampling rate of 6.4 kHz or 12.8 kHz and a storage depth of 1024 bit. Therefore the frequency resolution is $f_{r,max}$ = 6.25 Hz. Accuracy of the device is 0.2 % with long-term storage capacity.

The following table shows an overview of power quality parameters used for the evaluation and gives the reasons for their appearance.

Table I: Power quality parameters and their origin

Parameter	**p[1]**	**np[2]**	**Frequency range**	**Cause**
Harmonics	X		> 50 Hz	Non linear consumers, Switching events
Interharmonics	X		0 ... > 50 Hz	
Subharmonics		X	< 50 Hz	
Voltage deviations		X	< 0.01 Hz	Power changes
Flicker	X	X	(0.01 ... 35 Hz)	Power changes
Transients		X	> 50 Hz, accidental	Switching events

[1]periodic [2]non-periodic

Again it can be noticed:
- the steeper the signal the higher the generated frequencies
- periodic signals deliver discrete spectra
- non-periodic signals deliver continuous spectra.

2. GENERATOR TYPES

The gearless synchronous generator (SG) works with full inverter coupling to the grid, while the geared doubly-fed asynchronous generator (DFIG) has a direct stator winding connection to the grid and an inverter coupled wound-rotor to the grid. Typical technical data can be taken from table II.
Measurements were done on the low-voltage side but also on the 20 kV voltage level.
Grid connection of all the variable speed wind generators is realised in our investigation with voltage source inverters (VSI). Figure 1 shows the generator concepts which were typical for our investigation.
Although the inverter dc link capacitor bank smooth dynamic generator voltage changes, all the WEC-types show current distortions because of the limited switching frequencies of the power electronic switches due to their specific switching losses. Typical switching frequencies – depending on the power level – range between 2 kHz and 12 kHz. The lower the switching frequency the worse is the shape of the inverter current output. Other grid distortions result from the fast power changes caused by variation of wind speeds and switching operations in the wind park.

Table II: Technical data

WEC type No.	**4**	**5**
Generator type Nominal power [MW]	DFIG 1.5	SG 1.8
Voltage [V] Pole pairs	690 2	400 36
Gear ratio VSI type	1 : 90 A	- C
Pulse frequency [kHz] Transformer [V/kV]	3 690/20	5 – 12 400/20
Rotor speed range [rpm] Nominal rotor speed [rpm]	11 – 22 12	8 – 22 12
Rotor diameter [m] Tower height [m]	70.5 100	70 98

Power changes generate fast changing currents which result in deviations of the grid voltage.

In these days WEC's are typically concentrated in wind parks which are connected to the medium voltage level of 20 kV. Measurements of single WEC's are necessary to describe the system behaviour and experimental investigations on the medium voltage level are necessary to find out the damping effects of the 0.4/20 kV or 0.69/20 kV transformers within the wind park. It is also of interest to study the pulse pattern of the inverters and their influence on the total power factor and therefore on the energy yield. The goal is to have already at partial load a power factor of unity. Reactive power should be close to zero for a wind park. Fig. 2 depicts the variation of the total power factor for different WEC's.

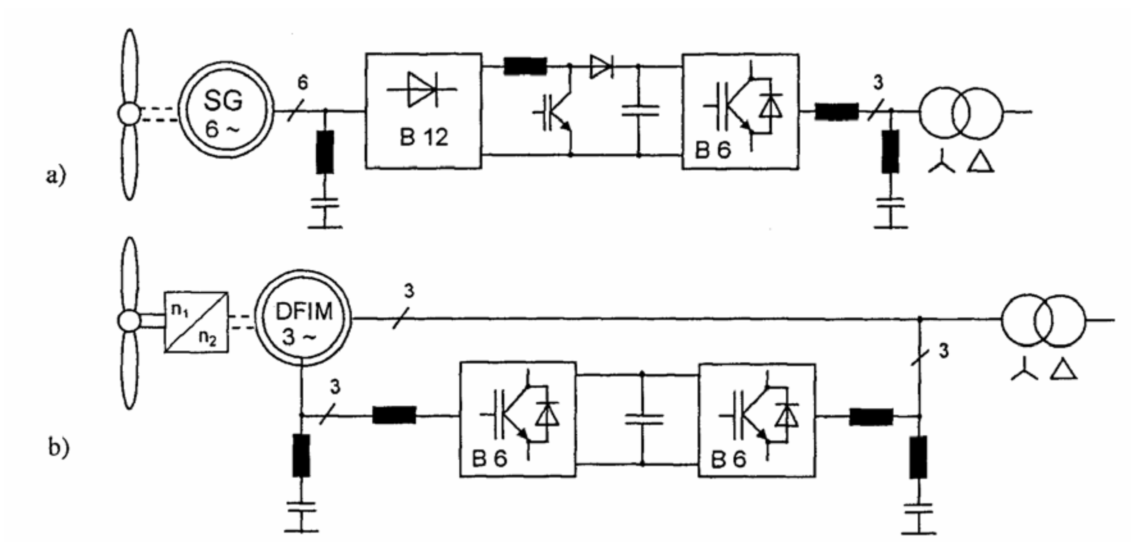

Fig. 1: Generator concepts

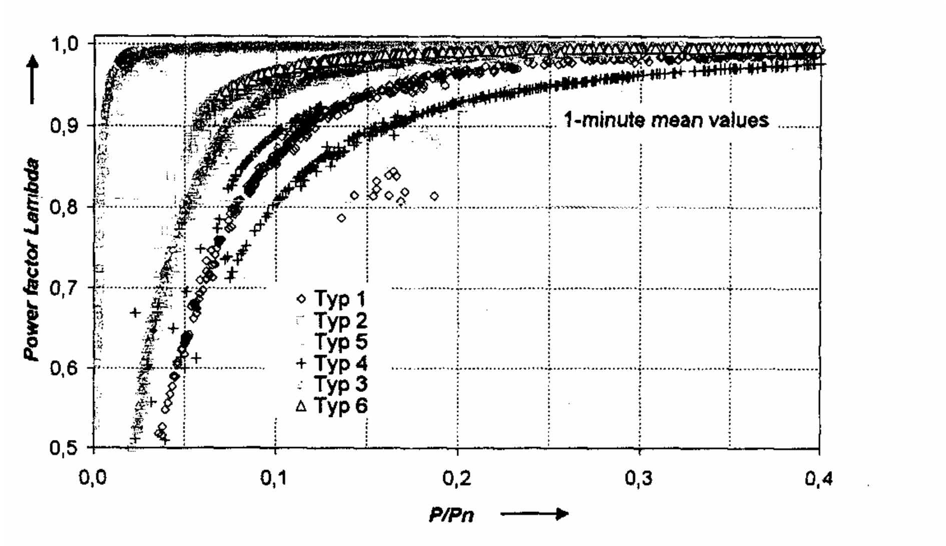

Fig. 2: Total power factor λ of different WEC's

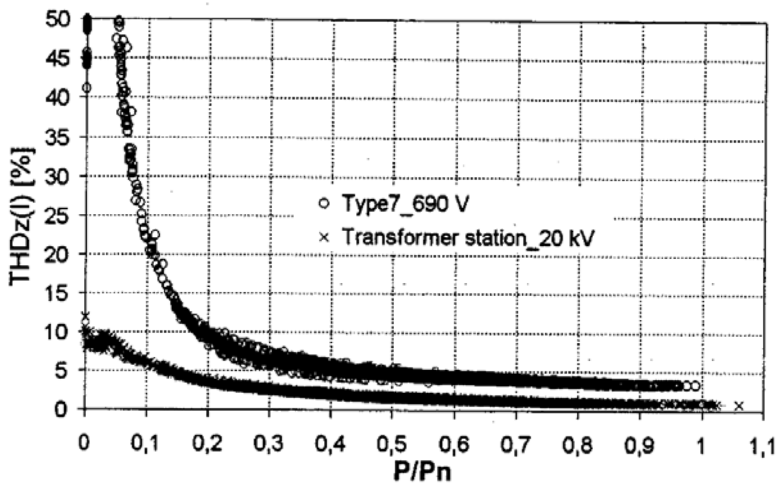

Fig. 3: Total harmonic distortion for a selected WEC (No. 7)

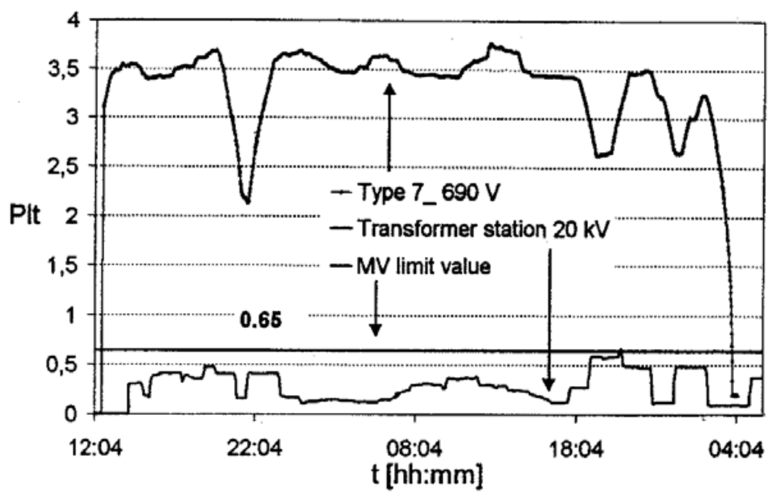

Fig. 4: Long-term flicker for a selected WEC (No. 7)

3 RESULTS

Measurements have shown that the current distortion is quite high at partial load and decreases with increasing power. The point of common coupling (PCC) has an influence on the voltage distortions because of differences in the grid impedance. The difference in the power factor can be related to differences in the inverter switching strategy, type of filters and type of grid chokes. Figures 3 and 4 show the total interharmonic distortion and the long term flicker for the two voltage levels.
The effect of damping on the harmonics due to the transformer is obvious. At nominal power a current distortion of only 1 % was measured on the 20 kV level. Long-term measurements have shown that the wind park operates within the flicker limits of 95 % below $P_{lt} = 1$ within one week according to grid quality standard EN 50160 and also complies with the guidelines of grid connection of the energy authorities which demand flicker values below 0.65.

4 CONCLUSIONS

The connection of WEC's in the MW power range to the grid is affected by the power quality standards and guidelines of energy authorities. Large differences in the power factors result in large differences in the energy yield and therefore novel control techniques are under development. In the future DSP controlled three-phase inverters will help to overcome the above mentioned difficulties. The result for the 20 kV level is that the upper limit values of harmonics and flicker were not exceeded. In addition to these findings should be pointed out that WEC's are an option for reducing CO_2 emissions.

5 LITERATURE

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