THE INFLUENCE OF WIND TURBINES ON POWER QUALITY IN THE HV NETWORK IN POLAND

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Introduction

Wind turbines, due to their structure and the nature of their work, may be a source of disturbances in the networks which they are connected to, and affect the quality of power. Therefore the power quality factors became an issue of considerable importance, particularly at the point of common coupling (PCC) of wind turbines to the grid. Analysis of the influence of operating, grid-connected wind farms, and measurements of power quality parameters were carried out. The measurement results were compared to limit values defined in Polish standards and binding regulations.

Wind turbine in electric power system

The operation of a wind turbine, connected to electrical network, may affect the quality of power and the state of the electric power system. This results from the fluctuating nature of the energy source – the wind. Operation of wind power plants, connected to the power system should be mainly considered in terms of:

- fluctuation of RMS voltages at the point of the connection and other nodes of the network,
- voltage and current distortion.

The adverse impact of a wind farm on the power system results in temporary changes in active and reactive power. The wind turbines can be a source of disturbances resulting from: different wind speeds at different altitudes, the shadow effect, and other phenomena, like: oscillations in the tower, rotor, and elastic coupling.

The measurement site

The measurements have been carried out at the 30 MW Wind Farm Zagorze in the north-west of Poland. The wind farm consist with 15 pitch-regulated, V 80 - 2 MW Vestas turbines, each driving a doubly-fed asynchronous generator with an IGBT converter. The voltage is directly transformed up to 15 kV and the energy is transmitted to the 110 kV distribution network by the Reclaw substation. The electrical system of the wind farm Zagorze is presented in Figure 1.

Measurement procedure

The measurements were taken using the SIMEAS Q power analyser. The power analyser was connected by a serial link to a PC, that controls the power analyser and logs data to disk. The power analyser measures 3 line-to-line voltages and line currents at 6.4 kHz sampling rate. The power quality characteristics were measured on the wind turbine substation at HV side of the step up transformer, from December 2003 to June 2004. During this period, the following parameters have been recorded: active and reactive power, frequency, voltages (RMS), currents (RMS), voltage and current THD and flicker severity (Pst and Plt).

Assessment of power quality was made by comparing the measurement results with the data contained in standards and regulating documents on the power quality in distribution systems.

In Poland, basic documents determining standards for the quality of power in supply networks are:

- IEC 1000-3-7:1996 standard, determining limits voltage fluctuations in MV, HV and EHV networks,
- IEC 1000-3-6:1996 standard, defining limits of harmonic emissions,
- EN 50160:1998 standard, containing characteristics supplying in LV and MV networks,
- "Regulation of the Minister of Economy of 20 December 2004 in the matter of the detailed conditions of connecting entities to power grids, grid operation and maintenance”, determining standards of the power quality in distribution networks,
Operating Manual,
- Distribution System Maintenance and Operating Manual,
- IEC 61400-21 standard, describing power quality requirements for wind installation and measuring procedures, used for specification of qualitative indices for single turbines and wind farms.

The measurement results

The influence of a wind turbine on the power system depends on wind conditions, especially wind fluctuations, the wind turbine construction and the level of the power generation and consumption.

![Fig. 2. Active and reactive power in measurement period from 19.05 to 25.05 2004](image)

Fig. 2 shows 10-minute average values of active and reactive power, measured at the primary side (110 kV) of the Reclaw substation. As seen from the graph, the interaction of a wind farm with the power system is marked by continuous changes in both: the active power generation and reactive power consumption, also presented in Figure 3.

![Fig. 3. Reactive power vs. active power in the measurement period from 19.05 to 25.05 2004](image)

As can be seen from the measurements, the wind farm Zagorze was drawing a significant amount of reactive power from the power system when a high level of the generation was recorded. On the other hand, at low power demand, the wind farm was generating the capacitive power to the network.

Polish regulations and voltage quality standard specify the tolerance of ±10 % in LV, MV and HV networks [1]. Figure 4 shows 10-minute average line-to-line voltages, measured at the 110 kV side of the Reclaw substation.

![Fig. 4. Line-to-line voltages in the measurement period from 19.05 to 25.05 2004](image)

The curves in Figure 4 show daily variations, with voltage decrease during peak load period in the evening and voltage increase at night-time. The voltage level at night-time is on average about 2 kV higher than during the day. The steady-state voltage in Reclaw was within limits during the whole measurement period.

The injection of a wind power into the power system may affect the voltage magnitude. The impact depends on the strength of the network and the active and reactive power of the wind power installation.

In order to determine the influence of the wind farm generation on the voltage magnitude, the line-to-line voltage $U_{12}$ and line current $I_1$ at the point of the wind farm Zagorze connection to the system (PCC) were plotted in Figure 5.

![Fig. 5. Voltage $U_{12}$ and current $I_1$ from 19.05 to 25.05 2004](image)

As seen from the plot in Figure 5, the periods of the high wind generation (large current values) was corresponding to lower portions in the supply voltage waveform. It is also visible that operation of wind farm had small impact on voltage changes.

The harmonic emission level depends on the type of generating equipment used and on the generated power level. Figure 6 shows the voltage dominant odd harmonics, measured at the HV side of the substation.
All measurements show significant harmonic distortion of supply voltage, in particular from odd harmonic. The dominant distortions have been identified as the 5th and 7th harmonics. The calculated values of the voltage 5th harmonic for this period exceed the values given in regulations (2% for 5th harmonic) [3]. It should be noticed that large values of harmonic distortion correspond with weekend and evening peak load periods. The measurements carried out during weekend days are indicated in Figure 6.

Polish regulations limit the voltage harmonic distortion THD in HV network to 2.5% [1]. As seen in figure 7, the values exceeding the permissible level were recorded during the measurements. As already mentioned, this occurred during the power system peak load periods.

Thus, the harmonic distortion occurred when the system was loaded due to a large consumption from residential consumers. Figure 10 shows harmonic distortion as a function of the line current. As the plot in figure 10 shows, there was no correlation between the voltage harmonic distortion and the line current during the wind farm operation.

A visible result of voltage fluctuation in power system is the flicker effect. The level of flickering is determined by the short term \( P_{st} \) and long term \( P_{lt} \) flicker severity indices. The flicker emissions from a wind turbine installation should be limited to comply with the flicker emission requirements and planning levels [5]. Indicative values of planning levels, given in the standard, are: \( P_{st} = 0.8, P_{lt} = 0.6 \) in HV power system. It is also recommended [4] that in networks of voltage 110 kV and higher, the flicker emission of fluctuating loads from wind farm should be below \( P_{st} = 0.35, P_{lt} = 0.25 \). This is also assumed to be applicable to the wind turbine installations, however, different utilities may have different flicker emission limits.
As seen from Figures 11 and 12, the flicker severity values recorded during the measurements were much lower than the planning and limit emission levels.

**References**

1. EN 50160: 1999, Voltage characteristics of electricity supplied by public distribution systems.
2. Regulation of the Minister of Economy of 20 December 2004 in the matter of the detailed conditions of connecting entities to power grids, grid operation and maintenance (in Polish).