The Analysis of Wind Farm Impact in Primary Radar System

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***Abstract*—The paper deals with problematic of the influence of the wind turbines on the Primary Radar System. A real scenario that includes two wind turbines was chosen for the analysis. A simulator of reflected signals from the wind turbines was developed. In the start of paper, the principle of the developed simulator is described followed by the own analysis. The results from the work will be used for developing of the mitigation techniques for suppression of this influence.**

Keywords—wind turbine; primary radar system; reflection, Radar Cross Section, wind farm, Doppler shift, RCS

I. INTRODUCTION

In the previous research a simulator of reflected signals from a wind farm was developed. The description of the reflected signals model is presented in [1], [2]. The simulator is a general design, and it is possible to simulate almost any real wind turbine(s) or wind farm. The crucial input variable parameters are:

- Number of simulate wind turbines (WT)
- Number of blades
- Positions of Wind turbines in Cartesian coordinates
- Parameters of Primary Radar System (PRS)
- Number of Reflections between individual wind turbines

In the Primary Radar System, the simulator is important from the point of view of effectively eliminating wind farm influence on detection, tracking, false alarms etc.

The number of wind farms in last decade has dramatically increased due to emphasis on the growth of green energy. Countries such as Denmark (39%), Portugal (18%) and Spain (16%) already generate a significant part of their energy from the wind [3]. The rapid growth of wind turbines in the environment have not only had a positive impact. The wind turbines are a source of great “noise” for radar systems. The main two negative contributions of wind turbines are a big reflection area of transmitted signals (Radar Cross Section) and Doppler Shifts of reflected signals due to the high-speed rotation of blades. The Doppler shift and RCS can mask signals from a target and cause decreasing capabilities of the radar system. This is very dangerous from the point of view of safety.

The analysis of wind turbine impact was made on PRS with selected parameters: detection distance 12-150 km in “long” detection range, pulse intermodulation based on polyphase pulse compression technique P4 (with length 80 μs, carrier frequency 2,7-2,9 GHz), antenna gain 33,7 dB, antenna beam width 1,4°, pulse repetition period 1 ms, and antenna rotation speed 12,5 rpm. [1], [2].

The resolution in distance of PRS is computed from the properties of the autocorrelation function of pulse (P4). The resolution of two close targets in distance is computed through the effective bandwidth by the formula

$$\Delta R = \frac{c\Delta t_{\min}}{2} \cong \frac{c\tau_{ef}}{2} = \frac{c}{2B}, \quad (1)$$

where c is speed of light, $\Delta t_{\min}$ is minimal time delay between two close targets, τ_{ef} is effective width of autocorrelation function and B is band width computed by the formula $B = \int_{-\infty}^{\infty} S_P(\omega)\, d\omega / \max_{\omega}(S_P)$, where $S_P(\omega)$ is power spectrum of the P4 pulse. The computed resolution for the PRS parameters is, in our case, approximately $\Delta R = 146$ m. Figure 1 presents distance resolution for two close same targets for different phases of reflections. The worst case occurs for phase 0°.

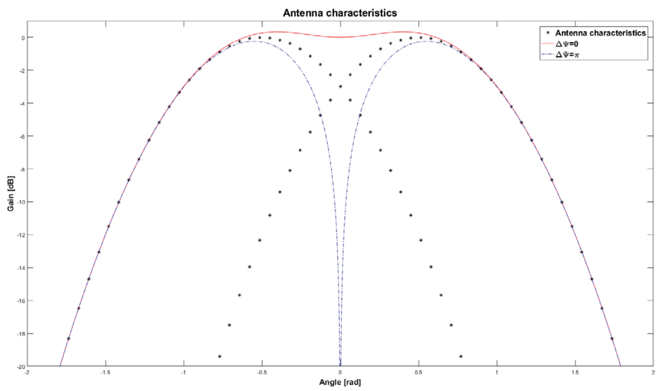

Fig. 1. The resolution of two targets in distance in present PRS

The resolution in the angle is defined by antenna characteristic properties (value 1,4°).

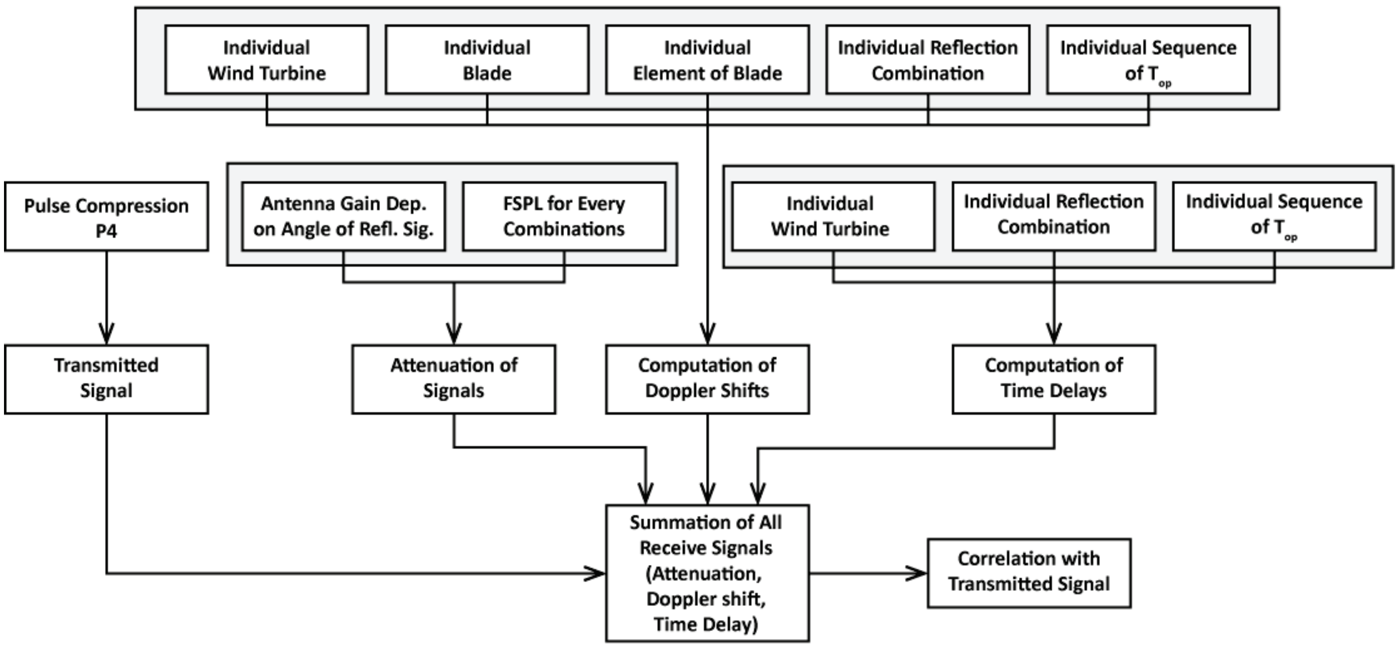

Fig. 2. The resolution of two targets in distance in present PRS

The model of computation of the reflected signals is described by the structure in Figure 2. The structure is divided into four main computation areas:

(1) The computation of the transmitted signal. Transmitted signal is created by the pulse length 80 µs with intermodulation P4.

(2) Doppler shift computation for selected scenario (positions of wind turbine(s) and PRS). The computation of the Doppler shift of received signals is dependent on the number and position of the wind turbines, the properties of individual wind turbines as a number of blades, the number of elements in one blade, the number of considered reflections (maximal number of reflections is 3 – the higher number is not necessary to compute due to a big attenuation of reflected signals; influence of the higher reflections is minimal, but computation complexity is very demanding), the number of combinations of reflections that depend on the number of wind turbines and sequence of the period repetition.

(3) Time delay computation represents time delay of reflected signals that depends on the path of reflection (distance). The time delay similarly to Doppler shifts depends on the number of wind turbines, number of reflection combinations and sequence of the period repetition.

(4) Attenuation of reflected signals represent attenuation caused by multipath propagation, antenna radiation pattern and Free-Space Path Loss.

The final received signal is computed as a summation of all time-delayed, Doppler shifted signals for all combination of reflected signals between power turbines, blades and element of blades. The last step is computation of the correlation function between the final received signal and transmitted signal.

TABLE I. PARAMETERS OF THE SIMULATIONS

Position of Wind Turbine 1 (WT1)	49°49'56.3"N 16°22'08.6"E
Position of Wind Turbine 2 (WT2)	49°50'04.6"N 16°22'18.5"E
Parameters of the PRS North	
Positions of the PRS	50°00'43.7"N 16°22'08.6"E
Azimuth of PRS to WT1 & WT2	180° & 179,428°
Distance of PRS to WT1 & WT2	20 & 19,746 km
Parameters of the PRS East	
Positions of the PRS	49°49'55.1"N 16°38'49.4"E
Azimuth of PRS to WT1 & WT2	270,213° & 270,952°
Distance of PRS to WT1 & WT2	20 & 19,804 km
Parameters of the PRS South	
Positions of the PRS	49°39'09.0"N 16°22'08.6"E
Azimuth of PRS to WT1 & WT2	0° & 0,558°
Distance of PRS to WT1 & WT2	20 & 20,256 km
Parameters of the PRS West	
Positions of the PRS	49°49'55.1"N 16°05'27.8"E
Azimuth of PRS to WT1 & WT2	89,787° & 89,063°
Distance of PRS to WT1 & WT2	20 & 20,199 km
Parameters of the Wind Turbines	
Number of blades	3
The height of Wind Turbines	120 m
The length of blade	60 m

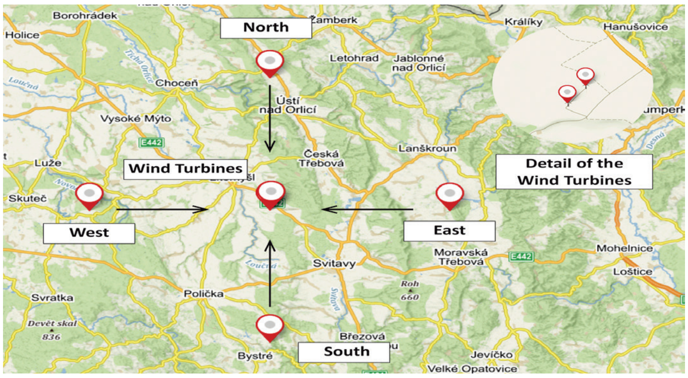

Fig. 3. The simulation scenario [4]

II. Analysis of the Influence of Wind Turbines in Real Scenario

The analysis of the simulated data was made for several scenarios. This section include relatively simple scenarios includes two wind turbines and several positions of radar. The analyzed parameters are:

- Analysis of the number of considered reflections
- Analysis of the radar positions to the respect of the wind turbines
- Analysis of the rotation speed of the wind turbines

The parameters of simulation are present in Table I. The scenario of simulation as positions of wind turbines and different position (north, east, west, south) of PRS are present in map with highlighted azimuth are shown in Figure 3. All analysis results will be presents in frequency-range domain. The frequency corresponds to Doppler shift caused by rotation of the blades.

A. Analysis of the number of considered reflections

The analysis is based on PRS placed in West position. The Figure 4 shows range-frequency domain with considered only one reflection (no multipath). In the figure, can be shown three red circles that correspond to the distance of the wind turbines for three blades with corresponding Doppler shift.

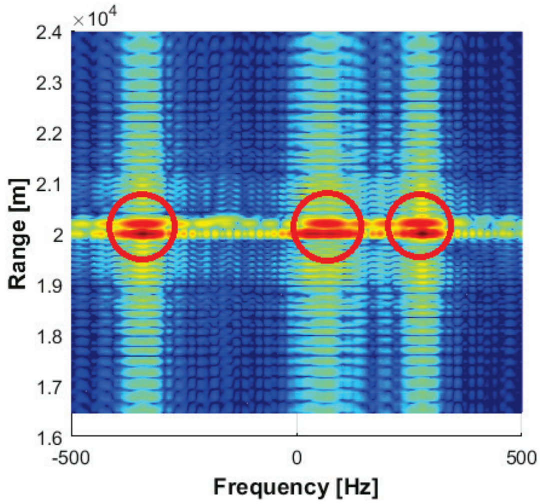

Fig. 4. The range-frequency domain for one reflection

The shape of the function of individual wind turbine corresponds to the sum of the three blades and each blade correspond to the used pulse compression techniques (poly-phase pulse compression P4) and in 3D is present in Figure 5.

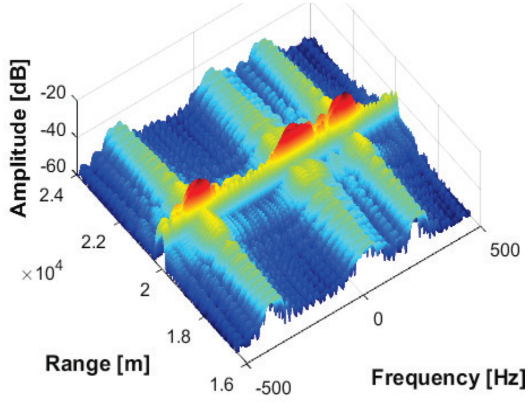

Fig. 5. The range-frequency domain for one reflection in 3D

The Figure 6 shows results from the simulation with consideration of three reflection. Reflections between wind turbines caused spreading in the frequency domain due to summation of reflected signals with different Doppler shifts. The shifting in frequency domain is highlighted by the green rectangles.

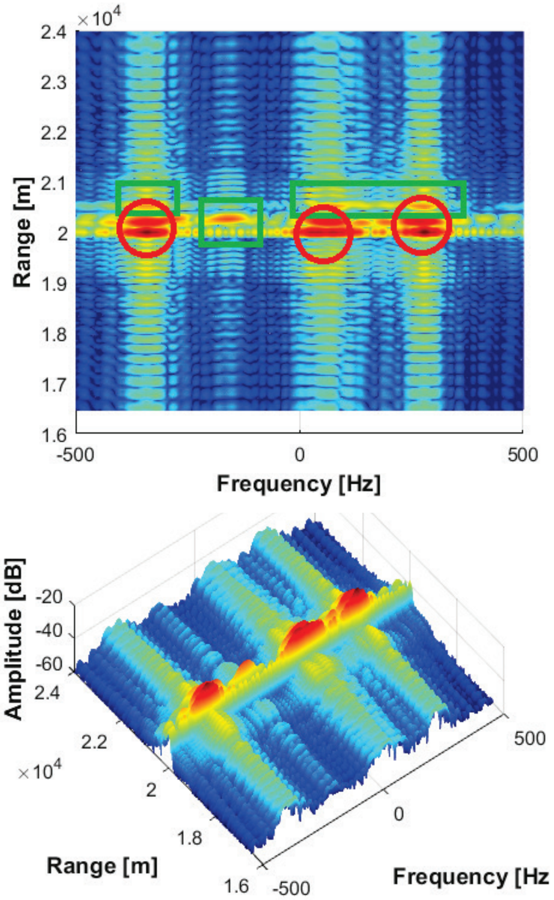

Fig. 6. The range-frequency domain for three reflections in 2D and in 3D

B. *Analysis of the radar positions to the respect of the wind turbines*

The various positions of the PRS with respect to the wind turbines evince very different results, specially in frequency domain, caused by different visibility of the blades for with respect to the PRS. The rotation speed for this simulation was 12,5 rpm. The results are present in Fig. 7 (north, east, west and south position). The North and South position of the PRS is frontally to the wind turbines and Doppler shift is almost zero for both positions of the Doppler shift. The Doppler shift will be smaller than for East and West position of PRS. The result for East position has positive Doppler shift and in West position negative Doppler shift. This difference is caused by the rotation of the wind turbines (clockwise and anticlockwise).

The sampling frequency is defined by the pulse repetition of the period (1 ms). The range of the Doppler shift is $\langle -500, 500 \rangle$ Hz. If the received signal includes higher Doppler shifts frequencies, then is considered range come to the mirror of the real Doppler frequency to the invalid value and subsequently to the bad identification of the real value Doppler shifts. The appropriate valued of Doppler shifts with minimal differences are for North and South positions of the PRS. For North and South positions the Doppler shift for each blade is the same and zero. Therefore, in Fig. 7 only two peaks are shown (two wind turbine). The bad identification of Doppler frequencies occurs for East and West positions of PRS. The real values of the Doppler shifts can be computed by the reduction of the -1000 Hz from the measured value. It is exactly same principle as in under sampling of the signal.

C. *Analysis of the rotation speed of the wind turbines*

The changes in rotation speed of the wind turbines changes Doppler shift frequencies. In the Fig.8 is shown influence of the different rotation speed for 5 rpm, 7.5 rpm, 10 rpm and 12,5 rpm. The PRS is placed in Western position. With the increasing rotation speed the Doppler shifts also increasing - the peaks moving to left until the Doppler shift exceeds the ± 500 Hz, then occurs reflection of the original Doppler shifts.

III. CONCLUSSION

The paper presents analysis of different parameter wind turbines influences in range-frequency domain in the PRS. It was shown strong variability of analysed parameters as different rotation speed of the WTs, position of the PRS with respect to the WTs, and considered different number of reflections. The analysis was done in simulator of the reflects signals from WTs described in [1], [2]. The future work will be focus on the mitigation of the WT influence.

ACKNOWLEDGMENT

This paper was supported by the by the Specific Research Funds of the University of Pardubice, partly by Penelitian Unggulan Terpadu Universitas Indonesia 2017 and by the project No. FV10484 of the Czech Ministry of Industry and Trade.

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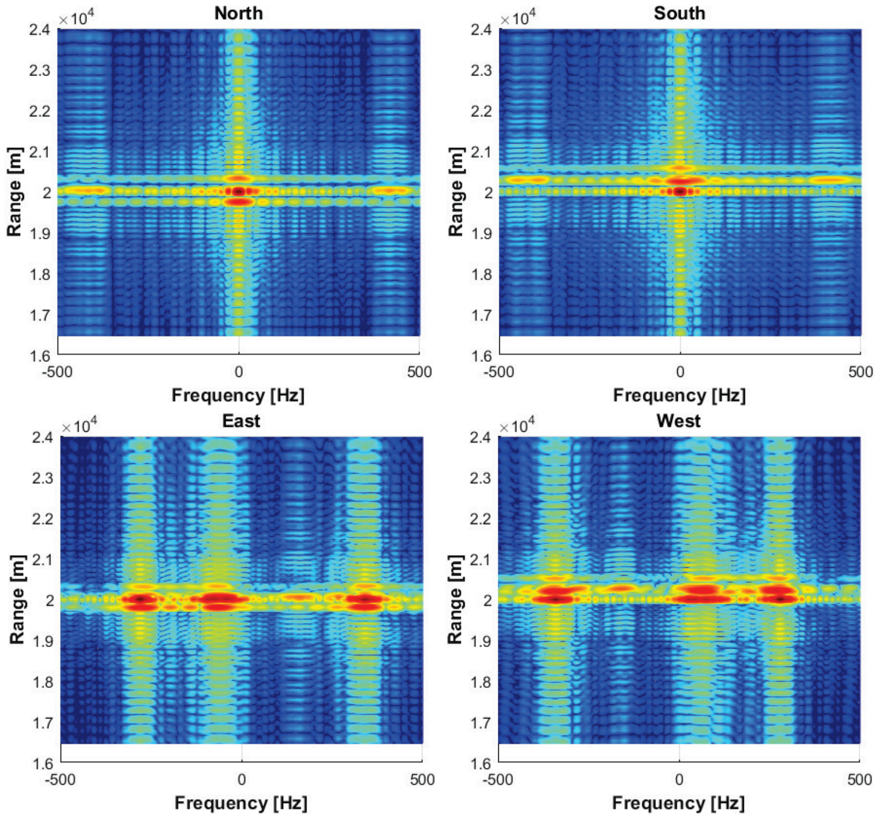

Fig. 7. Analysis of the radar positions to the respect of the wind turbines

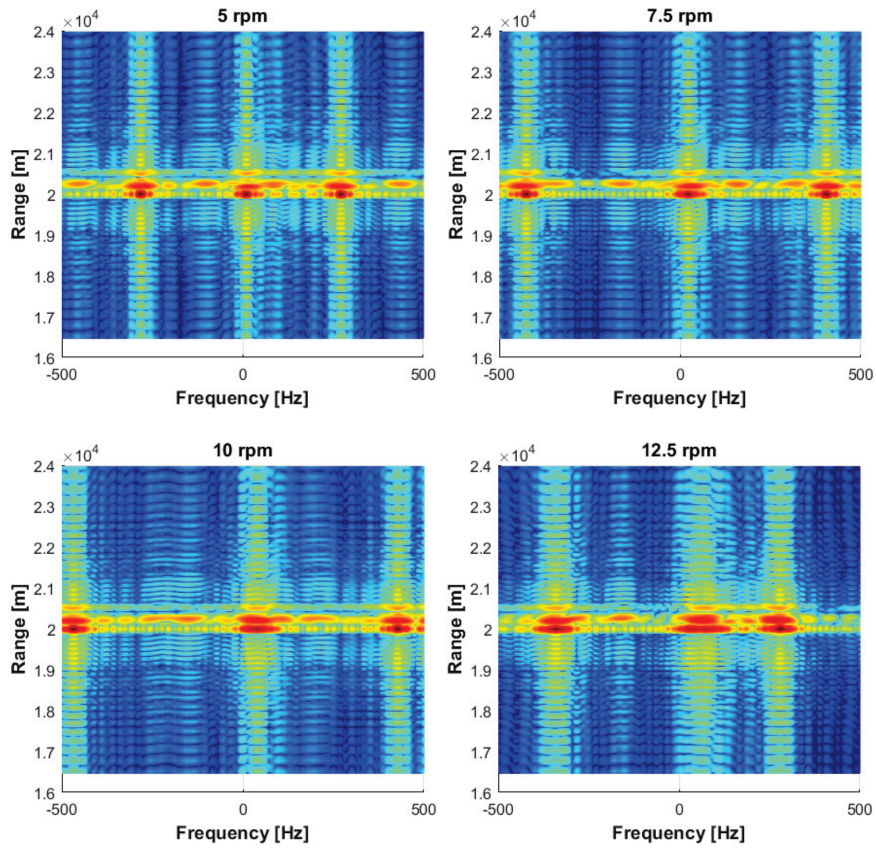

Fig. 8. Analysis of the rotation speed of the wind turbines