SIGNAL ANALYSIS AND MODELING OF WIND TURBINE CLUTTER IN WEATHER RADARS

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1. INTRODUCTION

The production of wind energy has greatly accelerated around the world in the last few years as wind is a renewable and clean energy source. Global Wind Energy Council reports United States becoming the world's largest wind-power producer in 2008 [1]. There has been a surge in the installation of several wind farms near the weather radars as, in both the cases, secure and unpopulated sites are desired. However, strong reflections from the wind tower structure can drive the radar receivers to saturation and the echoes originating from the rotating blades can affect the measurement of the wind speed [2]. This has generated considerable interest in the problem of identifying and mitigating the clutter originating from the presence of wind energy farms. In this paper, we present a numerical model for theoretical analysis of scattering from a wind turbine. This model is then compared against the actual signal returns from two different wind farms as observed by an S-band radar.

2. NUMERICAL MODEL OF RETURNED SIGNAL FROM A WIND TURBINE GENERATOR

The wind turbine generator (WTG) structures typically have a tower length of 44-105 m with a typical blade length of 25-40 m [3]. The wind turbine towers act as large radar targets while the rotating wind blades represent moderate radar targets. Usually a wind turbine blade is composed of a hollow shell of fiberglass-reinforced polyester. Within the dielectric shell of the blade, there exists a conducting wire (with a diameter of few mm) for the purpose of lightning protection. The rotating wind blades represent a time-varying radar cross-section. To model the radar return from a WTG, each blade can be assumed to be as a cylinder of length L [4]. The RCS due to the dielectric shell is usually much less than that of the lightning wire. Further, for radars operating in the S-band, the scattering regime for the lightning wire is optical. The RCS model of the WTG is then formulated to reflect the number of blades, speed, dimensions of the wind turbine and location with respect to the line-of-sight of the radar as shown in the Figure 1.

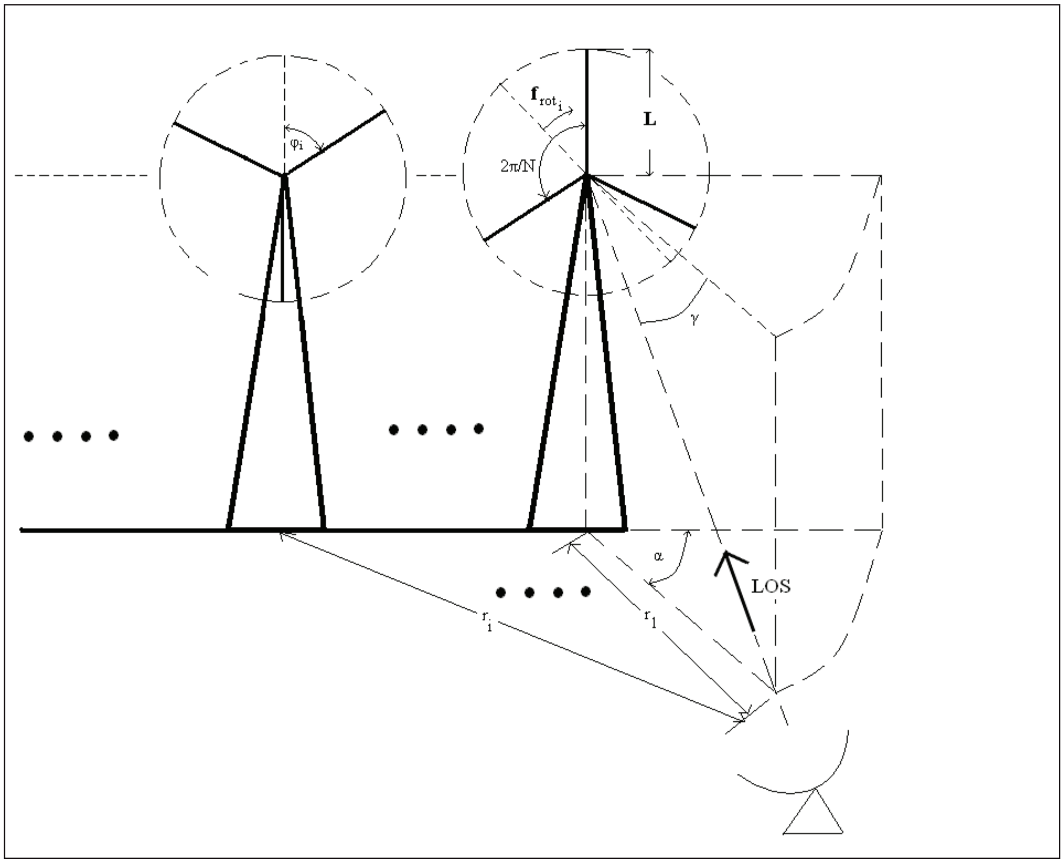

Figure 1. Geometry of the wind turbine for numerical modeling of the radar return. N is the number of blades per WTG, f_{roti} is the rotation speed of the i^{th} WTG in the resolution cell, r_i is the range at which the tower of i^{th} WTG is situated with respect to the radar.

3. OBSERVATIONS FROM AN S-BAND RADAR

CSU-CHILL S-band radar (at Greeley: 40.44625 N, 104.63708 W, 1426 m altitude) was used to record radar return from wind turbines at Ponnequin Wind Farm, Colorado. The wind farm is located at a range of approximately 62-63 km at azimuth 344-347° from the radar. Figure 2 shows the location of Ponnequin Wind Farm with respect to the CHILL radar. Radar echoes were recorded from the wind turbines on Aug 15^{th}, 2008 at 150m range resolution at a range of 63.15 km, 345.5° azimuth and 0.35° elevation. The observation was made at a fixed antenna position (*spotlight* mode). The time and spectral plots of this data are shown in Figure 2. Since the maximum return occurs when the wind turbine blades are perpendicular to the line of sight, the time domain return consists of large reflection "flashes". From this, an approximate value of rpm can be deduced which in this case can be in the range 10-20 rpm. The maximum Doppler frequency due to return from a wind turbine can be calculated as $f_{max} = 2v_{max}/\lambda$ where the maximum radial velocity $v_{max} = L*(2\pi/60)*rpm$. Using this information with the available specifications and locations of the particular wind turbines of Ponnequin Wind Farm, the theoretical return is simulated (Figure 3) and found in agreement with the observed return.

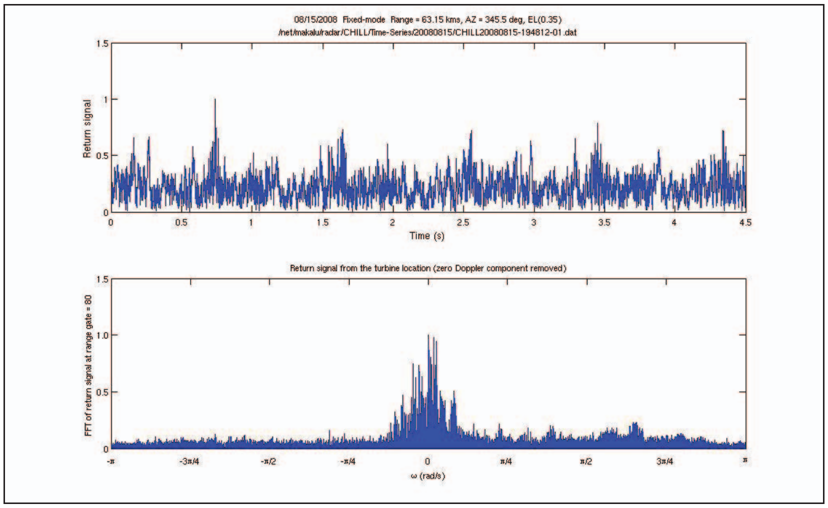

Figure 2. Time (top) and spectral (bottom) plots of a CSU-CHILL radar return from a WTG in Ponnequin wind farm.

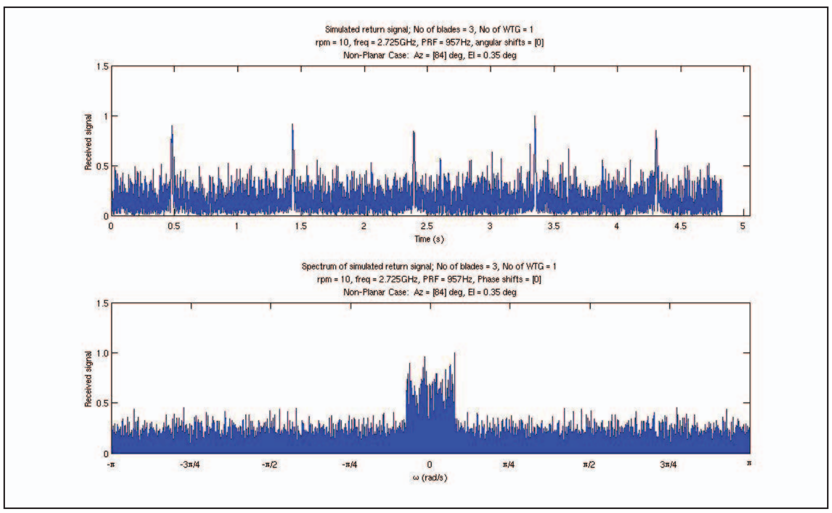

Figure 3. Simulated time (top) and spectral (bottom) plots for a noisy return from a single wind turbine (L = 24m, rpm = 10).

In this paper, we also explore the properties associated with the return signal of WTG and compare them with the simulations of the numerical model. Subsequently, this model is used to study the signal from turbines when overlaid precipitation, in order to develop techniques for identification and mitigation of wind turbine clutter. The paper presents preliminary analysis of the wind turbine signals as seen by weather radars.

5. REFERENCES

[1] Global Wind Energy Council, "Global Wind 2008 Report", p. 8, 2008.

[2] G. J. Poupart, "Wind Farms Impact On Radar Aviation Interests – Final report", DTI PUB URN 03/1294, Sept 2003.

[3] Vestas Wind Systems: http://www.vestas.com/en/wind-power-solutions/wind-turbines.aspx

[4] R. J. Riddolls, “Effects Of Wind Turbines On High Frequency Surface Wave Radar”, DRDC-OTTAWA-TM-2005-240, 2005.