9.3 WIND TURBINE CLUTTER MITTIGATION FOR WEATHER RADAR: A FEASIBILITY STUDY BY MEANS OF SCALED MEASUREMENT

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1. INTRODUCTION

With the extremely rapid growth of wind energy across the country, many wind farms have been built within the vicinity of NEXRAD network. It has been revealed by many studies (Michael Brenner 2008; Richard J. Vogt 2009; Richard J. Vogt 2011) that operating wind turbines within radar coverage will cause interference known as Wind Turbine Clutter (WTC). This will degrade radar data quality and even increase false alarm rate.

Some efforts have been made to eliminate WTC impacts on radar. Stealth technology (J. Pinto 2010) is being tested to reduce RCS of wind turbines so as to minimize WTC in the wind turbine manufacture process. Moment interpolation (Isom 2009) was applied to improve WTC contaminated radar data quality. Range Doppler (Feng Nai 2010) method has also been exploited to remove WTC from weather radar data.

The importance of studying WTC radar signatures, however, has hardly been addressed in previous studies. It is believed in this paper that with better understanding of the unique radar signatures of WTC, useful weather signals can be recovered from contaminated radar data with acceptable distortions.

To study WTC radar signatures, large amounts of wind turbine radar measurements need to be made and full control of wind turbine is required to study how wind turbine motions affect radar observations. This is very difficult to do on a full-size wind turbine since its motions are passive and determined by wind conditions. The scaled measurement, however, is able to use rotors to actively emulate blade rotation and yaw movement on a scaled wind turbine model. A scatterometer is also built to emulate weather radar functions. It will be discussed further how scaled measurements help model wind turbine radar signatures. A knowledge base aided adaptive mitigation scheme will also be studied to further mitigate WTC from radar data.

2. SCALED MEASUREMENT

To make scaled radar measurements, scaled wind turbine model and low-power radar are needed to emulate the full size wind turbine-radar interactions:

2.1 WIND TURBINE MODEL

A wind turbine model is customized for indoor measurements. The hub height is 1.2m and the rotor diameter is 0.7m. A programmable DC servo rotor is embedded within the nacelle to position and rotate rotor blades. The model is placed on an accurate AC rotary stage to emulate the wind turbine yaw movement. Fig.1 shows the model placed in the anechoic chamber.

2.2 SCATTEROMETER

The scatterometer is a low-power X-band Pulsed Doppler radar built specifically for indoor measurement. It features very fine range resolution, stable phase, which makes coherent measurement possible, adjustable pulse width, Pulse Repetition Frequency (PRF) and quad-channel real-time IQ data acquisition. The scatterometer also has a mode-switching module that switches transmitted pulse between single/dual/full polarization modes. A brief specification of the overall system is listed in Table-1.

The system block diagram is shown in Fig.2. All RF components, the clock sync block, the power unit and cooling parts are integrated into an aluminum case as shown in Fig.3. The clock sync unit is a PCB designed for synchronizing pulse trigger signal with the digital sampling clock.

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Fig.1 Scaled wind turbine model

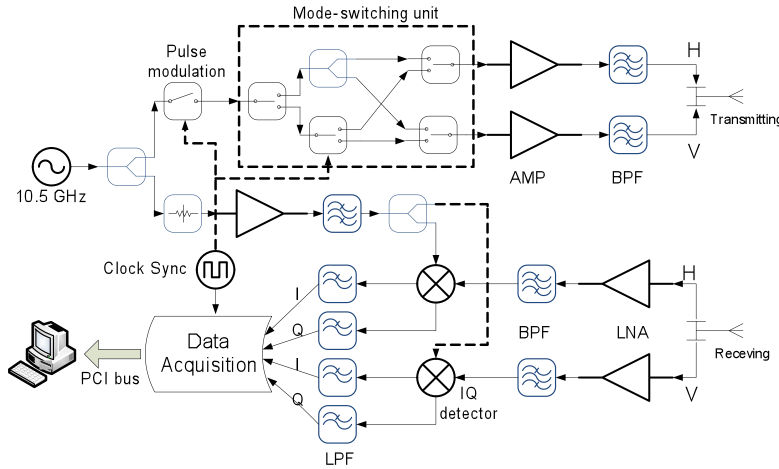

Fig.2 Scatterometer block diagram

Table-1 System specification of the scatterometer

System Parameter	Value	Unit
Operating frequency	10.5	GHz
Peak power	126	mW
Antenna gain	12	dBi
Antenna 3dB beam width	30	degrees
Transmit pulse width	8~ 20	ns
Pulse repetition frequency	95~24400	Hz
System bandwidth	100	MHz

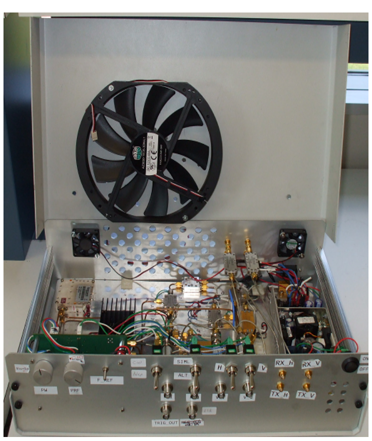

Fig.3 Inside the scatterometer

Fig.4 Measurement configuration

2.3 MEASUREMENT CONFIGURATION

The scaled model is placed in the center of an anechoic chamber. Antennas are set up 4 meters away from the model to ensure far field radiation. The antennas are mounted on top of a stepped motor, which can be programmed to emulate the VCP mode of weather radar. Measurements are configured by NI Labview interface as shown in Fig.4. Beside VCP mode, spotlight mode can also be emulated, which shows real-time range profile and spectrogram. The data acquisition module is fully synchronized with wind turbine motions.

3. SCALED VS. FULL-SIZE MEASUREMENT

To verify the scaled measurement, it needs to be compared with full-size wind turbine radar measurement. Time series data of full-size turbine are not only determined by turbine motion, but also related to terrain, weather, multi-path, etc., which is difficult to be used for comparison. The spectrogram, also known as the temporal Doppler spectrum evolution, has been found to be one of the most significant wind turbine radar signatures (Isom 2009), thus will be used to compare the similarity between scaled and full-size measurement.

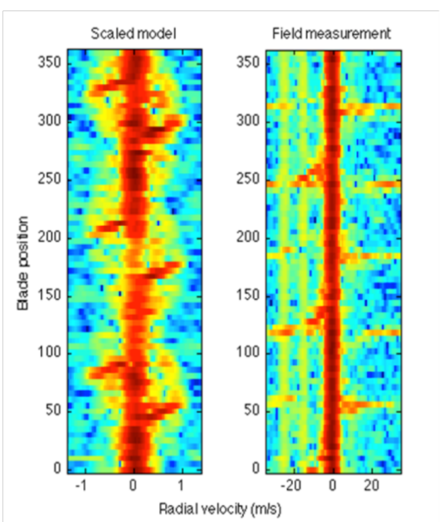

Fig.5 Spectrogram compare

As can be seen from Fig.5, the spectrogram from the scaled measurement features similar periodic flash as in full-size turbine measurement. The flash occurs when one of the blades is in the vertical position, which makes all scattering centers along the blade to be in-phase and not only causes the RCS jump but also creates a wide spectrum as is shown in Fig.5.

4. A KNOWLEDGE BASE AIDED ADAPTIVE MITIGATION SCHEME

The knowledge base is built from wind turbine size and shape information by EM modeling. As shown in Fig.6, the WTC knowledge base stores rough estimations of WTC time series from EM modeling. If telemetry information such as blade position and aspect angle are available from onsite sensors, the algorithm indexes the knowledge base and sends WTC estimate for current state to the adaptive filter. If telemetry information is not available, the WTC estimate can be retrieved by correlating corrupted data within the knowledge base. The adaptive filter constructs an optimal FIR filter that filters corrupted radar data to approximate the knowledge base output. The difference between filter output and corrupted data is thus the recovered weather signal assuming weather and WTC are completely independent.

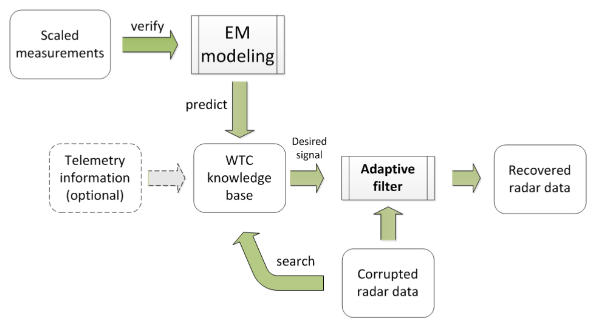

Fig.6 Block diagram of knowledge base aided scheme

The EM modeling method currently used is 0-order Physical Optics (PO) and is being revised by verifying the simulated results with scaled measurements. As is shown in Fig.7, although the simulation can roughly match the measurement, but it is not accurate enough to be applied to build the knowledge base.

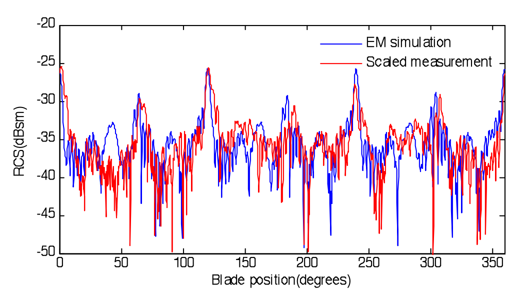

Fig.7 EM modeling simulated scaled model RCS compared with scaled measurement

In the case that EM modeling is not accurate enough, scaled measurements for different blade position and aspect angle are pre-stored as the knowledge base. In order to verify the scheme, simulated weather signal is superposed on top of scaled measurement. The Wiener filter is applied on this corrupted data as shown in Fig.8. The simulated corrupted data have such low signal to clutter ratio that it is impossible to distinguish it from the spectrum. But since the spectrum of WTC can be roughly estimated from the knowledge base, the weather signal is completely recovered from WTC contamination.

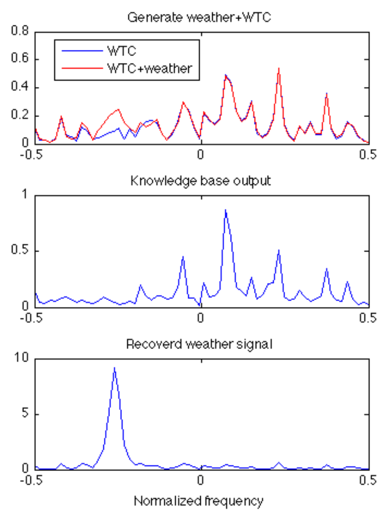

Fig.8 Illustration of adaptive filter process

5. CONCLUSION

WTC is difficult to mitigate from weather radar data due to its contiguous contamination to the spectrum. In-depth studies of WTC radar signatures by means of scaled measurements have been done to help EM modeling. Given WTC knowledge base with enough accuracy, the weather signal can be completely recovered from corrupted data by proposed knowledge base aided adaptive mitigation scheme. Current EM modeling method still needs to be improved to provide accurate a prior information of the wind turbine radar signature.

6. ACKOWLEDGE

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