RADAR SIGNATURES OF WIND TURBINES

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INTRODUCTION

The determination of the radar signatures of wind turbines has serious national security implications, particularly for offshore installations and wind farms in the vicinity of airports. Radar reflections from turbine blades can affect radar systems used in commercial and military installations, Air Defense Radars (ADRs) of E/F, I, J and K bands military assts, Phase modulated radar transmission with range resolution of 15 meters and 18 centimeters, Air Traffic Control (ATC) and air route radars, marine navigation and even weather monitoring and prediction.

The rotor blades cause a Doppler problem and the nacelle and structural tower contribute to false plots.

The UK's Ministry of Defense in 2005 asserted that four wind farms off the coast of Britain interfere with the radar antennae line of sight, creating radar holes in areas under radar surveillance that prevent the detection of aircraft flying above these wind farms.

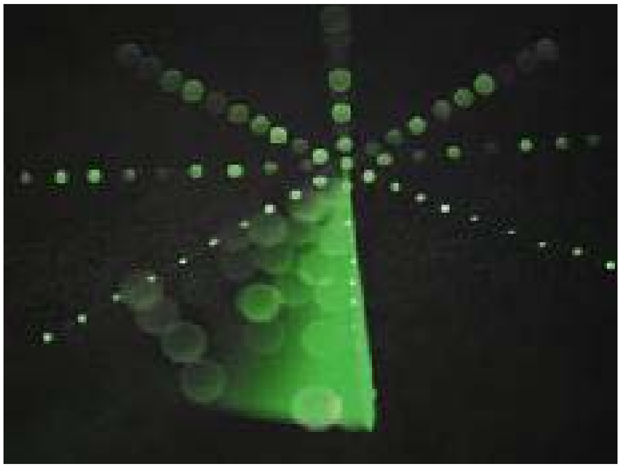

Fig. 1: Radar screen interference pattern from wind turbines.

Wind turbines have also led to the decrease in the radar sensitivity of civilian air traffic control near airports.

The resulting radar hole is independent of the height of the aircraft, the height of the turbine or the height of the radar station.

Wind turbines also create a shadow beyond the wind farm so that low flying aircraft flying within this shadow go undetected.

The magnified shadows of the turbines blades and the moving rotors are visible on the radar screens of weather and air traffic control radars.

RADAR CROSS SECTION, BLADE FLASH EFFECT

The rotating turbine blades fool the established radar techniques used to filter out tall buildings, trees and other stationary objects. And because different blades can be picked out during different radar sweeps, banks of turbines appear as a confusing, twinkling mass on screens that can make genuine targets difficult to pick out. There are even concerns that turbines cast a radar shadow behind them, within which enemy planes would be invisible, though recent measurements indicate that it would last for only a few hundred meters and would hide only very small objects.

Wind turbines have a large Radar Cross Section (RCS) compared with the target aircraft making it difficult to detect the aircraft. The RCS of a flying object is a measure of its detectability by radar. Commercial aircraft possess a large RCS, whilst stealth aircraft are designed to have a very low RCS. The RCS is dependent on the size of the object, the reflectivity of its surface and its shape.

A blade flash effect was also observed caused by the intermittent rotation of the wind turbine rotor blades.

The ratio of the RCS of wind turbines to that of aircraft was unchanged outside a 74 km range limit. Therefore it was suggested that this limit be dropped in the siting guidelines of wind projects in line of sight of radar surveillance stations.

The RCS of studied wind turbines was 25 $dB.m^2$. However, it was found that some offshore wind farms can have RCS values 100 times larger.

The large RCS, in addition to the blade flash effect result in a loss of radar sensitivity. The causes of why the wind turbines have a large RCS are:

1. Material reflectivity:

Most wind turbines rotor blades are made of Glass Reinforced Plastic (GRP) that is 38 percent reflective to microwaves.

Wind turbines reflect radar signals because their carbon fiber or glass reinforced plastic blades are shot through with metal lightning conductors. That means they are picked up by the radar used for controlling air traffic and current systems cannot distinguish between flying airplanes and whirling turbines, creating serious safety concerns.

Specular reflection of the radar signals occurs off the leading edge of the rotor blade. The trailing edge has vibration absorbing foam that also reflects radar.

When the rotor blades are in their vertical position, leading as well as trailing edge radar flashes are produced.

2. Yaw and pitch effects:

The RCS value of a wind turbine depends on the yaw or overall orientation of the turbine as well as the blade pitch of the individual rotor blades.

3. Nacelle and tower:

The nacelle and the structural tower of wind turbines have a large RCS. The RCS of a cylindrical shape is quite large and is proportional to the square of its length.

4. Array configuration:

The spacing of the turbines in a wind farm affects the RCS. Even if a single turbine has a small RCS, tightly packed turbines present a large RCS.

INTERFERENCE EFFECTS

There are several ways in which wind turbines can interfere with radar surveillance, especially if they are in groups, in radar line of sight, and located within 28 km or less of the radar head:

1. Swamping the receivers:

This refers to primary radar, and occurs when the bulk of the wind turbine structure may reflect sufficient energy to swamp any reflected energy of aircraft in the same area.

2. Defeating moving target processing:

If the rotating wind turbine blades are within or close to the radar line of sight, then the Doppler shift in reflected energy from the blades may defeat any moving target processing and display the blades as targets or tracks that could be mistaken for aircraft.

3. Presenting an obstruction:

If the wind turbines are within radar line of sight and aircraft are required to be detected at longer range behind the wind turbines then the following two effects may occur:

a) **obstruction**: when aircraft detection is lost in the shadow of the wind turbines; and,

b) **diffraction:** with partially obscuring of the aircraft radar reflections by the wind turbines causes azimuth errors at the radar resulting in that the aircraft can be displayed in a skewed position, or appears to jitter in position as it passes behind multiple blades.

4. Secondary Surveillance Radar (SSR) reflections:

Secondary surveillance radar energy may be reflected off the structures in both the uplink and downlink directions. This can result in aircraft, which are in a different direction to the way the radar is looking, replying through the reflector and tricking the radar into outputting a false target in the direction where the radar is pointing, or at at the obstruction.

5. Navigation aid signal effects:

Depending on the relative position of a wind farm, it can affect the propagation of the radiated signal from instrument landing systems. As a result, the integrity and performance of these systems can be unacceptably degraded.

REDUCING THE RADAR CROSS SECTION

Stealth blades are under development for wind turbines intended for location in the proximity of radar installations. Cost effective and weight acceptable stealth materials need to be developed for wind turbines rotor blades.

Radar Absorbing Materials (RAM) such as ferrites paint and parasitic claddings, show potential for the reduction of turbine RCS. The predicted reduction of the RCS is in the range of 10-20 $dB.m^2$.

Other than parasitic RAM incorporated into the turbine blades, the composite glass cloth layers can be replaced with version enabling thin composites, with a relatively smaller thickness than the incident wave length of the radar, to absorb most of the incident radar wave energy. Relatively thin composites can be modified to absorb low frequencies or long wave length radar waves efficiently. Such an approach requires no change in the mould design and manufacturing process.

Making the turbine blades from different layers of the right thickness can bounce back signals that neatly cancel out the arriving pings.

Honeycomb style foam can absorb enough of the incoming radar energy to send very little back.

Stealth turbine blades are expected to cost 10-20 percent more than the standard designs.

The nacelle and tower RCS can also be reduced by proper shaping. These structures should never present a flat surface to the radar bore sight. The tower and nacelle RCs can also be reduced by coating them with radar absorbing materials. The structural tower height does not appear to increase the RCS.

Computer modeling of turbine arrays placement in a wind form can offer a guide as to their placement such as their collective RCs is minimized.

Modeling techniques can be used during a wind farm design phase to identify sites and optimize the layout so as to provide minimal radar impact.

Studies can determine whether a wind farm project lies within the line of sight of a radar installation.

A propagation analysis can examine the propagation of the radar signal accounting for the atmospheric conditions and the surrounding terrain to determine the radar range and whether interaction between the turbines and the radar signal would occur.

A simulation of the flight of aircraft over a development site and the number of plots a wind farm produces on a radar operator's screen can be carried out.

HOLOGRAPHIC RADAR DEVELOPMENT

Air traffic control radars are designed to screen out stationary objects, identifying moving objects from the Doppler shift in their reflected signals. However, the resolution of current systems is not fine enough to distinguish between the Doppler shift from an aircraft and one from a moving turbine blade. Since the radar beam scans the horizon, hitting targets for only a few microseconds during every 4 seconds sweep, objects are not sampled for long enough to tell them apart.

The turbines look like twinkling blobs and an aircraft looks just like one of those blobs, so they cannot be distinguished.

Wind farms have only been built where there is no aviation radar nearby. Fourty wind farm projects that would have generated up to 6 gigawatts of power, representing £12 billion of investment in renewable energy have been refused planning permission in the UK for this reason.

A possible answer to the problem is to replace the troublesome scanning process with one that produces a low-power radar beam that illuminates the whole sky above a wind farm 10 times per second, rather than once every 4 seconds. This would produce a three dimensional picture of the airspace hence its designation as "holographic" radar. The increased sampling rate provides the Doppler resolution needed to distinguish between aircraft and wind turbines.

Software supplements the process since turbine blades have a spread of different velocities along them that generate little glints, and a computer can recognize those as very different from an airplane.

DISCUSSION

In order to make such turbines efficient, current 1.5 MW wind turbine towers and rotors are quite large large, with blades exceeding 67 m in diameter, and tower heights exceeding 55 m.

A problem with such large, moving, metallic devices is the potential interference such structures present to an array of civilian air traffic control and air route radars.

Determining and reducing the radar signatures of wind turbines and arrays of them in wind farms is a complicated science. Investigations need to be performed on a case by case basis. New turbines designs need to be developed to reduce the RCS signatures, as well as coatings and special configurations such as polyhedral shapes that would scatter rather than specularly reflect the radar echoes. Meanwhile, some offshore wind projects remain on hold waiting for a solution and improved design options and more information is generated.

REFERENCE

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