Design of a stealth wind turbine

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Abstract— **A hybridization method of Geometrical Optics and Physical Optics (POGO) has been developed to calculate the radar cross section (RCS) of electrically large targets. The GO technique takes high order interactions into account while the PO technique allows to get rid of caustics problems. This hybrid technique is well suited to calculate the field radiated by meteorological radars and backscattered by wind turbines. These radars, having to estimate the clouds speed by calculating the Doppler effects, are very sensitive to moving targets as explained in [1].**

Index terms; Numerical modeling, Physical Optics (PO), Geometrical Optics (GO), ray tracing, Radar Cross Section (RCS).

I. INTRODUCTION

In a first stage, the GO technique is used, launching a grid of rays. These rays transport an electromagnetic field, with a polarization, a phase and an amplitude. When a ray hits a perfect conductor, it generates an electric current $\vec{J}_e$ on it using the PO relation:

$$\vec{\boldsymbol{J}}_e = \hat{\boldsymbol{n}} \times (\vec{\boldsymbol{H}}_i + \vec{\boldsymbol{H}}_r) \qquad (1)$$

Where $\vec{H}_i$ and $\vec{H}_r$ correspond to the incident and reflected magnetic fields. A reflected ray, with a new polarization and a new direction of propagation is determined by the Descartes-Snell's law. This ray may be a part of a new grid and is launched again in order to take the following interaction into account. When all rays have been launched, the scattered far field $\vec{E}_S(R.\hat{e}_r)$ is calculated using the currents generated on the surfaces:

$$\vec{E}_S(R\hat{e}_r) = \frac{j\omega\mu}{4\pi}\frac{e^{-jkR}}{R}\, e^{j\omega t}\hat{e}_r \times \int_S \left(\hat{e}_r \times \vec{J}_e\right) e^{+jk\hat{e}_r.\vec{r}}\, dS \qquad (2)$$

Where $\hat{e}_r$ is the direction of observation, $R.\hat{e}_r$ is the position of the observer, $\vec{r}$ the coordinates of the surface element dS, and k is the wave number. In the numerical implementation, the integral becomes a discrete summation over the surface *S*, meshed with triangles of indices *i* (surfaces dS_i).

The technique has been applied to RCS calculation of a wind turbine at 1 Ghz. The structure has been meshed with triangles. Considering the dimensions, the meshing task takes a significant CPU time. However this task is done only once. Taking moving parts into account does not need to re – mesh the structure. In the results hereafter presented, 120 different positions (aspect angles) have been considered.

In the first section of this paper, reference geometry of a wind turbine is presented. In the second section, a perfect absorbing material is introduced, in order to identify the contributions of the different surfaces to the RCS. In the third section, the geometry is changed in order to reduce the RCS level.

II. REFERENCE CASE

For the reference case; called W0, the turbine tower is a cylinder, 102 m height and 4m diameter. The blades are 42.5m long. The nacelle is about 18m long, as shown in Fig.1. The material is assumed to be a perfect conductor.

In the analysis presented in this paper, the wind turbines (W0, W1, W2 and W3) are illuminated by a plane wave. The electric field is perpendicular to the ground (vertical polarization). The frequency is *f*=1GHz. The angle between the incident wave direction and the blades rotation axis was set arbitrarily to 36°. The angle between the incident wave direction and the tower axis is 90°.

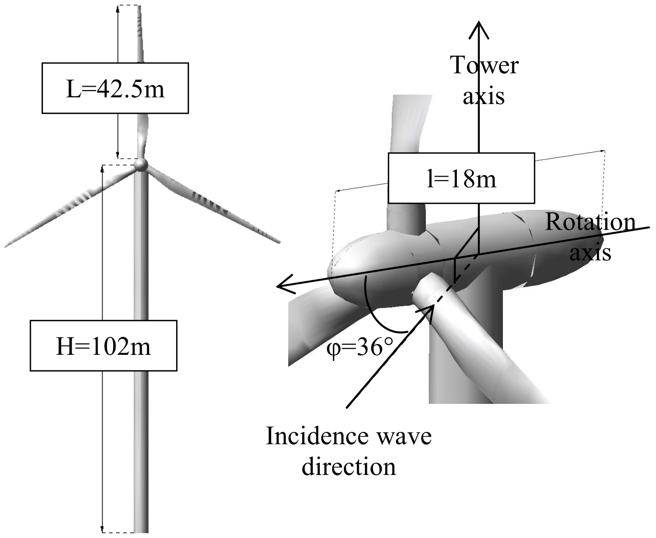

Fig.1 : geometry of the reference wind turbine: W0

The mesh size is λ/5=6cm and the number of triangles is about 1,300,000. The surface currents on the nacelle, on the blades and on the tower are shown on Fig.2 for the first rotor position. The algorithm takes second order interactions into account. This is the case of interactions between blades, between each blade and the nacelle and between the nacelle and the tower.

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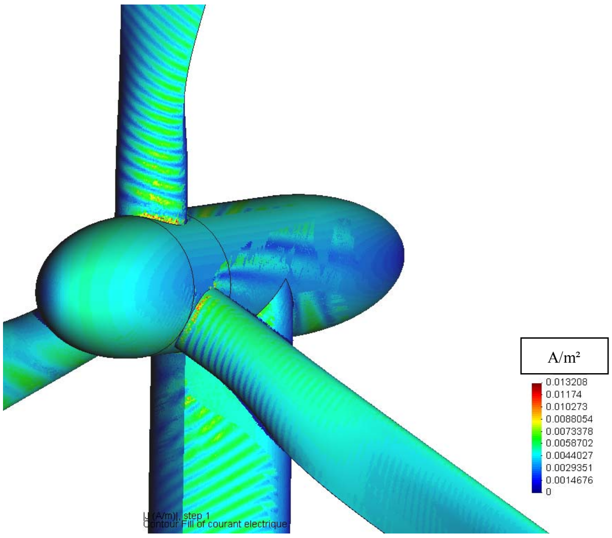

Fig.2: Magnitude of the surface current.

The CPU time for 120 blades positions (120° with a step of 1°) is approximately 186 minutes, using a single processor of 3GHz. Associating a position to an instant, it provides a temporal series which repeats periodically as shown on Fig.3. The RCS obtained is very high. It is almost constant, except when a blade is aligned with the tower.

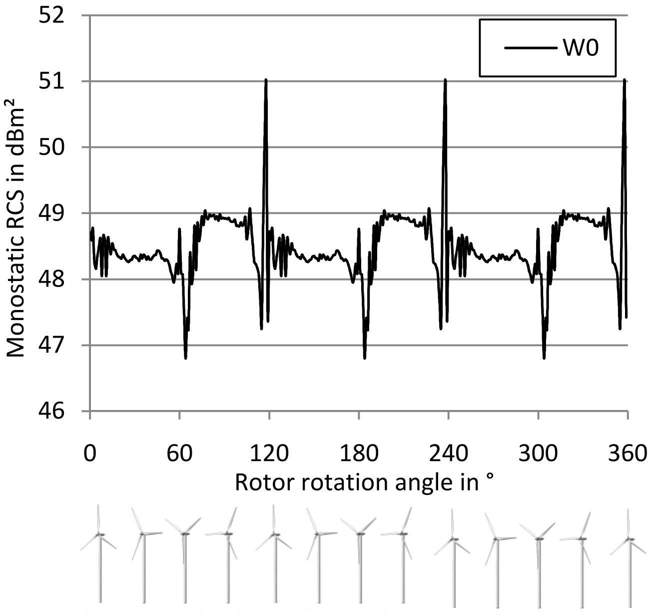

Fig.3: temporal variation of the wind turbine RCS response.

Around 60° the shadow of the blade seems to reduce the tower RCS response while at 120° the blade aligned over the tower may increase its RCS response due to the specular line along the blade.

III. IDENTIFICATION OF THE CONTRIBUTORS

A. Definition of the perfect absorbing material

The perfectly absorbing material considered in this paper is a fictitious material. It is only used to identify the wind turbine contributors to the RCS time response. When a ray hits this material, no current is induced on it and no reflected ray is generated.

B. Contribution of the blade shadow on the tower

To analyze the discontinuity around 60° a perfectly absorbing material has been placed on the tower front face. Fig.4 shows a comparison of this new wind turbine RCS (referenced W1) as compared to the initial wind turbine RCS (referenced W0)

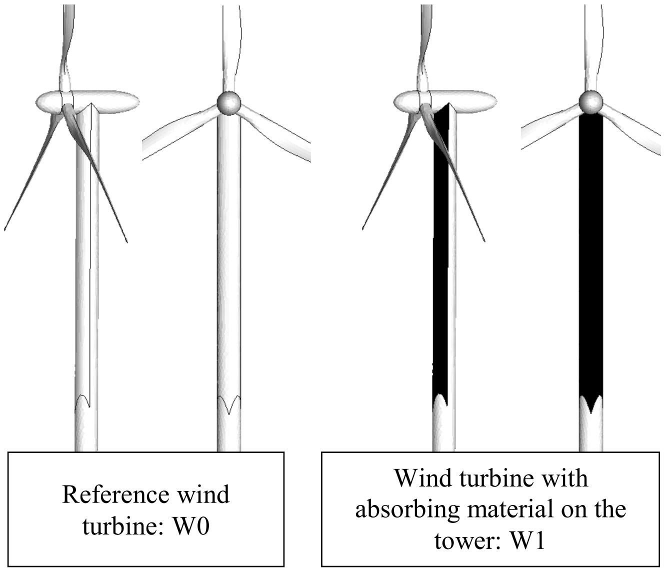

Fig.4 : Comparison between the reference wind turbine and the wind turbine with perfect absorbing material on its tower. The absorbing material is black in color.

The comparison of the RCS response is presented on Fig.5:

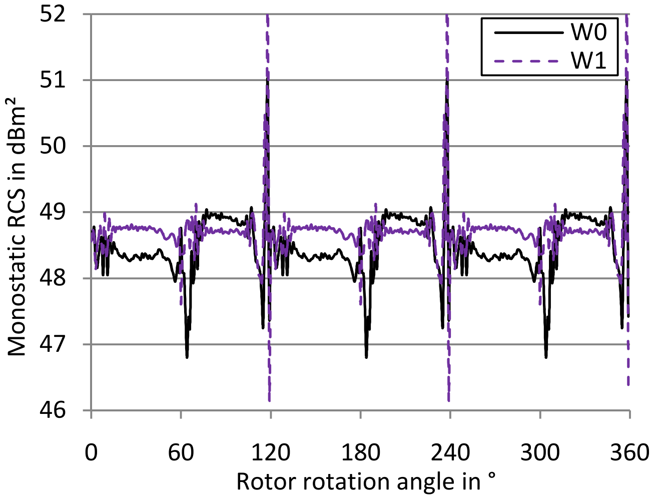

Fig.5: comparison of the RCS response if an absorbing material is applied on the tower.

The RCS level remains in the same range for both cases. The discontinuity in the RCS response is almost removed at around 60° but the peak around 120° is remaining. For

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different aspect angles, the perfectly absorbing material placed on the tower has the effect to flatten the RCS response.

C. Blades Contribution

To remove the peak level at around 120° a perfectly absorbing material has been placed on the rotor and on the blades. Although not a possible solution for aerodynamic reasons, this configuration gives more insight on the RCS contributors. This new wind turbine; W2, is compared with the reference wind turbine; W0, on Fig.6:

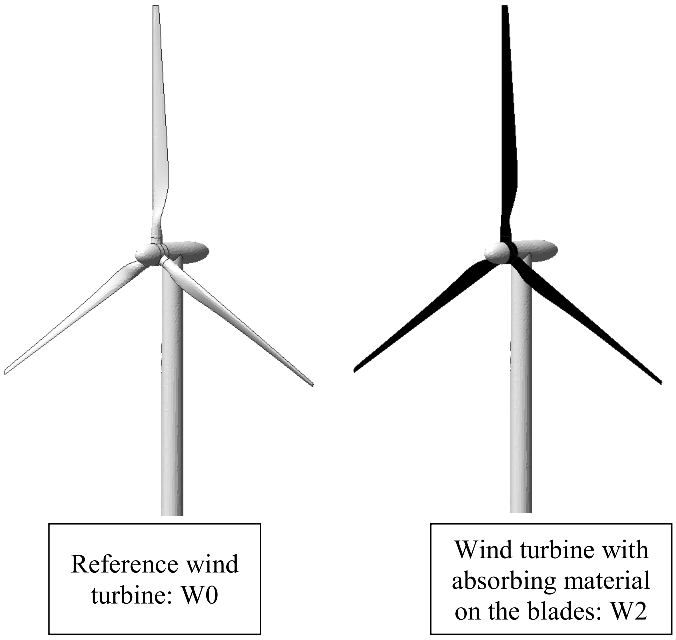

Fig.6: Comparison between the reference wind turbine and the turbine with perfect absorbing material on its blades. The absorbing material is black in color.

The comparison of the RCS responses is presented on Fig.7:

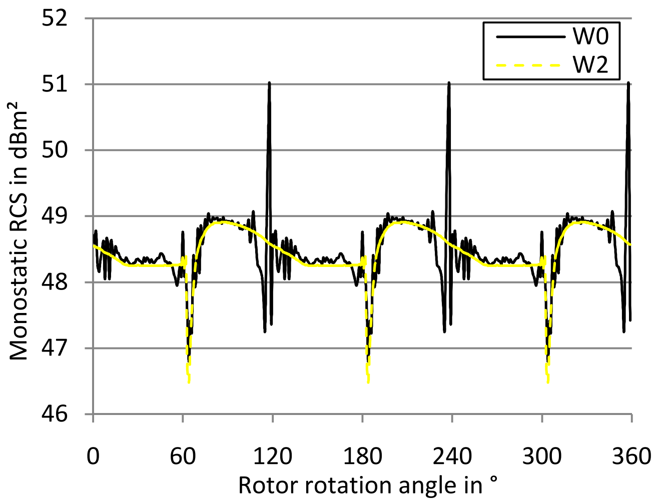

Fig.7: comparison of the RCS response if an absorbing material is applied on the blades.

Once again, the level of the RCS response is almost the same in both cases. The peak response at 120° is removed, while the discontinuity around 60° due to the shadow remains. For different aspect angles, the RCS response is smoother on presence of the perfectly absorbing material.

IV. REDUCTION OF THE RCS LEVEL

The cylindrical tower seems to be responsible of the high RCS level, because of the specular line along its axis. Matthews, J. C. G. et al. suggested in [2] to use a conical tower. The same approach is presented here and a fourth wind turbine model; W3, is presented on Fig.**8**.

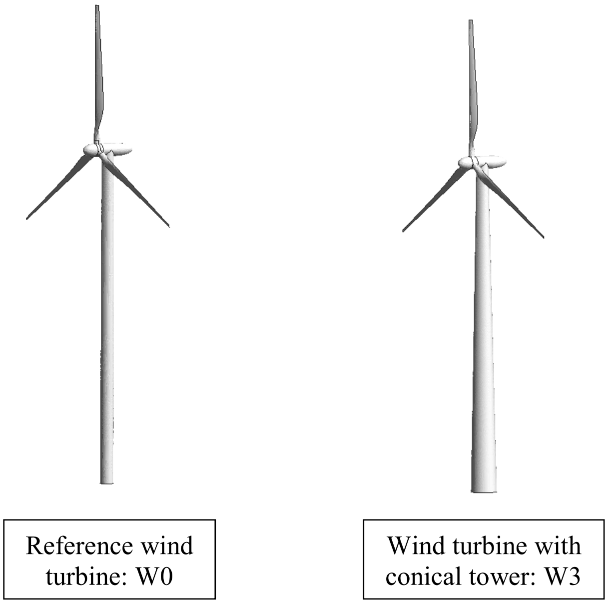

Fig.8: Comparison between the reference wind turbine and the turbine with a conical tower.

The comparison of the RCS response is presented on Fig.9:

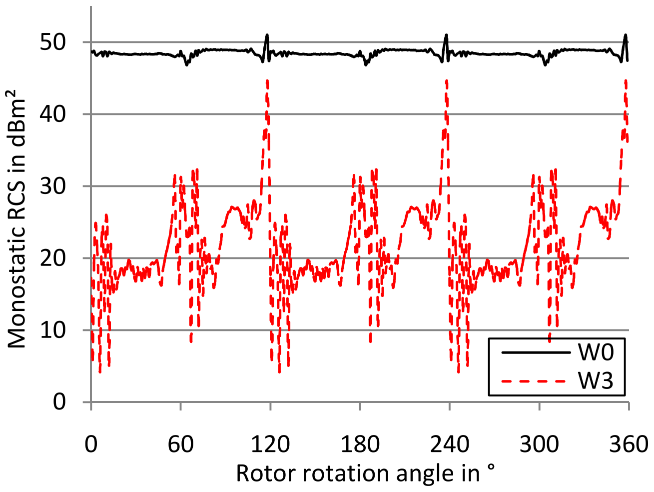

Fig.9: comparison of the RCS response for a conical and cylindrical tower.

The level of the RCS response is, as expected, significantly lower. The gap around 60° becomes a peak, corresponding to the specular line on the blade which was already observed at 120° and which is also still remaining. Changing the tower geometry is also a good way to decrease the wind turbine RCS response. Other modifications on the structure are not presented here, such as the shaping of the nacelle, but they may also decrease the RCS response as shown in [2].

V. CONCLUSION

A numerical method to compute the RCS response of electrically large target has been presented. The calculation technique implemented named POGO was proven to be most efficient and very well suited to this analysis.

A wind turbine geometry was considered as an example. Two kinds of RCS decreasing techniques were analyzed, placing absorbing materials on the main contributors when possible or modifying the tower geometry. This last modification is the most efficient with a RCS decreasing as large as 30 dB. However this shape modification has counterparts on the aerodynamic requirements.

The spectrum of the backscattered field may be also studied as it has already been done for a helicopter rotor in [3]. This may imply to increase the number of blades positions and so the calculation time.

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