Influence of the lightning protection of blades on the field scattered by a windturbine

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***Abstract*—This paper investigates the influence of the lightning protection in windturbine blades for their electromagnetic modelling. Two realistic models of blade with lightning protections are compared with two homogeneous models: metallic and dielectric.**

***Index Terms*—Windturbines, windfarm modelling, VOR, lightning protection.**

I. Introduction

The fast-growing number of windturbines constrains manufacturers to consider every free space as a possible area for windfarm implantation. In particular, plains are appropriate for windturbine erections. However, these plains are also commonly chosen for civil aviation system implantation such as radar and VHF Omnidirectional Range (VOR). These latter are essential for the navigation of airplanes. Regulations exist to contain the windturbine proliferation nearby VOR. Nevertheless, a relaxation of this regulation could be possible with a trustful modelling of the effect of the windturbines on the VOR signal.

To achieve such an investigation, the precise interactions between the windturbines and the VOR signal have to be known. Thus, accurate simulations are required. Considering the large size and the dielectric composition of the blades, the real structure can not be simulated with a reasonable computing time. So, several simplified modellings of the blades have been developed these last years with different approximations.

A common approximation is to consider blades as metallic [1] [2] with their original geometry. Other authors additionally propose a geometrical simplification of the blade, approximating the shape by canonical forms [3] or considering it as plane and rectangular [4]. These modellings are fast to compute but can overestimate the VOR error due to the windturbine.

The present article is based on the dielectric modelling of the blade presented by Morlaas *et al.* [5] where the blade is approximated by its dielectric spar. This model has been geometrically simplified by two parallel homogeneous dielectric and profiled slabs [6]. However, the lightning protections are not accounted.

This paper proposes to investigate the influence of the lightning protection in the windturbine blades in order to refine the previous modelling. Two typical lightning protection technologies [7] have been compared with the two dielectric profiled slabs and the metallic profiled slab modellings. In section II, the geometric considerations and the process for comparing the blade models are presented. The results are exposed and analysed in section III. A short discussion on the relevancy of a Physical Optic solver using this model is performed in section IV. Section V concludes this work.

II. Comparison Process of the Blade Models

In order to determine the influence of the lightning protection in the modelling of windturbine blades, the electromagnetic behaviours of the three blades constituting the rotor have been investigated. The comparisons are realised between four modellings on FEKO simulations using method of moments (MoM). For all the blade models, only the spar is considered. The spherical coordinates are used in this whole paper.

As illustrated in Figure 1, two different technologies of lightning protections are added to this modelling. The first technology (A) consists in a metallic rod (diameter = 1.6 cm) in the middle of the dielectric structure of the blade. The second one (B) consists in a thin metallic slab (width = 3 cm) on the dielectric surface of the blade. Finally these two modellings are compared to the dielectric model proposed by Morlaas *et al.* [6] and to a metallic and profiled slab.

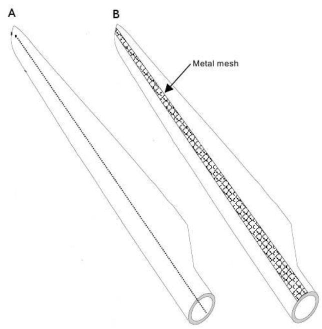


Figure 1: Two technologies for the lightning protection: (A) a metallic rod inside the structure and (B) a metallic slab on the blade [7].

The three blades constituting the rotor of the windturbines do not have the same orientation. So there are some cross-polarisation effects participating to the global scattering of the rotor. For this reason the whole rotor is presented in this here rather than one only blade results.

As the rotor rotates, various positions need to be simulated (Figure 2). The rotor is a periodic structure with three identical blades spaced from $120°$. Moreover the positions $\alpha_{rot} = 0°$ and $\alpha_{rot} = 60°$ are horizontally symmetrical and $\alpha_{rot} = 30°$ and $\alpha_{rot} = 90°$ are vertically symmetrical, as described in Figure 2. Therefore, the study is performed on the 2 positions $\alpha_{rot} = 0°$ and $\alpha_{rot} = 30°$. The incident field is a plane

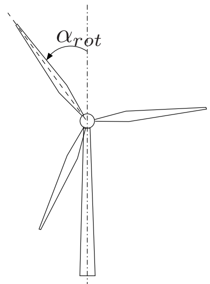


Figure 2: Sketch of the windturbine with a rotor rotation angle of α_{rot}.

wave at VOR frequency. Three directions of incidence are investigated. Nevertheless, for the sake of conciseness, only the results with the directions of incidence $\theta_{inc} = 90°$, $\varphi_{inc} = 45°$ and $\theta_{inc} = 90°$, $\varphi_{inc} = 90°$ (Figure 3) are presented in section III. The other results lead to similar conclusions.

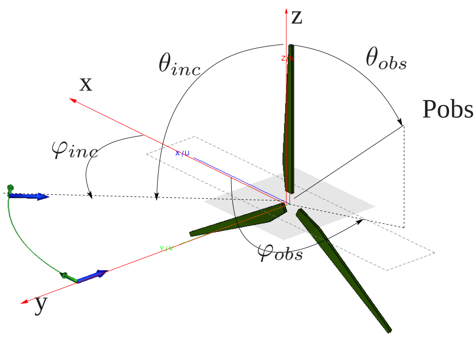


Figure 3: The two incidences investigated on three blades.

As the VOR receiver does not receive the cross-polarised wave, only the co-polarised scattered fields are computed. The fields are observed in the backscattered, reflected and transmitted areas shown in Figure 4 which are the main scattering planes.

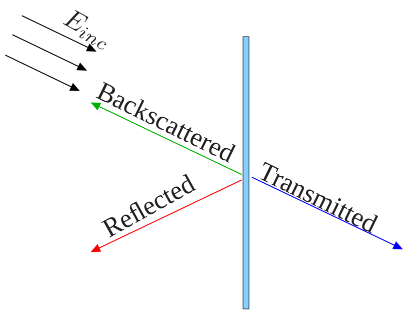
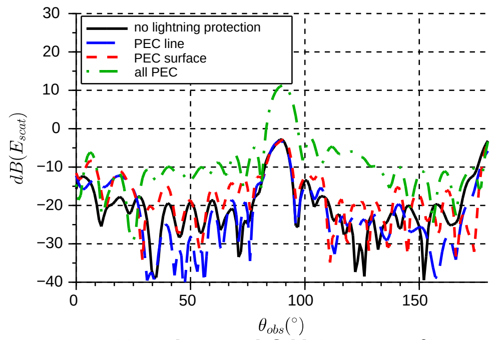


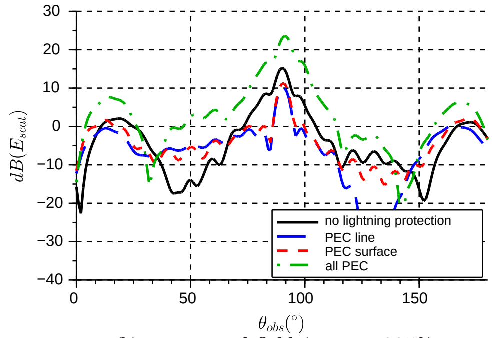
Figure 4: The 3 main directions of the scattering field.

III. Results

The scattered fields are observed for the four blade models. The incident field is a plane wave, horizontally polarised at frequency 114 MHz. As the windturbines are generally far



(a) Backscattered field ($\varphi_{obs} = 45°$).



(b) Transmitted field ($\varphi_{obs} = 225°$).

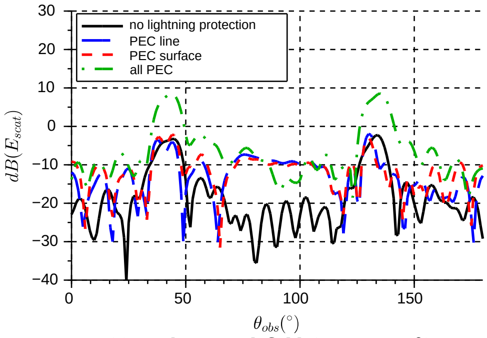
Figure 5: Field scattered (dB) by the rotor with the dielectric modelling alone (black), with PEC rod (blue), with PEC slab (red), and by the metallic modelling (green), with respect to θ_{obs} (°) for a plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 45°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 0°$.

from the VOR emitter, the angle of exposition is close to $\theta_{inc} = 90°$. Thus, the incidence directions are set with this value.

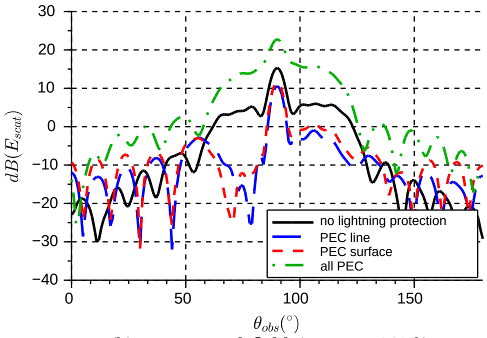
The scattered fields are computed for homogeneous dielectric blades (black), for blades with a metallic rod (dotted blue), with a metallic slab (long dotted red), and for metallic homogeneous blades (mixed green line). The co-polarised scattered fields are plotted in Figures 5 to 8 for the incidences $\varphi_{inc} = 45°$, $\theta_{inc} = 90°$ and $\varphi_{inc} = 90°$, $\theta_{inc} = 90°$, and for $\alpha_{rot} = [0°, 30°]$, with respect to the observation angle θ_{obs} in the backscattered and transmitted planes (Figure 4. As the transmitted and the reflected fields have the same behaviour, only the first one is presented here.

Firstly, the two kinds of lightning protection have a similar behaviour. Indeed, their scattered fields have similar shapes except for low scattering directions with a normal incidence and $\alpha_{rot} = 30°$ (Figure 8).

The dielectric models with and without lightning protection have similar behaviours. The main lobes have the same level for these both modellings. However the influence of the lightning protection is significant for the direction of incidence $\theta_{inc} = 90°$, $\varphi_{inc} = 45°$. The field scattered by the blades, only 5 dB below the main lobe, is underestimated of 10 dB with

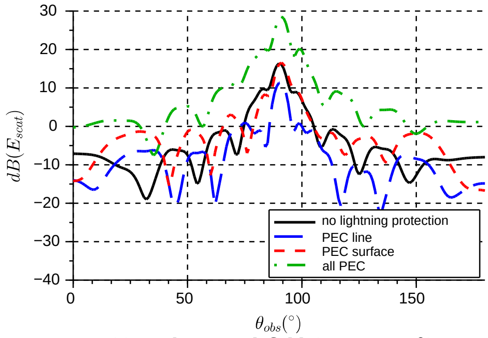


(a) Backscattered field ($\varphi_{obs} = 45°$).

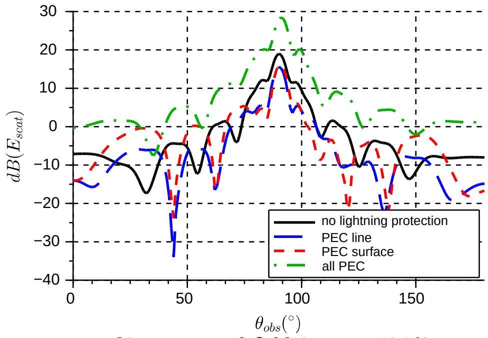


(b) Transmitted field ($\varphi_{obs} = 225°$).

Figure 6: Field scattered (dB) by the rotor with the dielectric modelling alone (black), with PEC rod (blue), with PEC slab (red), and by the metallic modelling (green), with respect to θ_{obs} (°) for a plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 45°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 30°$.



(a) Backscattered field ($\varphi_{obs} = 90°$).



(b) Transmitted field ($\varphi_{obs} = 270°$).

Figure 7: Field scattered (dB) by the rotor with the dielectric modelling alone (black), with PEC rod (blue), with PEC slab (red), and by the metallic modelling (green), with respect to θ_{obs} (°) for a plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 90°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 0°$.

the homogeneous dielectric model. Thus, this model does not describe precisely the behaviour of the blades with lightning protection.

The metallic modelling highly overestimates the scattered field, in particular for the main lobe. This homogeneous model gives values from 10 to 15 dB higher than the model with lightning protection (Figure 5).

To conclude, the lightning protection needs to be taken into account to simulate the windturbine effect on the VOR signal and can not be approximated by an homogeneous model for an accurate simulation.

IV. Relevancy of a PO solver

This dielectric model with lightning protection is projected to be integrated in a simulator using PO method. So, now that the blade model is validated, its relevancy to this method has to be investigated.

PO method is faster than the Method of Moment (MoM) but neglects the interactions between the different objects and the diffraction by the edges. Thus, these approximations are validated through a study highlighting their influence on the field scattered by the rotor. Only the most relevant results are presented here.

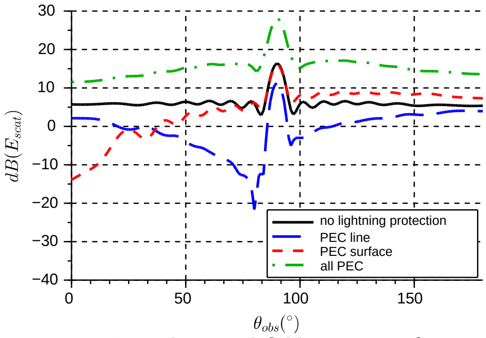
Four different results are compared : the blade model with lightning protection computed by MoM and by PO, the blade model with no lightning protection computed by PO and the metallic blade computed by PO. These scattered fields are plotted in Figure 9 with respect to the observation angle θ_{obs}, in the backscattered ($\varphi_{obs} = 20°$), reflected ($\varphi_{obs} = 160°$) and transmitted ($\varphi_{obs} = 200°$) planes and for an incident plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 20°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 30°$.

Compared to the MoM, the PO method globally overestimates the scattered field (Figures 9). The combination of PO and blade with no lightning protection provides a field lower than the reference (MoM), particularly in high scattering direction (Figures 9 (a) and (b)). The combination of PO and metallic blades is not accurate either considering the underestimation of the main lobe for some incidence (Figures 9 (a)).

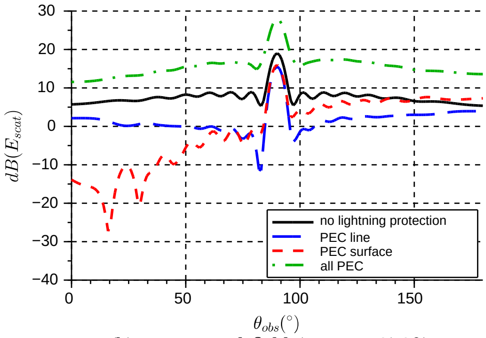
Finally the model developed in the previous section is appropriate to the PO method.

V. Conclusion

In this paper, an investigation on the electromagnetic influence of the lightning protection in the windturbine blades



(a) Backscattered field ($\varphi_{obs} = 90°$).



(b) Transmitted field ($\varphi_{obs} = 270°$).

Figure 8: Field scattered (dB) by the rotor with the dielectric modelling alone (black), with PEC rod (blue), with PEC slab (red), and by the metallic modelling (green), with respect to θ_{obs} (°) for a plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 90°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 30°$.

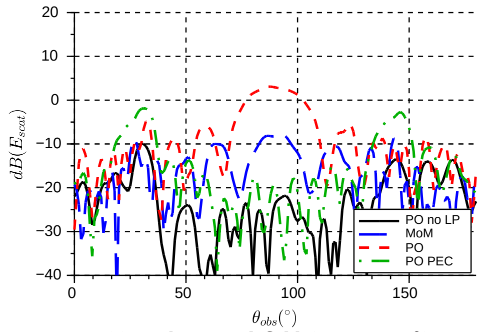
has been performed. Comparisons have been made between four models of blade: homogeneous dielectric, dielectric with metallic rod and metallic slab, and homogeneous metallic. The FEKO MoM has been used to compute the scattered fields.

Considering the different orientations of each blade in a windturbine rotor, the three blades have been simulated for various rotation angles of the rotor. Although the influence of the lightning protection is moderate, the homogeneous dielectric model underestimates some significant scattered fields. The homogeneous metallic model is not accurate either and highly overestimates the scattered field.

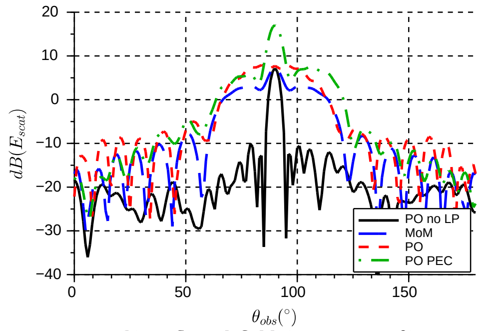
In order to finally use the dielectric model with lightning protection in a PO solver, the interactions between blades have been analysed. The PO method, compared to the MoM, slightly overestimates the scattered field. So the model is validated for a PO solver.

To conclude, the two homogeneous blade models examined in this paper are not appropriate to simulate with precision a blade including a lightning protection. The metallic model can be used for a coarse approximation of the scattered field. The relevancy of the PO methods to compute the field scattered by a windturbine rotor has been demonstrated.

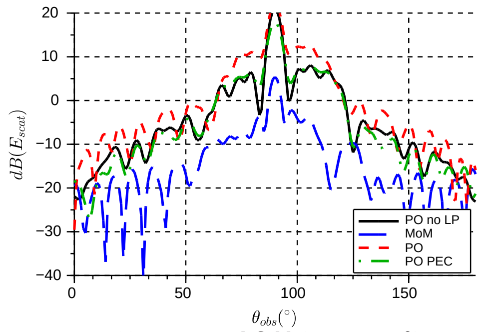
In further work, with this accurate model, the contribution of the rotor blade to the total field scattered by the windturbine could be properly evaluated and integrated to a VOR error simulator.



(a) Backscattered field ($\varphi_{obs} = 20°$).



(b) Reflected field ($\varphi_{obs} = 160°$).



(c) Transmitted field ($\varphi_{obs} = 20°$).

Figure 9: Fields scattered (dB) by the 3 blades with a direction of incidence of $\theta_{inc} = 90°$ and $\varphi_{inc} = 20°$ without lightning protection by PO (black), with a metallic line by MoM (long dotted blue) and by PO (dotted red) , and by metallic blades (green mixed line), with respect to θ_{obs} (°) for a plane wave horizontally polarised and incident along the direction $\varphi_{inc} = 20°$, $\theta_{inc} = 90°$ and with $\alpha_{rot} = 30°$.

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