Performance Comparison between Rigorous and Asymptotic Techniques Applied to the Analysis of Wind Turbines

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Abstract **─** The scattering field analysis of wind turbines using asymptotic and rigorous techniques is presented. Several simulations considering different configurations and frequencies are conducted to compare the performance of the electromagnetic techniques. These predictions are very useful for studying the influence of wind farms in terrestrial radio systems. On the other hand, not only a static analysis has been done but also a study of the scattered fields when the blades are in movement. The Doppler effect due to the blade movement has been taken into account to achieve some simulation results. Modules FASANT and MONURBS of NEWFASANT computer tool have been used. FASANT is based on the geometrical theory of diffraction (GTD) on its uniform theory of diffraction (UTD) formulation and MONURBS is based on the method of moments (MoM) and physical optics (PO). A comparison of the results obtained with both codes is shown, as well as the CPU-time and computer memory required.

Index Terms **─** Electromagnetic propagation, radiofrequency interference, wind energy.

I. INTRODUCTION

Concern about energy and the future exhaustion of fossil fuels have led to the use of renewable energy. As an example, it is expected that wind energy will cover 12% of the global energy demand in the next 12 years. According to the Global Wind Energy Council's most ambitious scenario for wind energy development, wind could produce 2,600 TWh of electricity and save 1.5 billion tons of CO2 in 2020 [1]. However, wind energy also implies problems related to electromagnetic interference.

Wind turbines in deployment nowadays consist of a tower with over 80 meters in height and blades of over 40 meters in length, therefore, they are potentially interfering structures for electromagnetic waves with wavelengths comparable or smaller, as is the case of radio communication services operating in VHF bands or higher. For instance wind turbines could interfere with aerial radio navigation, radar, and TV broadcast systems, [2-5].

Before installing a wind farm, a study of the scattered field by the wind turbines must be carried out to avoid any possible interference with nearby radio systems; the location of the wind turbines have to be chosen in function of this study. There are two alternatives considered in this study. The first one is to create a measurement campaign to compute the scattered field of the windmill over the terrain. This solution is often discarded because it implies a high cost in terms of equipment, time, and personnel. The second alternative consists of carrying out several electromagnetic simulations with appropriate computer tools to analyze the behavior of the wind turbines without wasting too many resources.

In this paper, different kinds of simulations comparing GTD/UTD [6], PO, and MoM approaches have been performed to analyze the electric field scattered by a wind turbine. GTD/UTD and PO are asymptotic techniques used to analyze the scattered fields produced by complex bodies at high frequencies. Their main disadvantage is that they do not work properly at low frequencies but have the advantage of spending fewer resources than rigorous techniques. On the other hand, MoM is a rigorous method that can be applied to any frequency. However, one drawback with MoM is that more computer resources are required when the simulation is performed at high frequencies. A comparison of rigorous and asymptotic approaches is performed to evaluate the efficiency of each one at different frequencies.

This paper is organized as follows: section II presents modules FASANT and MONURBS of NEWFASANT computer tool [7-10]; section III describes the geometrical model of the wind turbine; section IV gives the results obtained; and section V presents the conclusions.

II. DESCRIPTION OF THE COMPUTING TOOLS

FASANT and MONURBS modules have been improved recently with the inclusion of new algorithms, parallelization schemes. Both modules share the graphical user interface of NEWFASANT that makes design and simulation easier. This tool allows creating any geometrical model for analysis. The tool also allows the optimization of geometrical parameters to achieve design specifications.

One important feature the modules share is that the structure analyzed is modeled using parametric surfaces. Thus, an accurate representation of the real shape is meshed and analyzed. NEWFASANT has its own meshing tool that provides different mesh sizes depending on the simulation frequency and module considered. Any surface of the model is divided mainly into curved quadrangles as shown in Figure 1. The meshing tool is parallelized using a cluster of processors to quickly obtain the mesh of a wind turbine in a few seconds.

Different versions of NEWFASANT are available for several operating systems and platforms. FASANT and MONURBS have been successfully tested and applied to the analysis of the radiated and scattered fields of several complex structures such as ships, satellites, on board antennas, electromagnetic compatibility, radar cross sections, microstrip circuits, etc.

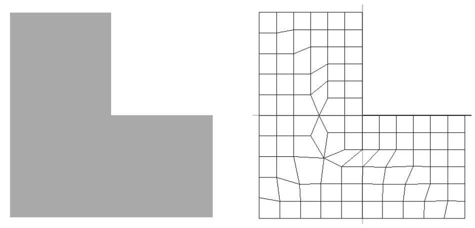

Fig. 1. Mesh of an arbitrary surface.

A. FASANT

FASANT is based on GTD/UTD techniques and ray-tracing methods. A combination of the angular Z-buffer, the volumetric space partitioning, and a new iterative heuristic algorithm is applied for accelerating the ray-tracing technique. The antennas and the environment can be defined by conductors, dielectric materials, periodic structures, or metamaterials.

B. MONURBS

MONURBS is based on MoM and uses the multilevel fast multipole method (MLFMA) [11], the characteristic basis functions method (CBFM) [12], and the message passing interface (MPI) standard [13] to solve large scale structures. PO is also included to reduce the computation time and memory requirements incurred from conventional MoM when analyzing very large structures at high frequencies.

III. WIND TURBINE MODEL

Figure 2 shows an example of a geometrical model of a wind turbine, modeled by 244 parametric surfaces. The size of the model is 120 m high and 64 m between the ends of the blades. This means that the electrical size is 640λ at a 1.6 GHz simulation frequency.

This model can be imported and/or exported to FASANT and MONURBS using CAD formats such as DXF, ACIS SAT, IGES, etc. Both codes are compatible with modern CAD tools. Once the geometry has been imported, it can be analyzed to obtain the scattered field by using the three techniques previously described.

In this study, the source antenna is placed 20 km away from the wind turbine. The source is modeled as a vertical dipole oriented along the z axis with a dipole moment of 1 and elevated 60 m above the reference plane (z=0). The observation points are distributed over a circle with a 5 km radius and elevated 60 m. Figure 3 shows the simulated scenario.

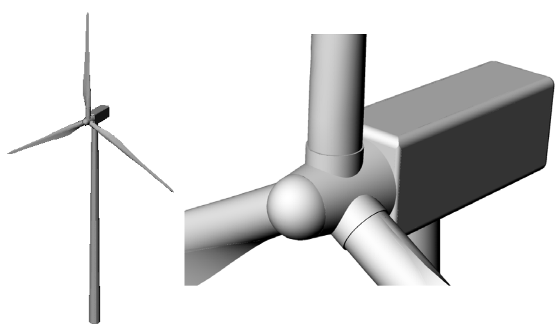

Fig. 2. Geometrical model of the wind turbine.

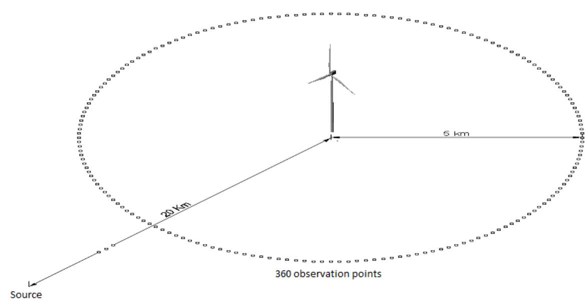

Fig. 3. The wind turbine is located inside the circumference of 360 observation points.

IV. RESULTS

Two different configurations of the wind turbine have been analyzed to study the interference due to its presence on the surrounding radio systems. The first one is related to the static structure (with static blades) and the second one considers the movement of the blades. The Doppler effect has been considered for obtaining realistic results in the second configuration.

A. Study of the wind turbine scattering with static blades

Several simulations were conducted to compare the performance of the different electromagnetic methods at several frequencies. GTD/UTD results were obtained with FASANT, whereas MoM and PO results were obtained with MONURBS.

The scattered field by the wind turbine is computed by taking into account the bistatic and the monostatic analysis at 100 MHz, 200 MHz, 400 MHz, 800 MHz, and 1.6 GHz. Note that only the z component of the electric field (the dominant component in this case) is depicted in Figures 4-8.

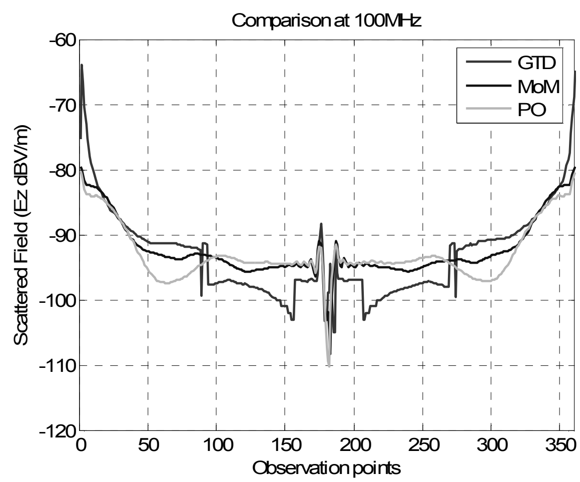

Fig. 4. Comparison of the scattered field at 100 MHz in the bistatic mode.

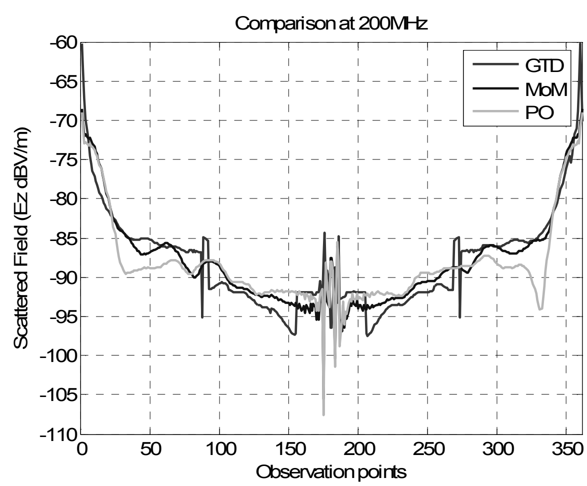

Fig. 5. Comparison of the scattered field at 200 MHz in the bistatic mode.

According to the results, there are significant differences between the asymptotic (PO-GTD/UTD) and rigorous (MoM) solutions at 100 MHz, as can be observed in Figure 4. This occurs because there are parts of the wind turbine that are too electrically small at low frequencies for the asymptotic techniques to provide accurate solutions. When the frequency is higher, the results of the three methods converge to the same solutions, as shown in Figures 5-8.

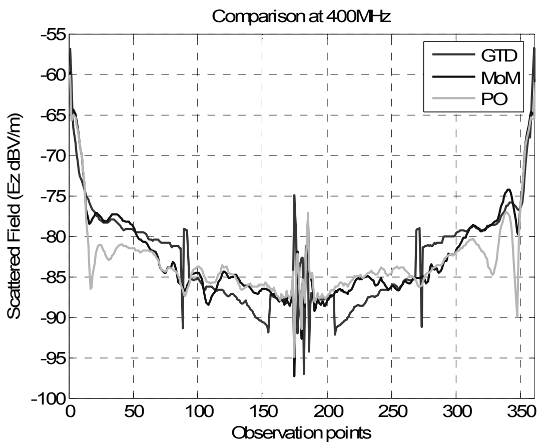

Fig. 6. Comparison of the scattered field at 400 MHz in the bistatic mode.

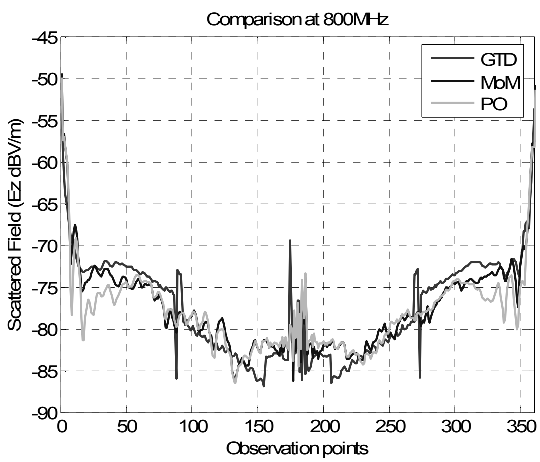

Fig. 7. Comparison of the scattered field at 800 MHz in the bistatic mode.

Regarding the CPU time, the asymptotic techniques take significantly less time than MoM. For instance, FASANT spends 2 hours and 50 minutes to solve the problem for all the frequencies in a single-processor PC. FASANT considers all the frequencies in one simulation because the ray tracing is the same for every frequency. However, MONURBS must calculate the induced currents for each frequency, notably increasing the CPU time. Table 1 shows the CPU time that MONURBS spends using 8 processors to solve the problem from 100 MHz to 800MHz. However, 30 processors have been used to solve the problem at 1.6 GHz. If the PO currents are used, the CPU time for the same computer decreases, as shown in Table 1.

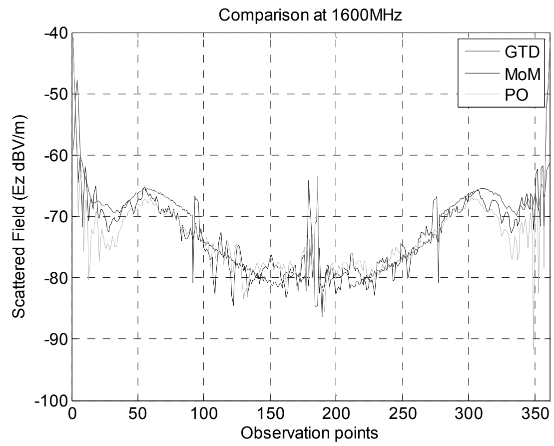

Fig. 8. Comparison of the scattered field at 1600 MHz in the bistatic mode.

Table 1: CPU time comparison for different frequencies

Frequency (MHz)	MoM	PO	Nº processors
100	3min. 36s.	38s.	8
200	6min. 42s.	1min. 15s.	8
400	10min. 35s.	2min. 22s.	8
800	29min. 5s.	7min. 38s.	8
1600	2h. 28min.	11min. 58s.	30

The number of unknowns in the MoM approach increases at high frequencies because the discretization process is performed depending on the frequency. Many MoM computer codes use subdomain basis functions defined over flat faceted meshes of the problem geometry. These codes require a mesh density of 10 divisions per lambda or higher. However, MONURBS uses as basic functions modified rooftop functions defined over curved quadrangles or triangles. Therefore, MONURBS can work with mesh based on curved quadrangular/triangular elements. These meshes fit better to curved surfaces and avoid the truncation errors caused by modeling curved surfaces as a set of flat facets. As a consequence, MONURBS can solve problems involving smooth surfaces with a lower sampling density in the mesh. MONURBS therefore requires fewer unknowns than codes based on flat faceted meshes. The number of unknowns is reduced using MONURBS when the geometry does not present electrically small features. The geometry of the wind turbine can be considered almost uniform because it is composed of smooth surfaces. To ensure this statement is true, a study of the number of divisions per lambda was performed. Figure 9 displays the scattered field at 800 MHz for five different mesh sizes. Table 2 shows the number of unknowns required for each mesh density.

Table 2: Comparison of the number of unknowns at 800MHz for different mesh densities when using MoM technique

Mesh size	MoM unknowns
Lambda/2	41.884
Lambda/3	96,834
Lambda/4	191,947
Lambda/5	265,278
Lambda/6	379,157
Lambda/7	517,782
Lambda/8	674,539
Lambda/10	1,026,132

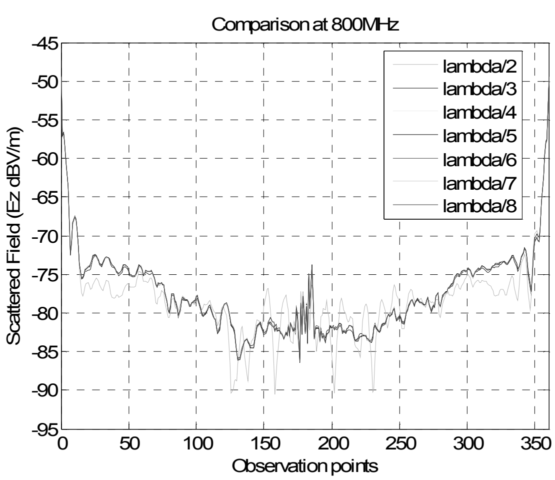

Fig. 9. Comparison of the results for several mesh sizes when using MoM technique.

As shown in Figure 9, only a few slight differences are found when the mesh resolution is increased. Figure 9 shows that the five solutions are similar. The MoM results of Figures 4-8 was obtained with a mesh density of 3 subdomains per lambda.

B. Study of the wind turbine with the blades in movement

One of the main interference problems in the deployment of wind turbine farms in the vicinity of radio communication systems is due to the Doppler frequency spectrum spreading and Doppler frequency shift generated by the rotation of the blades.

The first case we considered in the study of the Doppler effect is a test case defined by the rotating cube of 1 meter side centered at the coordinated axes shown in Figure 10. The y-axis had been chosen as the rotation axis. The transmitting and observation points are static and both located at point (5.0, 0, 0). The angular speed is 1.5 rad/sec. The transmitter emits a pure monochromatic tone of a frequency of 1 GHz. A correlation time of 1 second is considered in the receiver that means that the Doppler spectrum is computed considering spectral windows of 1 Hz width (in other words, for a given frequency f_0 all the fields contributions in a frequency band of 1 Hz centered at f_0 are coherently added).

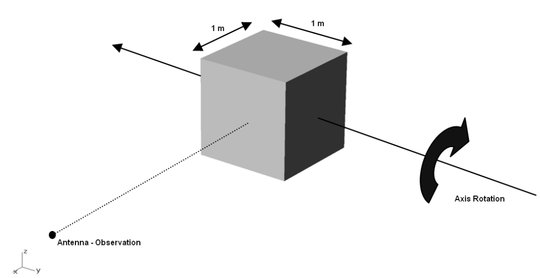

Fig. 10. Rotating cube throw an axis and location of the antenna – observation point.

Figure 11 shows the Doppler spectra for an incident tone of frequency 1 GHz obtained with the GTD/UTD and MoM approaches. The phase delay due to change of the path length due to movement from the transmitter to the scattering (two way path) is considered for each contribution (MoM subdomain current or reflection/diffraction

GTD/UTD point). It can be noticed that the GTD/UTD technique gives an unrealistic discontinuous Doppler spectrum. That is because the GTD formulation computes the fields in terms of a discrete set of ray-path contributions. Each contribution is computed using an asymptotic expression for computing the physical optic integral that does not take into account the phase delay in each point of the surface current due to the movement.

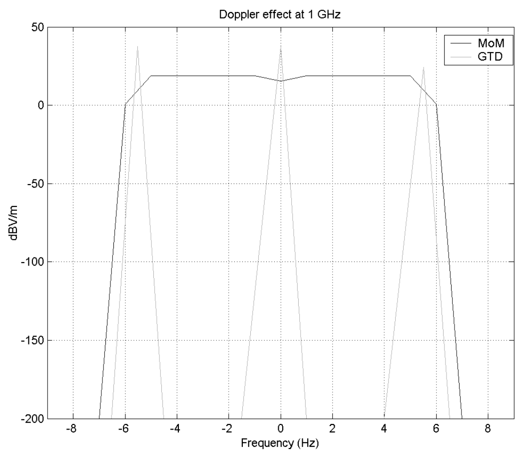

Fig. 11. Doppler spectrum of the scattering field at the observation point for the rotating cube test case comparing MoM and GTD approximation.

An example of analysis of the Doppler effect of the wind turbine test case shown in Figure 12 is presented here. The turbine blades rotate around the axis defined by points (7.27, 0.0, 79.38) and (-21.193, 0.0, 81.87), (the rotating axis is in the y=0 plane). The transmitting and observation points are static in the point (-130, 10, 90) and the angular speed of the blades is 2.0 rad/sec. The transmitter emits a tone of frequency 1.2 GHz.

Figure 13 shows the Doppler effect in the spectra obtained with the MoM and the PO approximation showing good agreements. The GTD/UTD results have been discarded because this approach gives unrealistic results, at least using the expression for the computation of reflection/diffraction coefficients for static cases.

V. CONCLUSION

A preliminary study of the scattered field from a real wind turbine has been presented using GTD/UTD and MoM-PO techniques. It has been demonstrated that the asymptotic techniques do not provide good solutions at lower frequencies. When the frequency is increased, the results converge to a similar solution with GTD/UTD and PO spending less CPU time than the rigorous technique. Additionally, the use of the asymptotic techniques allows higher frequency analysis without requiring higher computational resources. The asymptotic technique also allows the study of more than one wind turbine to analyze the effects of a wind farm. Note that this study would be quite complicated to be performed with rigorous methods due to its limitations when the structure under analysis is too large.

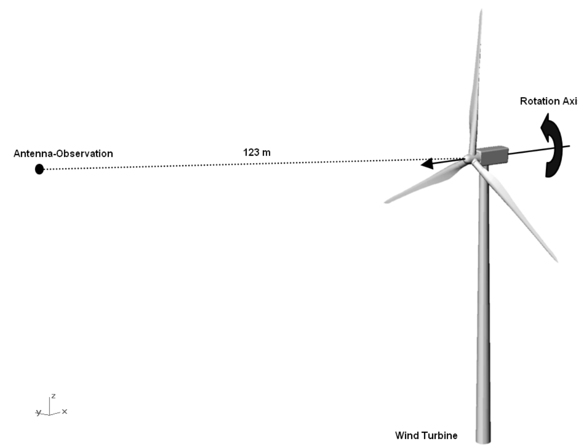

Fig. 12. Rotating blades of the wind turbine and location of the antenna – observation point.

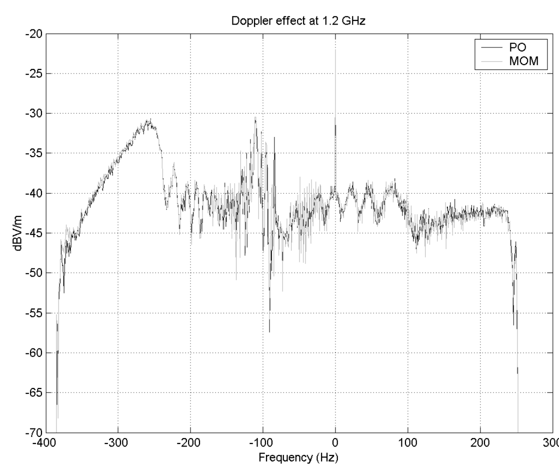

Fig. 13. Doppler effect of the rotating blades of the wind turbine.

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