Software Tool for the Analysis of Potential Impact of Wind Farms on Radiocommunication Services

D. de la Vega, C. Fernández, O. Grande, I. Angulo, D. Guerra, Y. Wu, P. Angueira, J. L. Ordiales

***Abstract*—The prediction of the potential impact of a wind farm on the existing radiocommunication services before its installation allows the planning of alternative solutions to ensure the coexistence of wind energy and telecommunication facilities. Although some guidelines for safeguarding radiocommunication services have been recently published, the precise impact on a specific service can only be determined on a case-by-case basis, due to the multiple factors that must be considered in the analysis. This paper presents a software tool that allows the accurate analysis of the degradation of the different radiocommunication systems. The calculations are based on the configuration of a specific wind farm and the different transmitters and receivers over a terrain database containing high resolution altimetry data. For each type of service, suitable calculation algorithms and interference criteria are applied. Graphic and numerical results of the analysis are presented on a map, which allows an on-the-spot evaluation of the degradation mechanisms for each wind turbine.**

***Index Terms* — Propagation and Coverage, DTV and broadband multimedia systems, Channel modeling and simulation**

I. Introduction

Due to the significant growth in wind energy deployment in the last years, concerns have been raised about the impact of wind farms on radiocommunication systems, in particular on radar systems, fixed radio links and broadcasting services.

The prediction of the potential impact of a wind farm on the existing radiocommunication services before its installation allows the planning of alternative solutions to ensure the coexistence of wind energy and telecommunication facilities. On the contrary, once a wind farm is set up, corrective measurements are usually technically complex and/or cost prohibitive.

A great deal of effort has been devoted by some of the organizations involved in the recent years, and some guidelines for safeguarding radiocommunication services to be applied during the pre-planning process of wind farms have been published. However, further collaborative work between all the involved parts is essential in order to define generally accepted interference criteria and reach agreements about clearance zones to be respected.

Although general agreements are needed in order to establish proper regulations and guidelines, the precise impact on a specific service can only be determined on a case-by-case basis, due to the multiple factors that must be considered in the analysis.

The software tool Wi^2 described in this paper has been developed by the University of the Basque Country (UPV/EHU). It includes several models and algorithms to estimate the potential impact of a certain wind farm on the surrounding telecommunication services taking into account the particularities of the case under study.

The objective of this paper is twofold: firstly, a compilation of the methods for estimating the potential degradation on radiocommunication services due to the proximity of wind turbines is presented. Secondly, the functionalities and the structure of the software tool are described.

II. Impact of Wind Farms on Radiocommunication Systems

An horizontal axis wind turbine is composed of a metallic supporting mast, a nacelle where the fundamental machinery is located and a rotor with three blades made of non-metallic materials (usually composite and fiber-glass).

The metallic mast is the only static part of the turbine. The blades rotate to turn the wind power into electric power, the yaw mechanism turns both the nacelle and rotor according to the wind direction, and the pitch control makes the blades turn along its longitudinal axis to vary the blade area that faces the wind. These three different movements of the turbine cause significant variability with time in the degradation effects.

The degradation mechanisms that may occur in the presence of wind farms are of different nature, and they are related to the structure and working regimes of the turbines:

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- When a wind turbine obstructs the wave front of a transmitted signal, *diffraction effects* cast a shadowed zone behind its structure.
- *Reflected and scattered signals* are generated by the components of the wind turbine, mainly by the metallic mast. These scattering signals may be observed in the receiver location as a time varying multipath channel.
- The reflected signals are Doppler shifted due to the blade rotation. The *Doppler Effect* depends on the rotation angular speed, the blade length and the rotor orientation with respect to the transmitter and receiver locations.

The impact of these effects on the different radiocommunication services depends on several factors, such as the frequency band, the modulation scheme and the discrimination of the radiation pattern of transmitter and receiver aerials.

The radiocommunication services that may be affected by the presence of wind turbines are the following: fixed radio links [1]-[3], broadcasting services (mainly analogue television [4]-[9] and digital television to a lesser extent [1], [10]-[13]), Air Traffic Control Radars [14]-[20], VOR [20], [21], and Weather radars [22]-[24].

A. Potential Interference on Fixed Radio Links

There are two main degradation mechanisms that must be considered when a wind turbine is located in the proximity of a fixed radio link: a potential obstruction of the radio link due to diffraction effects and reflection or scattering from the turbine structure [1], [2]. Other mechanisms such as near field effects are not as relevant as those mentioned above [3].

Diffraction effects occur when the radio path between transmitter and receiver is obstructed by a wind turbine. The Fresnel volume around the transmitter-receiver path is the clearance volume that should be avoided from obstruction. The attenuation due to this obstruction becomes significant for higher frequency links, especially when the wind turbine lies on the vicinity of one of the terminals of the link.

The second criterion is based on reflection and scattering of the incident signal by the components of the wind turbine, especially the metallic mast, generating interfering signals that may reach the receiving antenna of the radio link. Such reflected and scattered signals may combine destructively with the direct path signal to generate fades of significant amplitude.

Apart from the above-mentioned theoretical criteria, field trials carried out in [3] obtained the necessary distance between the link and the turbines not to exceed a specific time percentage of loss in excess of free space. This clearance area, delimited by a fixed lateral separation from the transmitter-receiver path, can be seen as an easy rule of thumb to apply in the wind farm planning that can be accommodated to the specific conditions of the radiocommunication systems and the wind farm layout.

B. Potential Interference on Terrestrial Television Broadcasting

Television signal can be affected by two different mechanisms: the time varying multipath due to signal scattering on wind turbines and shadowing effects.

The wind turbine may cause scattering of the broadcasting signals. The scattering signals are attenuated, time-delayed, and phase shifted replicas of the original signal, which vary with blade rotation and rotor orientation [12], so that a varying multipath channel is observed in the receiver location.

There are several models (Sengupta [4]-[6], BBC Research Department [7], Van Kats [8], Rec. ITU-R BT.805 [9]) to estimate the scattering signals as a function to the relative position of the transmitter, the wind turbine and the receiver and the wind turbine dimensions.

To assess the impairment caused to analogue television reception by the scattering signals, Recommendation ITU-R BT.805 [9] establishes a threshold for the required wanted to unwanted signal ratio as a function of the delay between wanted and unwanted signals. Below this threshold, the viewer will perceive quality degradation of the television signal. The criterion for digital television reception will be published soon in a new ITU-R Recommendation [10], [11].

C. Potential Interference on Radar Systems

The effects of wind turbines on radar services are beam obstruction, clutter returns due to scattering on wind turbines and Doppler Effect generated by the rotating blades [16]-[18], [22]-[24].

Target detection may be degraded when the radar beam is obstructed by one or more wind turbines. This partial obstruction may cause loss of information in a certain volume behind the wind farm if a significant percentage of the transmitted power is blocked.

Clutter refers to undesired echoes reflected back to the radar that come from objects different to the desired target. In this case, clutter is due to power reflected on wind turbines. The portion of energy that is reflected by a wind turbine is represented by its Radar Cross Section (RCS), which depends on its dimensions, materials and shape, mainly. The energy scattered from a wind turbine may be considerably higher than the energy reflected by the target, so that the effective noise floor of the radar receiver will be increased, and therefore, some targets could not be detected by the radar, or even false targets could be generated.

Significant clutter returns can be generated by a wind turbine also for the radar antenna sidelobes. This clutter effect could cause targets to be lost in directions other than that of the wind farm [18]. Therefore, radar antenna sidelobes must be also considered in the study, especially if the wind farm is located close to the radar site and it is in line-of-sight to the radar.

Different interference criteria must be considered depending on the radar use. The radar services usually interfered by wind farms are Air Traffic Control radars and Weather radars. Both are affected by shadowing, clutter returns and Doppler Effect.

In the last years some criteria for assessing part of the degradation mechanisms have been proposed by organizations related to these services [18]-[20], [22].

Last, the combined effects of multiple turbines on shadowing and clutter returns are not known, especially when several turbines lie on aligned within the radar beam. Some authors propose a linear combination of the effects of individual turbines [18], but further research is needed.

III. Description of Wi^2 Software Tool

A. Overall Description

Wi^2 is a powerful software tool that allows the accurate analysis of the potential impact of wind farms on radiocommunication systems.

The calculations are based on the configuration of a specific wind farm and the different transmitters and receivers over a terrain database containing high resolution altimetry data. For each type of service, suitable calculation algorithms and interference criteria are applied.

The simulation tool provides graphic results viewable on Google Earth, displayed as colored areas or volumes according to different criteria (see Fig. 1 to Fig. 5). The user can access to the numerical values and some additional graphs by just clicking on the graphic results of the map (see Fig. 2).

This representation allows to make an on-the-spot evaluation of the degradation mechanisms of each wind turbine, and it constitutes a great help for evaluating the potential impact of a wind farms in a certain area.

Numerical results can also be separately stored for further processing, if needed.

B. Structure of the Software Tool

The Wi^2 software tool is composed of four principal modules: a database containing all the necessary data about the wind farms and the radiocommunication services under study, external altimetry data sets, a graphic user interface, and the main module.

The software tool is designed to easily configure the input data required for the different studies by means of a database which contains:

- Wind farm data: number and layout of wind turbines on the terrain, representative parameters of wind turbines (dimensions, materials and Radar Cross Sections values), blade rotation rates, etc.
- Radiocommunication services data: location of the transmitters and receivers, characteristics of the radiating systems, antenna patterns, transmitting frequencies, sensitivity thresholds and other technical specifications.

As previously mentioned, the calculations are based on altimetry data of the area under study. The software tool is able to deal with different formats of digital terrain maps, reference datum and coordinate systems.

The graphic user interface allows the user to select the type of study to be carried out, and the main module is responsible for executing the appropriate algorithms and applying suitable criteria to determine disturbance limits for each radiocommunication service. Numerical and graphic output files viewable on Google Earth are provided as a result.

C. Types of Study

Preview Study

In order to obtain a first overview of the case under study, the software tool provides a scale representation of the telecommunication infrastructures and the wind farm, correctly geo-located on Google Earth (see Fig. 1).

Fig. 1. Example of a "Preview Study" on Google Earth, showing a television tower and two wind turbines

Moreover, the altimetry of a predefined zone can be obtained as a two dimensional map according to a color scale. The opacity of this altimetry layer can be selected by the user from completely transparent to completely opaque.

Study of Potential Interference on Fixed Radio Links

The algorithm for estimating diffraction effects is based on calculating the potential intersection between the second Fresnel ellipsoid and the volume occupied by wind turbines, taking into account the dimensions of the turbine components and all the possible orientations of the wind turbine rotor. Terrain elevation data are included in the assessment in order to consider the relative position of all the elements involved. The obstruction analysis detects if any of the wind turbine components enters the second Fresnel ellipsoid around the radio path (see Fig. 2). In case of obstruction, the algorithm also estimates the necessary distance between turbine and Fresnel zone to avoid such obstruction.

The algorithm for determining the impact due to reflected or scattered signals provides a clearance area delimited by the threshold C/I ratio necessary for avoiding this type of degradation. The magnitude of the clearance zone depends mainly on both the directivity of the aerials and the required threshold C/I ratio [2]: the threshold C/I ratio for each frequency band and modulation scheme determines the maximum interference level; the discrimination of the radiation pattern of transmitter and receiver aerials may considerably reduce the impact, and they must be considered in the assessment.

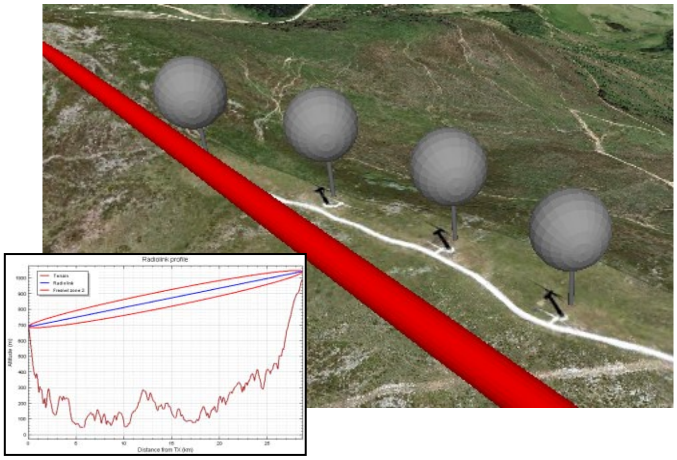

Fig. 2. 3-D representation of the Fresnel ellipsoid of a fixed radio link and wind turbines considering all possible rotor orientations. Additional graph containing the radio link profile is also shown.

Study of Terrestrial Television Broadcasting

The simulation tool calculates the amplitude of the signals scattered by each turbine according to the above-mentioned theoretical models [4]-[9] for all the possible reception locations in the coverage area, taking into account the radiation patterns of the transmitting and receiving antennas. A comparative analysis of the above-mentioned prediction methods with results from field trials showed that none of the models provides results accurate enough to estimate the multipath generated by a wind farm on the UHF band [13]. For this reason, an empirical model developed by the authors has also been implemented in the Wi^2 software tool.

The results are given as Carrier to Interference ratios (C/I) for each wind turbine, i.e., the ratio between the direct signal from the transmitter and the signal scattered by a certain wind turbine at each reception location, expressed in dB. The tool Wi^2 provides graphic results on a map containing both C/I ratios for each receiver location and areas where impairment is expected when the criterion of Rec. ITU-R BT.805 is applied (see Fig. 3).

This kind of study can also be performed for a certain group of reception locations, in order to evaluate their particular conditions. This may be useful in order to evaluate potential degradation on a certain repeater or gap-filler located in the coverage area of the main transmitter.

Study of Radar Systems

Three types of impact on radar services are estimated in Wi^2: beam obstruction, clutter returns and Doppler Effect. Although some basic calculations are common, the interference criteria depend on the radar use (Air Traffic Control radar [18]-[20] or Weather radar [22], [23]).

In order to evaluate possible beam obstructions, the software tool calculates and represents on a map the volume where the radar beam is obstructed by each wind turbine, and therefore, the volume where the detection capability might be reduced [18], [19], [22] (see Fig. 4).

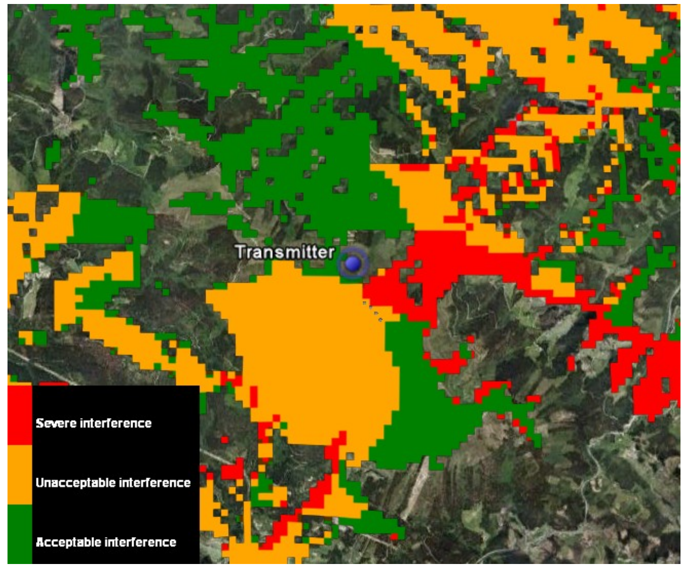

Fig. 3. Example of Wi^2 result for potential degradation on analogue TV.

The impact due to clutter returns is estimated by calculating the reflectivity values that each turbine generates on the radar receiver. The effects on the detection capability are evaluated as a function of the interference level with respect to the noise floor of the radar [18], [22].

The third aspect estimated by Wi^2 is the Doppler Effect. The software tool calculates which parts of the wind turbines intersect the radar beam (tower and/or nacelle and rotor) for each elevation angle of the radar beam (see Fig. 5). Only the blades can degrade the Doppler detection of a radar, and therefore, only the blades that enter the radar beam at a specific beam elevation angle are considered in the analysis.

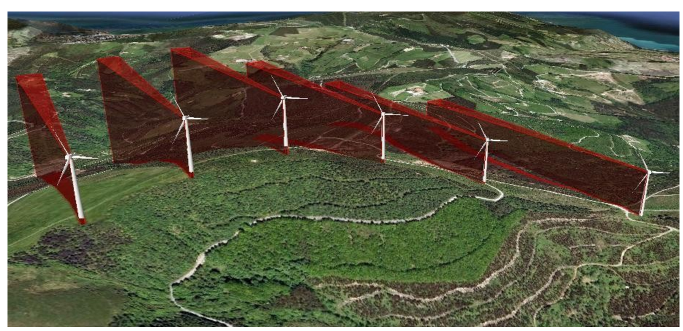

Fig. 4. Example of Wi^2 result for shadowing on target detection: volume where the radar beam is obstructed by each wind turbine.

IV. Conclusions

The software tool Wi^2 for the analysis of the potential impact of a certain wind farm on the surrounding telecommunication services is presented in this paper.

The software includes several models and algorithms to estimate the potential degradation on several services: fixed radio links, television broadcasting, Air Traffic Control radars and Weather radars. The calculations are based on altimetry data of the area under study, and the software is able to deal with different formats of digital terrain maps, reference datum and coordinate systems. The software manages a database containing all the necessary data about the wind farms and the radiocommunication services under study. The graphic user interface is designed to easily select the input data required for the different studies.

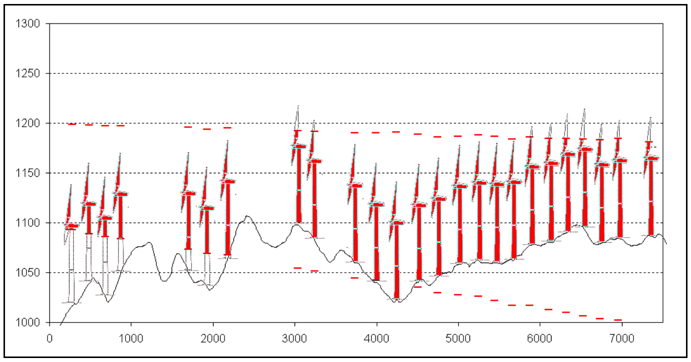

Fig. 5. Example of Wi^2 result for determining the parts of each wind turbine that intersect the radar beam.

The impact on fixed radio links is estimated by calculating diffraction effects and reflection or scattering from the turbine structure. A clearance area based on empirical trials is also assessed.

The multipath generated by the scattering signals from each wind turbine is calculated to evaluate the potential degradation of television broadcasting. Several scattering models are implemented and the interference criteria recommended by ITU-R for television services can be applied.

Radar services are analyzed by estimating both the shadowed volume due to the radar beam obstruction and the impact of clutter returns in the noise floor of the radar receiver. The tool also calculates if the blades intersect the radar beam in order to evaluate the Doppler Effect.

Results such as clearance areas, C/I ratios, interfered areas or shadow volumes are presented on a map. Numerical values and additional graphs are available just clicking on the map. This representation allows the evaluation of the degradation by each wind turbine, and it constitutes a great help for evaluating the potential impact of a wind farm in a certain area.

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