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New algorithms for estimating the impact of wind turbines on telecommunication services

I. Cascón[1], J. Cañizo[1], I. Angulo[1], D. de la Vega[1], D. Guerra[1], Y. Wu[2], A. Arrinda[1], I. Fernández[1], P. Angueira[1]

[1] Department of Communications Engineering. ETSI Bilbao, University of the Basque Country (UPV/EHU)
Alda. Urquijo s/n, 48013 Bilbao (Spain)
Phone/Fax number: +34 946 014127, e-mail: **david.delavega@ehu.es**

[2] Communications Research Centre,
3701 Carling Avenue, Ottawa, Canada
e-mail: **yiyan.wu@crc.ca**

Abstract. The estimation of the potential impact of a wind farm on the existing telecommunication services allows the modification of the wind farm layout or the planning of alternative solutions to guarantee the installation of a new wind farm without disturbing the surrounding services. This paper describes the development of new algorithms for the evaluation of the effect of a wind farm on telecommunication services (Air Traffic Control radars, Weather radars, radio links and radio navigation aids), and presents representative examples of impact studies. The novelty of these algorithms is that they estimate the safeguarding areas that should be avoided in the wind farm deployment, and therefore, they can be applied without a previous definition of the wind turbine locations. Therefore, results consist on the set of locations where a wind turbine might interfere in a specific service. These results are represented as visual masks on the terrain, easy to be used on GIS systems or Google Earth, and they are easy to combine with other constraints or datasets used in the wind farm design process (wind data, terrain slope, environmental protected areas, etc.). These algorithms will contribute to simplify and reduce the time required in the wind farm design process.

Key words
Wind farms, telecommunication services, impact studies, radar systems, radio navigation systems.

1. Introduction

In the recent years some cases of degradation on certain telecommunication systems have arisen due to the presence of wind farms. The telecommunication services that have demonstrated to be more sensitive to nearby wind turbines are Air Traffic Control radars [1]-[7], Weather radars [8]-[14], maritime radars [15]-[16], aeronautical navigation aid systems [6],[17]-[18], fixed radio links [19]-[20] and terrestrial television [21]-[29]. Corrective measurements are usually expensive and technically complex. For this reason, the development of impact studies before a wind farm is installed allows the modification of the wind farm design (selection of wind turbine model and locations), in order to avoid or minimize the impact on the telecommunication services in the surrounding area [30].

Some guidelines for safeguarding the radiocommunication services have been recently published [6]-[8],[11],[27],[28]. Nevertheless, 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, such as the terrain shadowing, the particular technical specifications of each service, or the combined effect of the turbines that compose the wind farm layout. An accurate assessment of the potential impact of a specific wind farm before its deployment will allow the planning of alternative solutions to ensure the coexistence of wind energy and telecommunication facilities.

For this purpose, a software tool for the analysis of the potential impact of wind farms on radiocommunication services was developed in the University of the Basque Country (UPV/EHU) [30]. This software tool allows the accurate analysis of the degradation of the different radiocommunication systems, according to the guidelines and interference criteria proposed by the regulatory organizations. The calculations are based on the configuration of a specific wind farm (dimensions and locations of the turbines), the requirements of the telecommunication services (transmitter location, coverage area and service requirements), and a terrain database containing high resolution altimetry data. Specific calculation algorithms and interference criteria are applied for each type of service, and numerical results of the analysis are presented on a map, which allows an on-the-spot evaluation of the potential impact.

New algorithms have been developed for the estimation of the potential impact of a wind farm. The purpose of these new algorithms is the assessment of the locations where a wind turbine, if it is installed, may degrade a specific telecommunication service. That is, the objective is but the estimation of the areas that should be avoided in the wind farm deployment, for a specific interference criterion related to a telecommunication service.

2. Impact of wind turbines on radiocommunication systems

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

- 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.

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 [19],[20].

Diffraction effects occur when the radio path between transmitter and receiver is obstructed by a wind turbine. 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.

B. Potential Interference on Terrestrial Television Broadcasting

The main effect on the television signal is that wind turbines may cause scattering of the broadcasting signals. In the receiver location, the scattering signals are attenuated, time delayed, and phase shifted replicas of the original signal, which vary with blade rotation and rotor orientation [25], so that a varying multipath channel is observed. The impact on the signal quality depends on the television standard characteristics [26].

C. Potential Interference on Radar Systems

The effects that wind turbines may cause on radar services are of different nature: beam obstruction, clutter returns due to scattering on wind turbines and Doppler effect generated by the rotating blades [3]-[13].

The obstruction of the radar beam may cause loss of information in a certain volume behind the wind farm, and therefore, the target detection may be degraded. Clutter refers to undesired echoes reflected back to the radar from objects different to the desired target. In this case, clutter is due to power reflected on wind turbines, which may be considerably higher than the energy reflected by the target. Consequently, 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. Last, Doppler Effect may severely degrade the detection capacity of Doppler radars.

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.

B. Potential Interference on Radio Navigation Aids

VOR (VHF omnidirectional radio) system is a radio navigation system that enables aircrafts to stay on course in approach procedures and on route navigation. ILS (Instrument Landing System) system guides aircrafts to a specific airport runway during landing procedure.

The International Civil Aviation Organization (ICAO) defines safeguarded distances named as Building Restricted Areas (BRAs) [6].These protected BRAs are also applicable to the deployment of wind farms. In case of a wind farm infringing these limits, potential issues concerning wind turbines should be dealt with on a case by case basis.

3. Guidelines for estimating the impact of wind turbines

There are several guidelines or handbooks about this issue. However, there is no general agreement by all the involved parties, and in most cases there is no international statement to be applied. Moreover, these proposals are usually promoted by the affected operators, and therefore, they may be too conservatives at times.

This context leads to the necessity of carrying out further studies on this topic, in order to achieve a better characterization of the phenomena, specially aided by real measurements, and obtain harmonized protection criteria. This need is expressed by the main regulation organizations that address telecommunication issues or services depending on telecommunication services. It is the case of the International Telecommunications Union, which has published recommendations regarding the impact on television services [27],[28] and on weather radar services [8]; aviation regulation organizations such as the International Civil Aviation Organization [6] or Eurocontrol [7]; and meteorological services providers such as the World Meteorological Organization [8], Eumetnet [11] and several national governmental agencies [18],[31].

4. Description of the new algorithms for estimating the impact of wind turbines

A. Objectives and scope

The main objective of the algorithms presented in this paper is to provide simplified results of the impact studies in order that these results may be directly usable and understandable by a non-expert user, such as wind farm promoters or personnel of the involved regulatory administrations.

With this purpose, results are shown as constraint masks, viewable on Google Earth, representing the areas that should be avoided in the analysis of the wind farm layout, in order to prevent a degradation of the surrounding telecommunication services. Hence, the software tool provides a safeguarding area for each analyzed service. This analysis may be applied within the wind farm design process, before the turbines micro-siting study is carried out. These algorithms are a valuable help in order to obtain the definite wind farm layout, which will be the optimal solution in energy production without causing interference in the telecommunication services.

The algorithms presented in this paper will be integrated in a new version of the Wi^2 software tool, and also in the SOPCAWIND GIS tool.Wi^2 is a stand-alone software tool specifically developed for the impact analysis of wind farms on radiocommunication services [30]. SOPCAWIND is a project for developing a multidisciplinary data pool and a GIS tool for wind farms deployment [32]. The SOPCAWIND GIS tool will include functionalities for optimizing the energy production of the wind farm, and also for developing impact studies related to different issues, such as impact on environment, telecommunication services, heritage, transport networks and near settlements, and flicker and noise studies of a specific wind farm.

B. Methodology

The procedure starts with the definition of a candidate area selected by the user for the wind farm deployment. The wind turbine model should be also selected, because the turbine dimensions are used in the impact studies.

The algorithm divides the area under analysis into a grid composed of small cells. Then, an iterative process is carried out consisting on locating the wind turbine model selected by the user at each cell of the grid, and developing the impact study on a specific service. For each cell, the potential interference or obstruction is evaluated in order to decide if such location is susceptible of generating a severe degradation on the service, in case a wind turbine is installed. As a result, a mask containing all the cells where a wind turbine might degrade a specific telecommunication service is generated. That is, the results consist of a categorization of the candidate area, differentiating the areas that should be avoided for the deployment of the wind farm.

In the impact study developed at each cell of the candidate area, the turbine dimensions, the technical specifications of the telecommunication service and the terrain altimetry data are considered. The evaluation of the impact level of a wind turbine is based on the technical requirements of the telecommunication service for a proper quality, and also on the limits or safeguarding threshold values proposed by the regulatory bodies.

D. Results

The results provided by the algorithms consist on constraint masks represented on the terrain of the candidate area, showing the specific locations where a wind turbine may degrade or interfere a specific service. These constraint masks, or safeguarding areas, are very useful in the micro-siting design process, either to select the specific locations of each turbine or to verify if a particular layout might cause some impact on any of the surrounding telecommunication services. An example of the constraint mask provided by the algorithms and the potential use of the results is shown in Figure 1.

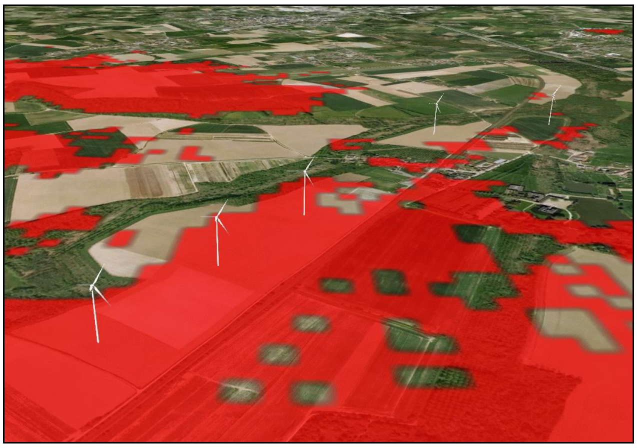

Fig. 1. Constraint mask provided by the algorithms. Area in red is composed by the set of locations where a turbine would degrade the telecommunication service under analysis. Turbines located out of this safeguarding area will not cause degradation.

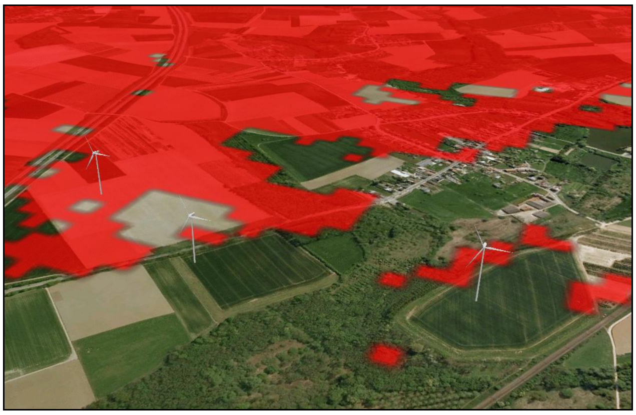

Fig. 2. Constraint mask may be easily combined with other protection criteria, such as buffer distances to transport networks or nearest buildings.

The constraint masks are easy to combine with other constraint masks (such as environment protected areas, nesting areas and buffer distances to settlements or transport networks), or other datasets used in the wind farm design process (such as wind data, terrain slope or topographic features), as it is shown in Fig.1 and Fig. 2. Results are easy to understand by a user without expertise in telecommunications, such as experts in wind resources, wind farm developers or personnel of the regulatory administrations involved in the authorization procedure.

The figures below show some examples of the results provided by these algorithms, applied to different telecommunication services. Hence, Figure 3 shows the safeguarding area for a specific radio link that is to be avoided in the definition of a real wind farm layout; Figure 4 illustrates the safeguarding area that is to be considered to avoid potential interferences on a real VOR radio navigation system close to an airport; and Figure 5 includes in red color all the locations where a wind turbine might degrade the proper operation of an Air Traffic Control radar. The different shape an extension of the constraint masks depend on the type of the telecommunication service, the terrain irregularity and the turbine dimensions.

Fig. 3. Aerial view that shows the results of an impact study on a fixed radio link, where Site I is one of the ends of the radio link. Area in red is the set of locations where a turbine would obstruct the link.

Fig. 4. Aerial views that show the results of an impact study on a radio navigation aid (VOR system). Area in red is the set of locations where a turbine would interfere in the restricted volume for the proper working of the system.

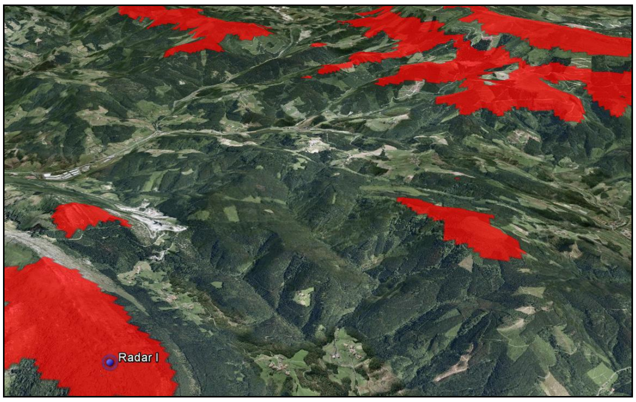

Fig. 5. Aerial view that shows the results of an impact study on an Air Traffic Control radar. Area in red is the set of locations where a turbine would degrade the detection capacity of the radar. The terrain irregularities of this hilly area have a great influence in this specific case.

5. Conclusions

A new set of algorithms for evaluating the effect of a wind farm on surrounding telecommunication services is presented in this paper. The novelty of these algorithms is that they estimate the safeguarding areas that should be avoided by this reason in the wind farm deployment. The algorithms take into account the terrain, the particularities of each telecommunication service and the turbine dimensions, and they can be applied without the previous definition of the wind turbine final locations. The algorithms provide visual constraint masks on the terrain that show the areas where a wind turbine might interfere a specific telecommunication service (Air Traffic Control radars, Weather radars, radio links and radio navigation aids). These masks are easy to combine with other constraints or datasets used in the wind farm design process (wind data, terrain slope, environmental protected areas, etc.). The results contribute to reduce the time required in the wind farm design process, mainly in the turbine micro-siting.

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