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Numerical modeling of wind flow over different terrain types*

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Abstract
Worldwide, the amount of energy produced by the power of wind rapidly increases. The installed capacity of wind farms has increased nearly 60 times for the last 20 years. The small wind turbines that have been installed 20 years ago are at the end of their operational life. Pretty soon they need to be replaced with bigger ones, which leads to a completely new micro-sitting of the wind farm. In case of a flat terrain the micro-sitting can be easily performed since the wind parameters (wind speed and direction) are known for a long period of time. For a hilly or complex terrains a couple of assumption needs to be made in order to have the most reliable results. Improvement of the results from numerical study is possible with the adjustment of the uncertainty of the used models. Some restrictions about the size of the domain where the numerical procedures will take place are also discussed.

Keywords: Wind flow, CFD modeling, complex terrains

1. Introduction

Global annual installed capacity of the wind power plants has increased 60 times for the past 20 years (from about 6GW in 1996 up to 370GW in 2014) and only in 2014 the installed capacities amounted to 51 GW [1]. Currently, the biggest wind turbine installed has a rated power of 8MW (2014). At least five companies are working on the development of a 10MW wind turbines. This is a proof that the share of this type of energy in the energy mix will increase in the future.

On the other hand the wind turbines installed 20 years ago are very “close” to their operational life, and recently they will need to be replaced. The modern wind turbines have greater installed capacity and respectively larger size so for the same spot fewer wind turbines can be installed with different micro-sitting scheme. The micros-sitting of the wind turbines (WTs) depends on many factors – size of the WTs, prevailing wind direction, local orography etc. Collected wind data during operational hours of the WTs are long-term data, and they are useful for arrangement of the new wind farm. The impact, however, between WT in the farm cannot be defined or measured on-site due to the large size of WTs. Different commercial products are used to model the wind flow behavior over the terrain. When the spot where the wind

*Lucrare inclusa in programul conferintei EENVIRO 2015 turbines will be installed is flat, and there are no any significant obstacles around, a good approximation of the wind flow over the terrain can be established. For hilly and complex terrains generated turbulent boundary layer significantly affect the general wind flow. The generated uncertainties affecting significantly the wind flow behavior. In addition the interaction of this flow with one disturbed by the blades of wind turbine resulting in a much complicated flow that cannot be easily and precisely studied with part of this commercial products. This requires implementation of experimental studies especially for large wind farms and very complex terrains. The limitations in experimental studies are because of the size of wind tunnel and size of the model tested.

Current study is about the possibilities of using commercial software products using numerical procedure technique to predict flow behavior over the terrains.

2. On-site measurements

Three different types of terrains are addressed to the current study – homogeneous and flat terrain (Shabla); hilly terrain (Ruen) and complex topography (Karlovo) (fig. 1).

Fig. 1 Terrains location on the territory of Bulgaria

On the selected sites are performed long-term measurements with tall towers. The summarized information about tall towers, measuring equipment and measuring periods is presented in Table 1.

Table 1. Summarized information about on-site measurements for the selected sites

Location	Type of tall tower	Height, m	Measuring period	Measuring equipment, calibrated
Shabla	Tubular	60	04.12.2008-30.12.2011	Anemometers on three heights – 30, 40 and 50m, wind vanes, temp. sensor, barometer, humidity sensor
Ruen	Lattice	70	05.10.2012-01.10.2014	Anemometers on three heights – 30, 50 and 70m, wind vanes, temp. sensor, barometer, humidity sensor
Karlovo	tubular	50	05.01.2009-30.11.2011	Anemometers on two heights – 30 and 50m, wind vanes, temperature sensor

The obtained data during on-site measurements have been carefully examined, as unreliable data have been excluded from the prepared statistical analysis. Below on Fig. 2 and 3 the directional and Weibull distributions for the selected sites are presented.

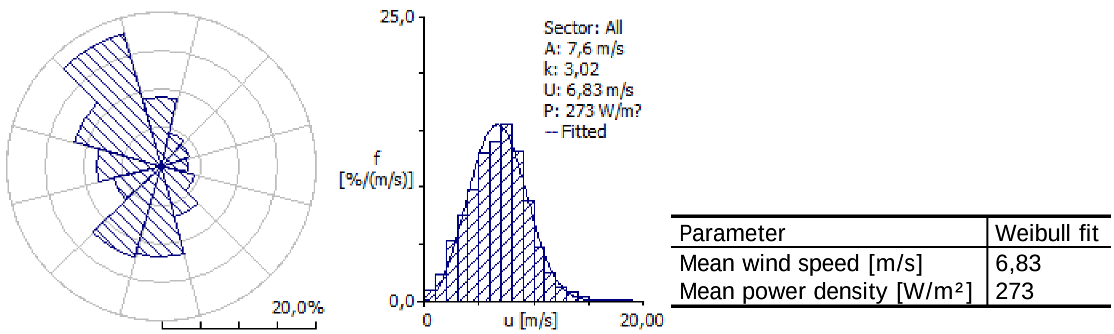


Fig. 2 Directional and Weibull distribution for Shabla site

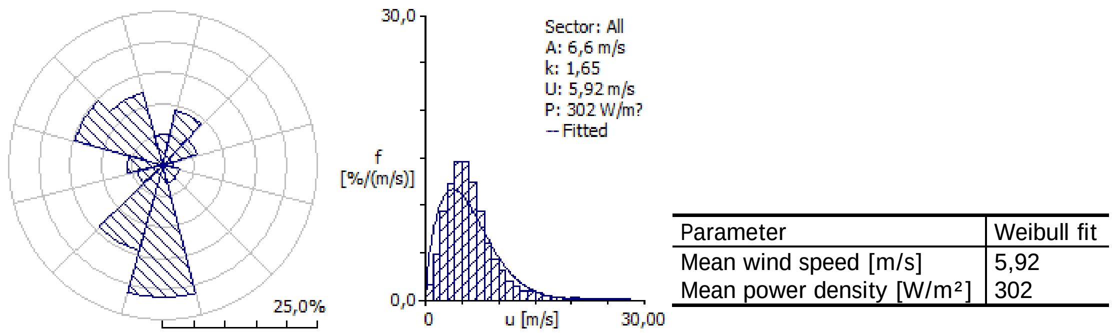


Fig. 3 Directional and Weibull distribution for Karlovo site

The prevailing wind direction for the Shabla site is from North-Northwest and South-Southwest. For the Karlovo site the prevailing wind direction is form South direction. The wind data from the on-site measurements are used as an input data for the numerical study presented below. The purpose of the study is to show wind flow distribution over the terrain through the means of numerical procedure techniques.

3. Wind flow modeling

3.1. Domain selection based on the orography specifics

Current CFD studies include 3D modeling of the wind flow over the selected terrains. The selection of size of the domain that will be used in the numerical study depends on the size of the wind farm and orography of the terrain. The size of physical spaces where all of the processes going on is determined by the terms for growing natural atmospheric boundary layer (ABL) over the spot where the on-site measurements were performed. In [2] is pointed that for a boundary layer to grow to 1km in thickness is necessary a domain of at least 60km. In many works [3], [4] the domain of at least 20km is needed to create natural ABL for complex terrains. For the selected sites the domain is accepted to be at least 25 per 25 km.

3.2. 3D surface modeling

3D models of the sites were created from available topographic maps with Didger [5] and Surfer [6] software products (Fig. 4 a-c).

Didger software is a powerful tool for transformation of topo maps into digital maps. On the other hand on-line web tool [7] successfully can be used for the collection of topography data for the domain with boundaries defined by the user. With the appropriate processing the data can be transformed in 3D surface.

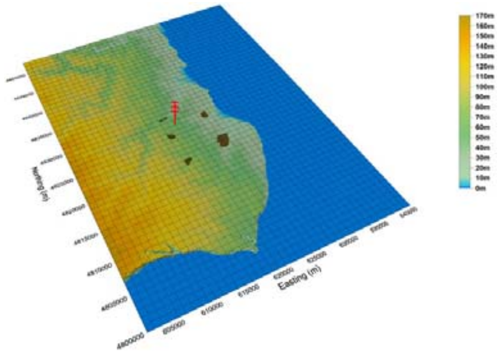
Surfer software is used for producing grid file and further visualization. There are different gridding methods available that can be used for producing 3D surface. Kriging method is a very flexible method that can be custom-fit to data by specifying appropriate variogram model. This method can be either an exact or a very smooth interpolator depending on the user's specifics. For the selected terrains (especially for complex one) Kriging method can be successfully used with default settings (Linear variogram model, slope 1 and Aniso 1) for preparation of 3D Surface.

3.3. Numerical study of the wind flow

Wind data from the measurements were presented as the frequency of occurrence of the wind in a number of sectors (as a wind rose) and wind speed bins. Then the parameters of the wind for the point of measurements are distributed up to the boundaries in respect with terrain orography. Roughness of the terrain is determined by the size and distribution of the roughness elements. Concerning European Wind Atlas [8] the different terrains are divided into four types, each of them with specific roughness elements.

Currently only the surface roughness is considered. The trees for example are not considered. Because of this roughness length of 0,03m in all sectors is accepted.

The numerical study is performed with WaSP – software that is developed by the Riso National Laboratory. The proposed software is used to predict spatial variation of the average wind speed, directional distribution, wind profile and ABL based on the theory of Jachson and Hunt [9]. The model is based on the resolution of linearized equations of motion for neutral flow. The model integrates the roughness terms into the scale decomposition.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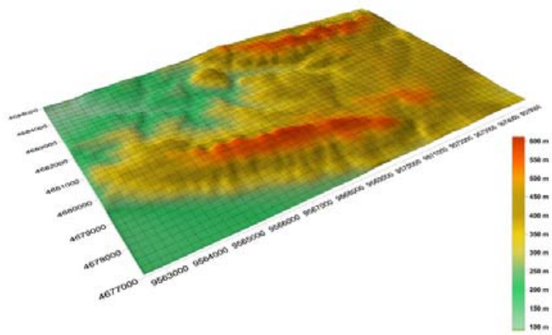
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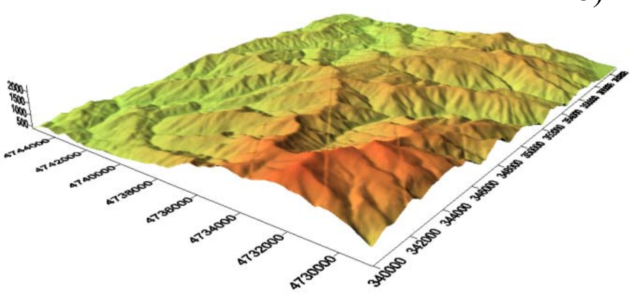
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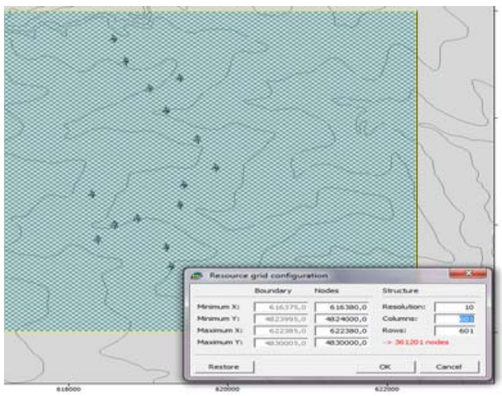
Fig. 4. (a) Flat terrain (Shabla location); (b) hilly terrain (Ruen location); (c) complex topography (Karlovo location).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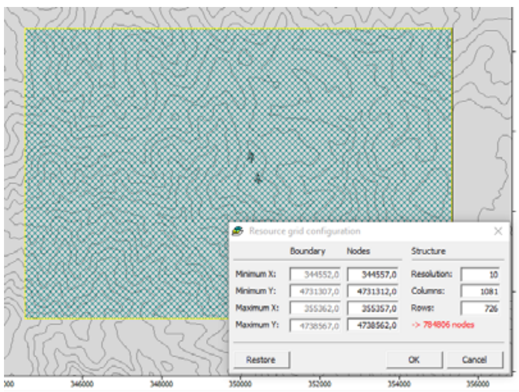
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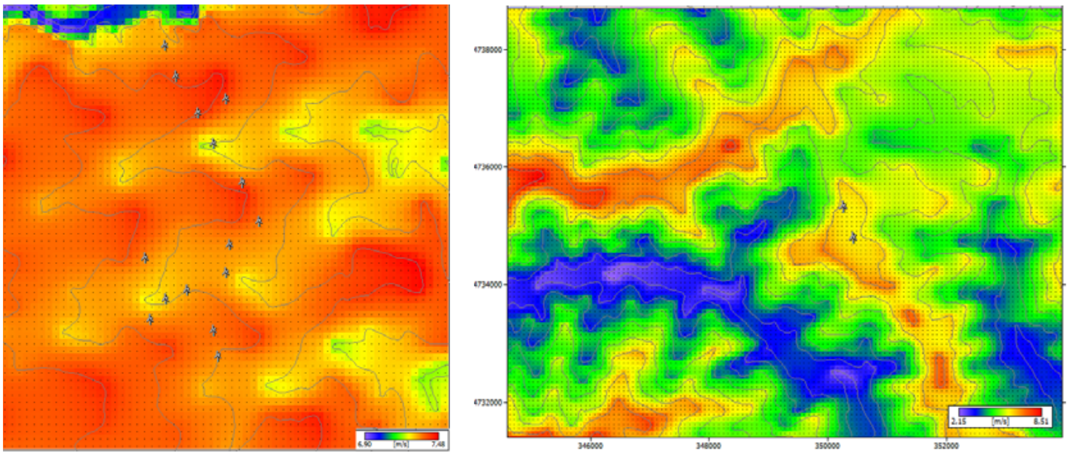
Fig. 5. Calculation domain (a) Shabla location; (b) Karlovo location



a) b)

Fig. 6 Wind speed distribution (a) Shabla location; (b) Karlovo location.

The numerical calculations are performed for the entire domain – wind farm site incl. at least 20 kms outside of the spot.

Mesh independent study was performed showing that for the complex terrain (Karlovo site) the domain was dived into 784 806 nodes (structural elements) (fig. 5a). For the Shabla site the domain is presented with 361201 nodes (Figure 5b).

The results from numerical studies are presented on Fig. 6 a-b. The figures present the velocity distribution over the terrain at the level of point of measurements. Very good distribution of wind flow in a respect with the orography is observed especially for flat terrains. Input data for the numerical study are data obtained through on-site measurements (Fig. 2 and 3). The size of the domain is in a relation with the orography of the terrain and prevailing wind direction. Those parameters have to be considered when determining thickness of the Atmospheric boundary layer. The accepted linear model during the numerical procedure for the flat terrains gives better distribution of the wind flow over the terrain. However, for complex terrains the linear model are not very applicable and additional CFD study with modeling of turbulence is needed to decrease the uncertainty.

4. Conclusion

The current study shows that the proposed software product can be applied in modeling of the wind flow over flat and hilly terrains. Because of the non-linear effects that appears over the complex terrains the applied linear models during numerical procedure increase the uncertainty. This uncertainty increases especially when calculating the wake losses between wind turbines in the Farm.

5. Acknowledgements

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