CFD study and wind flow modeling over different terrain types

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CFD study and wind flow modeling over different terrain types: *Worldwide, the amount of energy produced by the power of wind rapidly increases. For the last 20 years the installed capacity of wind farms increases in about 60 times. 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 a bigger one 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 semi- or completely complex terrains a couple of assumption have 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 constants when turbulence modeling. For the purpose is arrange an experimental study in wind tunnel where the scale model of the terrain will be tested. Some restrictions about the size of the model, and modeling of boundary layer during the experiment are resolved.*

Key words: *Wind, CFD modeling, experimental study, 3D modeling.*

1. INTRODUCTION

Global annual installed capacity of the wind power plants increased 60 times for the last 20years (from in about 6GW in 1996 up to 370GW in 2014) as only in 2014 the installed capacity 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 new wind turbines will have greater installed capacity respectively larger size leading to a decreased number of wind turbines for the same spot and different micro-sitting. 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 WT 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 CFD based products are used to model the wind flow behavior over the terrain. When the spot where the wind turbines will take place is flat, and there are no any significant obstacles around, a good approximation of the wind flow over the terrain can be established. For complex terrains generated turbulent boundary layer significantly affect the general wind flow. 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 CFD based 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 CFD based software to predict flow behavior over complex terrains and limitations in modeling of air flow wind tunnel with respect to wind speed and turbulence. Through the means of dimensional analysis are presented the options for modeling of main flow and flow in a boundary layer.

2. WIND FLOW MODELING

CFD based software products for modeling of wind flow require 3D model of terrain. In order to obtain a reliable wind flow over the spot where the wind farm will be installed a model of the terrain with at least 10 km outside of the boundary of the wind farm have to be created. Preparing a scale model for a wind tunnel experiments of such large terrain in most of the cases reduce the importance of terrain roughness, especially for complex terrain.

2.1. 3D orography modeling

In respect to experimental study three different orography terrains have been selected – flat, slightly complex and complex terrains. The spots are located on the territory of Bulgaria (fig. 1).

Fig. 1 Terrains location on the territory of Bulgaria

2.1.1. 3D surface modeling

Based on the respective topographic map 3D models of the sites with Didger [2] and Surfer [3] software were created (Fig. 2 a-c).

Didger software is a powerful tool for transformation of topo maps into digital maps. On the other hand on-line web tool [4] can be used to be downloaded information about the specified by the user region. The downloaded by the website information represents set of 3D points. After the appropriate processing can be obtained the needed 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 Kriging method was used with default settings (Linear variogram model, slope 1 and Aniso 1).

2.1.2. CFD study of the wind flow

On the selected sites for more than a year has been performed wind measurements with tall towers. The measurement were carried out on at least 3 different heights. Database contains 10 minute intervals readings about wind speed, direction, and temperature. All of the readings have been carefully examined and unreliable data have been removed.

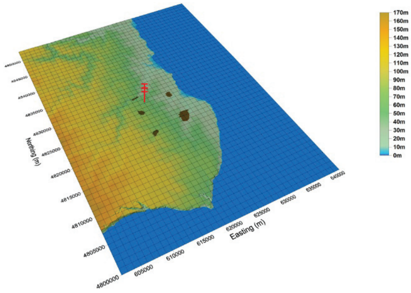
Wind data were presented as the frequency of occurrence of the wind in a number of sectors (as a wind rose) and wind speed bins. Then the parameters of the wind for the point of measurements are distributed up to the boundaries in respect with terrain orography. Roughness of the terrain is determined by the size and distribution of the roughness elements. Concerning European Wind Atlas [5] the different terrains are divided into four types, each of them with specific roughness elements.

In current case 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 results from CFD studies will be verified with those of experimental studies.

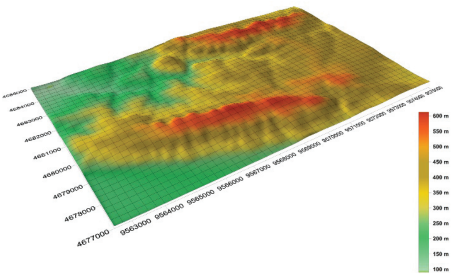
2.2. Experimental setup

2.2.1. Scale model production and experimental set-up

The presented results above from CFD study are obtained with a number of assumptions. When the terrain is flat all those assumption will not have a significant impact on distribution of wind flow over the terrain. When the terrain is slightly complex or fully complex then those assumptions have to be considered.



a)



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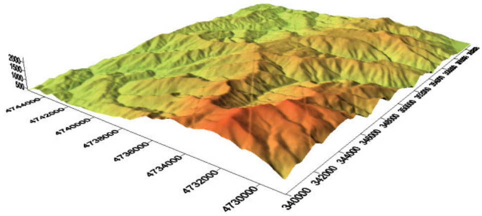
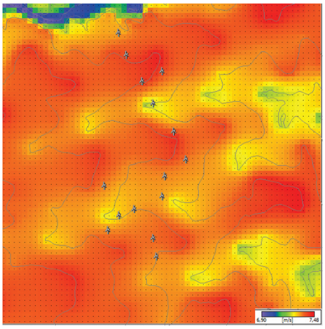
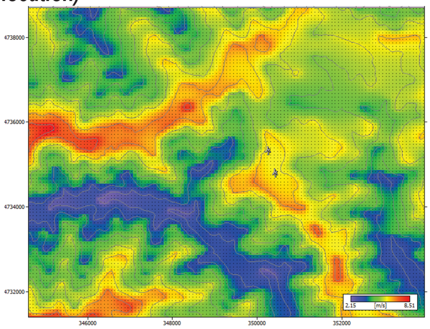


c)

Fig. 2- a) Flat terrain (Shabla location), b) slightly complex (Ruen location), c) complex terrain (Karlovo location)



a)



b)

Fig. 3- Wind flow distribution a) Shabla location), b) Karlovo location

CFD software products generally uses the governing equations of fluid flow. The set of equations that are applied are Navier-Stokes equations. The solution is possible after proper selection of turbulent model. The Reynolds average Navier-Stokes equations are time average equations that are primary used for description of turbulent parameters of the flow. For a semi-limited flows, selection of $k-\varepsilon$ turbulent model would be a good solution as well. Some adjustments of the constants in modeled equations could decrease the impact of the assumptions made during the CFD study. Such adjustments are possible if behavior of the flow is known before reaching the terrain or the degree of influence of orography elements under flow behavior. The above mentioned issues can be resolved when conducting experimental studies.

For the purpose scale model of the proposed terrains should be prepared. The scale factor is in accordance with size of wind tunnel and terrain orography. The prepared model is allowed to fill in about up to 40% of the working area of the tunnel. Picture of wind tunnel where the experiments will take place is presented in Fig. 4.

Figure 4 Wind tunnel at dept. of "Hydroaerodynamics and hydraulic machines", Technical University of Sofia [6]

The velocity drop in a wind tunnel when a small object (10-20% of the net cross area of wind tunnel) is tested is expected to be in the amount of 10% [6]. The results are presented in Figure 5.

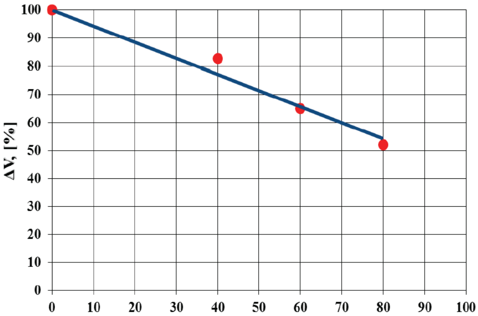
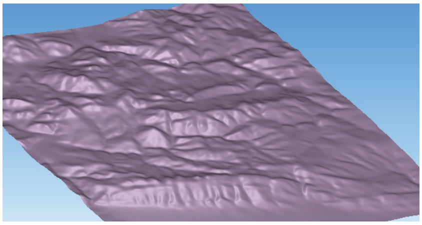
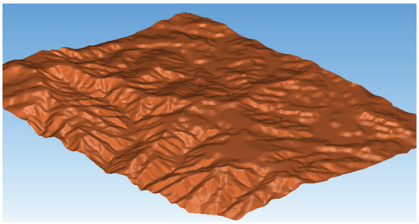


Figure 5 Velocity drop at different wind tunnel shading percentage [6]

Scale models that will be used for the experimental study are presented in Fig. 6 a and b.



a)



b)

Fig. 6- Scale models for printing a) Ruen (1:24 000)), b) Karlovo location (1:35000)

2.2.2. Dimensional analysis

Experimental studies in a wind tunnel will be accomplished in accordance with the theory of dimensional analysis. Complete (full) similarity is difficult to be achieved because of the size of model and limitations of the wind tunnel.

There are a couple of dimensionless parameters that are applicable when modeling open flows [7][8] [9] (Table 1).

Table 1 Dimensionless numbers applicable for open flows

Type of dimensionless parameter	Expression
Reynold number (Re)	$U.d/\nu$
Froude number (Fr)	U^2/gl
Rossby number (Ro)	$(U/l).\Omega$
Prandtl number (Pr)	$\nu/a = \nu\rho c_p/\lambda$

where: U – wind speed, m/s; d, l - length, m ; ν - kinematic viscosity, m^2/s; Ω – angular frequency, rad/s; a – thermal diffusivity, m^2/s; ρ – density, kg/m^3; c_p – specific heat $(J/kg).K$; λ - thermal conductivity, $W/(m.K)$.

Because of the great scale factor, modeling boundary layer parameters is of great importance. Below (Table 2) are presented the dimensionless parameters applicable for boundary layer [10] [11].

Table 2 Dimensionless numbers applicable for open flows

Type of dimensionless parameter	Expression
Roughness Reynold number (Re*)	$U_*.z_0/\nu$
Jensen's length scale criterion	δ/z_0

where: U_* – friction velocity, m/s; z_0 - roughness length, m ; δ - boundary layer thickness, m.

When a real flow past over flat terrain, a boundary layer is created. It exist regardless of wind flow parameters or terrain roughness. Test section of the current tunnel is very short for a boundary layer to grow naturally. A different methods are used to accelerate the growth of the boundary layer. In a similar studies [11] are analyzed several type of tools that can create different thickness of boundary layer in a short wind tunnels. The study shows that elliptic wedge generators did not give reasonable results for the current study.

Most of the studies [12] about boundary layers proposed that flat triangular spires are most suitable for generation of boundary layer in wind tunnel. The size and distance of the spires in front of the tested scale model depends generally of the type of wind tunnel.

3. CONCLUSIONS

In current work are presented the possibilities for creating 3D surfaces for flat, semi-complex and complex terrains from topographic maps. With a CFD based software is presented the flow behavior over the selected sites as are pointed the assumption considered during the modeling of the flow over complex terrains. Considering the improvement of the results from numerical study an experimental study was set-up, as the scale models of the terrain were printed on 3D printer. The purpose of the experimental study is to be adjusted the constants when turbulence modeling in order to obtain more reliable results during the CFD procedure.

4. Acknowledgment

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This paper has been reviewed.